APPENDIX A. SEATTLE HAZARD IDENTIFICATION AND VULNERABILITY ANALYSIS

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SHIVA – The Seattle Hazard Identification & Vulnerability Analysis

City of Seattle, Office of Emergency Management

(206) 233-5076

http://www.seattle.gov/emergency

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Upper Photo: Grand Trunk Dock Fire, 1914. Image Number 2002.3.2507. Courtesy the Museum of History and Industry.

Lower Photo: Perkins Lane, January 1997. Courtesy Tim Walsh.

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Acknowledgements

The Seattle Hazard Identification and Vulnerability Analysis (SHIVA) was prepared by the City of Seattle Office of Emergency Management, in coordination with numerous city agencies and city partner agencies. The SHIVA has a long history. It dates back to the 1980's when it was a slim document of 10 pages. In 1995 it was totally rewritten and greatly expanded. The 1995 edition was partially updated in 2001 and 2004. It underwent a major update in 2010. This update was finalized in March 2014. It is an incremental update. Specific changes are listed in the Executive Summary.

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Management

Barb Graff, OEM, Project Sponsor
Laurel Nelson, OEM, Project Supervisor

Project Lead

T.J. McDonald, OEM.

Reviewers and Participants in the Hazard Ranking

The Management Team, T.J. McDonald and the following people and groups evaluated and developed the hazard rankings:
Grant Tietje, OEM
Erika Lund, OEM
Ken Neafcy, OEM
Laurel Nelson, OEM
The Office of Emergency Management Strategic Workgroup composed of representatives from City departments and partner organizations supporting the Office of Emergency Management.

Reviewers and Information Sources

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Jerry Koenig, City Light
Ashley Kelmore, Public Health Seattle / King County
Ruth Decker, Washington State Dept. of Transportation
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Mark Mead, Seattle Parks Dept.
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Diana Canzoneri, Seattle Planning Commission
David Vestal, King County Metro
Frank Wittman, King County GIS Center
John Thomson, Washington State Dept. of Transportation
Greg Lipton, King County Metro
Ta-Win Lin, Washington State Office of Financial Management
William Beyers, University of Washington, Dept. of Geography

Jack Liu, WISERTrade (Holyoke Community College)
Brian Appert, U.S. Census
Brock Nelson, Union Pacific
Chris Hall, King County International Airport
Mark Wesoloski, Puget Sound Energy
Mary Shaw, United Way
Joe Fountain, Seattle Police Department
Stephanie Beecham, Seattle Office of Economic Development
Kathie Dello, Oregon Climate Change Research Institute, Oregon State University
Colleen Reid, University of California
Christopher Emrich, Hazards and Vulnerability Research Institute, University of South Carolina
John Lababie, Seattle Public Utilities
James Rufo Hill, Seattle Public Utilities
Julie Vano, Dept. of Civil and Environmental Engineering, University of Washington
Jim Ashby, Western Regional Climate Center
Janet Polata, City of Seattle, Office of the City Clerk
Lynn Highland, U.S. Geological Survey, National Landslide Information Center
Gary Odenthal, City of Portland, Bureau of Planning and Sustainability
David J. Ostanski, King County, KCGIS Center
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Executive Summary

"Reality is far more vicious than Russian roulette. First, it delivers the fatal bullet rather infrequently, like a revolver that would have hundreds, even thousands of chambers instead of six. After a few dozen tries, one forgets about the existence of a bullet, under a numbing false sense of security. Second, unlike a well-defined precise game like Russian roulette, where the risks are visible to anyone capable of multiplying and dividing by six, one does not observe the barrel of reality. One is capable of unwittingly playing Russian roulette - and calling it by some alternative "low risk" game."

- Nassim Nicholas Taleb

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 all of 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.

Major Findings

1. 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.
2. Snow and ice storms rank second. Individually they are less damaging than a powerful earthquake, but they are much more frequent.
3. Infrastructure failure is the third biggest risk due to infrastructure's dependence on networked computers systems that are exposed to attack. The chance of successful, large scale attack is small, but its consequences would be severe.
4. 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.
5. Our most vulnerable people live toward the outskirts of the city and along the Rainier Valley.
6. Climate change will broadly affect most of the hazards Seattle experiences.

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.

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.

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.

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.

Long-term and Emerging Threats
This section covers threats that the City of Seattle anticipates will become major hazards beyond the SHIVA's four year horizon. Currently, it consists of two threats: climate change and cyber disruption. Climate change affects nearly all the hazards covered in the SHIVA as it occurs over the coming decades. It is less of a specific hazard than a broad environmental change that affects many hazards. Likewise, cyber disruption is an emerging change in our built environment. It reflects our growing dependence on computers to mediate our experience of the 'real' world and the consequences of its loss. Our current exposure to computer failure is included in parts of the terrorism, power outage and infrastructure failure chapters.

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
- Disease/Pandemic Influenza

- Intentional Hazards
    - Social Unrest
    - Terrorism
    - Active Shooter Incidents
- 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

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..

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.

Hazard Chapter Summary

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

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 top 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) huge megathrust earthquakes that could reach magnitude 9.0 but would be centered 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 bridges 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 is 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. The Seattle Fault produced a tsunami when it was last active around 900 AD. A large landslide could also trigger a tsunami. A landslide triggered a tsunami in the Tacoma Narrows in 1949.

A seiche is 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 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. It the days that follow, rain and erosion would wash the sediment down the Duwamish creating a major navigation hazard.

Major ashfall is unlikely. 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.

Disease/Pandemic Influenza

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. The 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. 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.

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 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 anarchists groups. The largest centered on the 1999 World Trade Organization (WTO) meeting. Most of Seattle’s incidents have targeted property but assaults but one death has occurred. Most incidents can be handled by the Seattle Police Department, but large ones like the WTO protests require large amounts of outside assistance and can shut down large areas of the City. Most incidents occur in downtown area and on Capitol Hill.

Terrorism

Terrorism is a national threat. The Puget Sound region has active far-right and eco-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.

In 1999 Ahmed Ressam was caught smuggling bomb components into Washington State on his way to Los Angeles. The September 11, 2001 attacks raised awareness that Seattle could become a target especially after photos of Seattle were found in Al Qaeda facilities in Afghanistan. Later, the threat seems centered on homegrown terrorists like the two men arrested for plotting to attack a Seattle armed forces recruiting center in 2011.

In the aftermath of 9/11, Seattle actively plans for terrorism involving chemical, biological, nuclear, radiological and explosive and cyber means. It has been the recipient of several federal grants to bolster local security.

Mass Shootings
Recent attacks in Seattle and nationally underline Seattle's continued vulnerability to mass shootings. Seattle has had several high profile mass shootings including the Café Racer shooting in 2012 and the 2006 Capitol Hill shootings. Recent school shootings like the one in Newtown have focused attention on school safety. Mass shootings seem to be on the rise even as overall rates of violence are decreasing. Most attacks are carried out by a single attacker in a single location, but more complex attacks have been launched by terrorist groups.

Transportation and Infrastructure
This group 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 better fire code enforcement, but having a large concentration of high-rise buildings, hotels, entertainment venues and industry make 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 busy.

Hazardous Material Incidents
Seattle is a regional industrial center and major transportation hub raising its exposure to hazardous materials incidents that release of 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. Most incidents happen at fixed sites, but those that occur during transport are often more dangerous because they occur in uncontrolled, public spaces.

Infrastructure Failures
This chapter includes structural failure in buildings, dams and critical lifelines (transportation, water, communications, sewer and power). A special and emerging type of infrastructure failure is ***cyber disruption***. This topic covers the real world consequences of computer system outages whatever the cause (hacking, terrorism, accidents, and viruses). The consequence with the greatest impact would be a prolonged region power outage. Seattle is vulnerable to bridge collapse due to central role them play in

Seattle's transportation network. 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 US's power system. In December 2006 a week long power outage brought that message home. Since 2006 Seattle City Light has acquired a new power management system that allows it to better respond to unplanned outages. 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. 51% of Seattle's power is purchased so it is vulnerable to disruptions outside the City Light system. The Bonneville Power Administration (BPA) system is the most likely source of this disruption. Much of BPA's infrastructure is aging and in needs to be upgraded. As climate change increases summer temperatures power demand will increase making Seattle more vulnerable to summer outages.

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 (EHE)

Excessive heat can be an extremely deadly hazard. More than 700 people died during the 1995 Chicago heat wave. Despite a generally mild climate, the National Weather Service ranks Seattle 15th among at risk major urban regions. The reason is that temperature itself is just one factor driving the consequences of heat events. 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 Excessive Heat Event (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 may be on the rise. Increased exposure to EHE may help adjust people to relatively hotter conditions while simultaneously increasing the exposure of vulnerable populations.

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. It is not clear if Seattle is experiencing a trend toward higher intensity storms.

- Coast 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 this problem worse.
- Riverine floods happen 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 in areas that are prone to it.

- 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, Ice and Extreme Cold
Seattle's winter weather is generally mild, but world record snowfalls have occurred less than 100 miles away. When snow visits Seattle 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 is 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). Seattle 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 supply from melting snow. The main shortages 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 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 City Light 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. When storms occur outside winter they hit the trees in full leaf. The leaves act as sails causing more stress the tree. Windstorms often accompany other weather hazards producing complex emergencies the can include landslides, urban flooding, snow and extreme cold. Windstorms can damages 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.

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.

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

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.

History
This section is 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.

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.

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.

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.

Conclusion

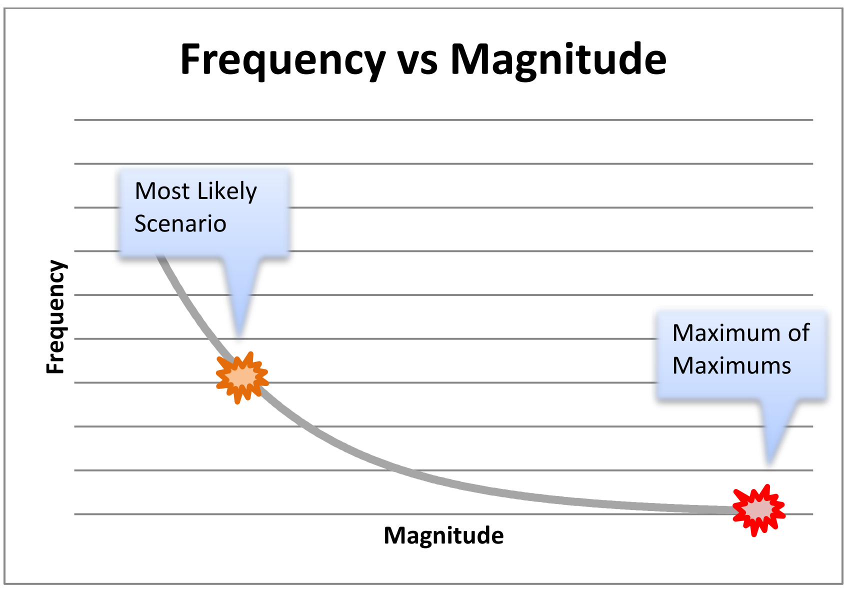
The conclusion is a brief summation of the major points of the text in a paragraph or two to help the reader remember the hazard.

Hazard Definition

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 "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.



Disaster Definition

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.

Vulnerability Definition

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 on page 30.

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 more costly than the direct damage. Interdependence is also a benefit undamaged communities can aid those that are.

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.

Summary of Document Updates

This version of Seattle's Hazard Identification and Vulnerability Analysis (SHIVA) updates the version published in 2010. It meets the requirements of the Federal Emergency Management Agency (FEMA) and the Emergency Management Accreditation Program (EMAP), both of which publish standards to guide this work and provide quality and consistency across jurisdictions. It also meets the State of Washington's legal requirement that local governments identify and evaluate their hazards, as specified in WAC 118-30-070.

Major changes are as follows:

- Added a section called “Emerging Hazards”.
- Addressed the growing threat of cyber disruption as an emerging hazard.
- Added two tables for each hazard that fill out the “Most Likely” and “Maximum Credible” scenarios.
- Added tables and charts summarizing land use, zoning, facilities and wildlife areas in areas subject to the following natural hazards: liquefaction (part of earthquake hazard), landslides, tsunami, seiche, flooding, urban flooding (i.e., drainage related flooding) and post-lahar sedimentation (a volcanic hazard).
- Incorporated research published between 2010 and 2014.
- Reassessed hazards.

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.

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.

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.

Even Minor Hazards Can Have Serious Consequences

For some people, a minor snow fall 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.

Hazard Ranking, Summary of Hazard Metrics, and Relationships between hazards

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

Table 1. Hazard Ranking

	Most Likely Scenario															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	4	5	5	5	5	5	5	5	5	4.9	2	5	7	34.3	3	**55.7**
Snow & Ice Storm	5	3	1	2	2	1	2	2	2	1	2.1	5	2	7	14.7	5	4	2	3	3	2	2	4	3	3	3.1	3	3	6	18.6	5	**38.3**
Infrastructure / Cyber	1	2	1	2	2	2	2	2	2	3	1.9	5	2	7	13.3	5	4	2	5	4	3	1	4	4	3	3.5	1	4	5	17.5	5	**35.8**
Windstorms	5	1	2	2	2	2	2	2	2	1	2.1	5	1	6	12.6	5	2	2	3	3	3	3	4	4	3	3.2	2	4	6	19.2	3	**34.8**
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**
Terrorism	1	1	2	2	2	2	2	2	1	3	1.8	4	2	6	10.8	4	3	5	5	5	5	5	5	5	5	4.7	1	3	4	18.8	5	**34.6**
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 / Atmo. River	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**
Fires	2	2	2	5	1	2	1	2	2	1	2.0	4	2	6	12.0	2	4	4	3	3	2	2	4	2	3	2.9	2	4	6	17.4	3	**32.4**
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	3	3	3	3.4	2	4	6	20.4	3	**32.2**
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**
Landslides	4	3	1	2	1	2	2	2	1	1	1.9	5	1	6	11.4	3	3	3	3	2	3	3	3	2	3	2.8	2	4	6	16.8	3	**31.2**
Social Unrest	3	1	2	4	1	1	2	2	1	3	2.0	5	2	7	14.0	5	3	3	5	3	1	3	2	2	5	3.2	2	2	4	12.8	3	**29.8**
HazMat Incidents	3	1	2	4	2	2	2	2	2	1	2.1	3	2	5	10.5	3	3	2	2	3	4	2	3	2	5	2.9	1	3	4	11.6	3	**25.1**
Volcano Hazards	2	5	1	4	3	2	3	2	3	1	2.6	2	1	3	7.8	5	5	1	2	3	2	4	4	2	1	2.9	1	3	4	11.6	3	**22.4**
Active Shooter	2	2	2	1	1	1	1	1	1	1	1.3	4	1	5	6.5	4	2	3	3	2	1	2	4	4	3	2.8	2	1	3	8.4	5	**19.9**

Table 2. Hazard Metrics

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.

Table 2. Continued

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

Table 2 continued

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 3. Relationships Between Primary and Secondary Hazards

Secondary Hazard / Primary Hazard	Earthquakes	Landslides	Volcano Hazards	Tsunami and Seiches	Disease Outbreaks	Civil Disorder	Terrorism	Mass Shootings	Transportation Incidents	Fires	HazMat Incidents	Infrastructure Failures	Power Outages	Excessive Heat Events	Flooding	Snow, Ice and Extreme Cold	Water Shortages	Windstorms
Earthquakes																		
Landslides																		
Volcano Hazards																		
Tsunamis and Seiches																		
Disease Outbreaks																		
Civil Disorder																		
Terrorism																		
Mass Shootings																		
Transportation Incidents																		
Fires																		
HazMat Incidents																		
Infrastructure Failures																		
Power Outages																		
Excessive Heat Events																		
Flooding																		
Snow, Ice and Extreme Cold																		
Water Shortages																		
Windstorms																		

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.

Community Profile

Seattle is the hub of the Pacific Northwest. With 634,535 residents (2012) and 502,000 jobs (2013)[8], 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., with 1 in 3 jobs dependent on international trade. 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 climate, environment, geography, infrastructure and a brief history. 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 4. Reference Cities.

Name	land area (sq miles)	Pop 2012 (estimate)	person / sq mile
Seattle	83	634,535	7,645
Atlanta	131	443,775	3,388
Boston	48	636,594	13,262
Denver	153	634,295	4,146
Nashville	473	624,496	1,320
Portland	134	603,106	4,501
San Francisco	46	825,863	17,954
Vancouver	44	603,502	13,716

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.

Location

Seattle is located in the extreme upper northwestern portion of the lower 48 states in Washington State along the shores of Puget Sound. Seattle is north of the 47th parallel. It is the northernmost major city in the lower 48. 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 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.

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 hour glass shape. Downtown is located 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 the downtown. A majority of the hospital beds in the City of Seattle are on First Hill, including Harborview, the only Level 1 Trauma Center in a four state region. In addition, there are four hospitals located north of the Ship Canal Bridge, one of which includes nearly all of 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.

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 modified land[9]. During earthquakes, shaking on modified 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 becomes saturated, heavier and less cohesive[10]. 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.[11]

In 2006, deposits of volcanic ash were found along Hamm Creek, a tiny tributary of the Duwamish located just south of the city limits.[12] Usually the prevailing winds carry ash from nearby volcanoes east, but the layer suggests that Seattle is not immune to ash fall.

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.

Influence of the 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 2.7 days over 90 degrees and just 2.7 days where the temperature never gets above freezing.

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

Figure 1. Topography

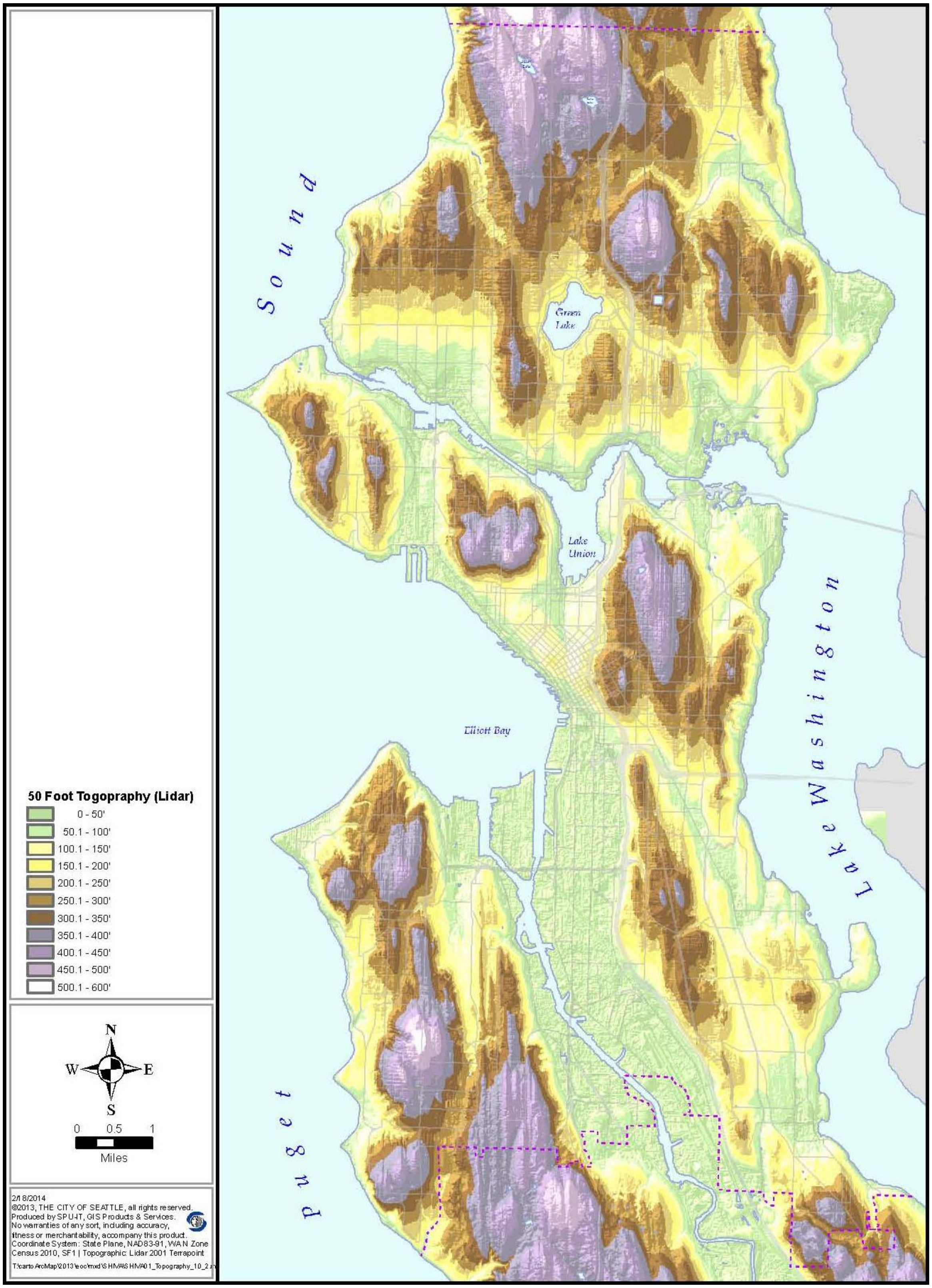
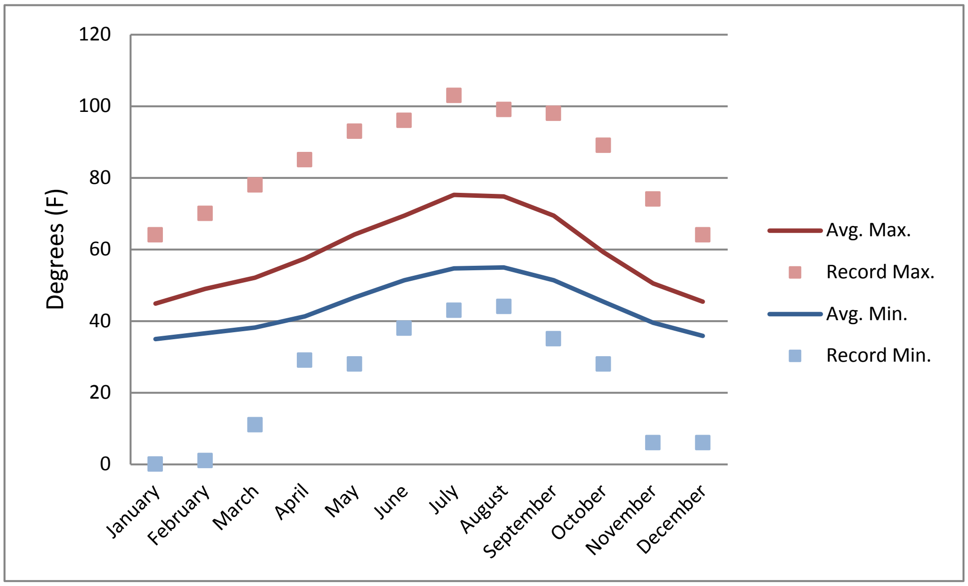


Figure 2. Temperature Summary (Seattle-Tacoma Airport 1948-2009)[13]

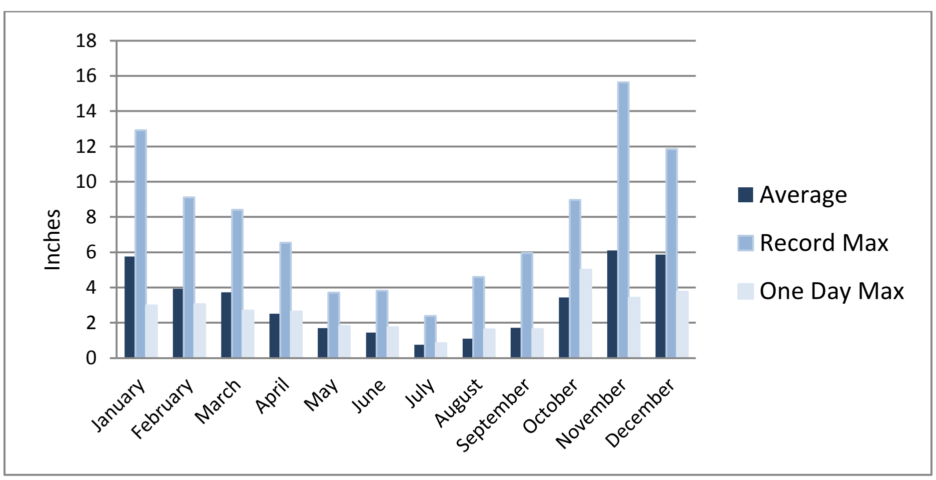


between October 1st and March 31st; just under half falls between November 1st and the end of February.

Influence of the Olympic and Cascade Mountains

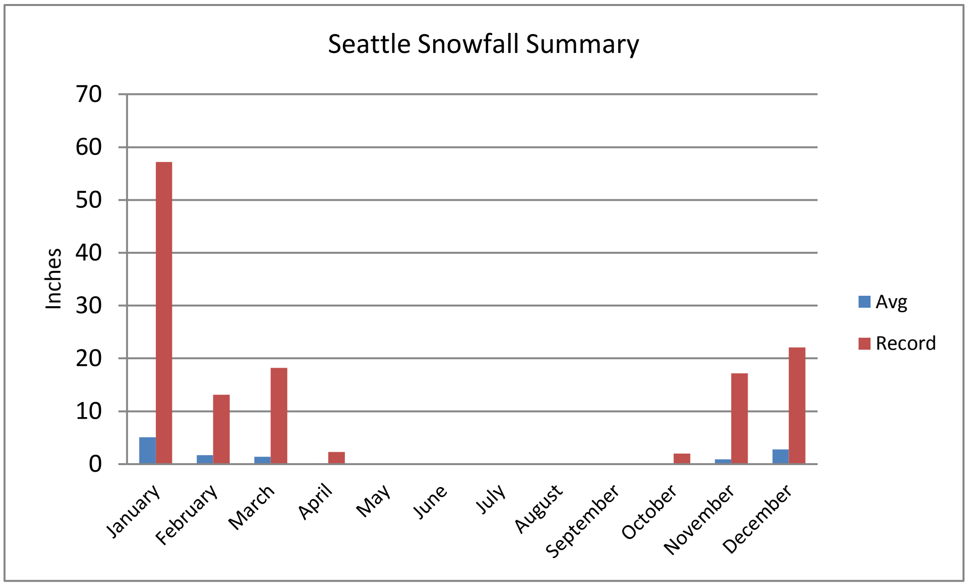
The Cascade Ranges is a barrier that keeps dry continental air out of the region and moist Pacific air trapped in it. Continental air is hot in the summer and cold in the winter, but the mountain barriers mean that temperate marine air is the main influence on Seattle's temperatures. This marine air 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 more rainy and overcast days but less total rain per year than many cities.

Figure 3. Precipitation Summary (Seattle-Tacoma Airport 1948-2009)[14]



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 4. Snowfall Summary (Seattle-Tacoma Airport 1948-2009)[15]



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.

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. Now trees cover between 18% and 23% of the city.[16] New York City in comparison is 21% tree covered.[17] 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 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.[19] 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.

To reverse tree canopy loss, the City of Seattle adopted an Urban Forestry Management Plan in April, 2007. Its goal is to increase Seattle's tree canopy to 30% by 2037 while accommodating increased population density. The results have been mixed. A May, 2009 City Auditor report found that a comprehensive tree inventory is needed to gauge success and better management structures are needed to ensure that success.[20]

Trees reduce stormwater runoff and reduce flooding. The City of Seattle Urban Forest Management Plan estimates that tree canopy loss costs Seattle $1,300,000 per year by causing an extra 7.5 million cubic feet in stormwater runoff – a factor in urban flooding. Trees also improve urban air quality by removing thousands of pounds of pollutants from the atmosphere.[21]

Trees are also a hazard. During storms they damage houses, power and telephone lines and their roots pull up underground pipes. 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. [22]

Seattle's shoreline is heavily modified. Only 10% is unaltered.[23] 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[24].

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.[25] In Seattle, much of the shoreline has been armored in an effort to prevent beach erosion and landslides. Shoreline 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.

Population and Economy

The United States is "undergoing a period of dynamic, volatile change, comparable in scale and complexity to the latter part of the 19th century," according to the Brookings Institute[26]. Our population is growing and diversity is increasing due to the most significant immigration in 100 years. Household size is shrinking as birthrates fall and the population ages. The economy is shifting from manufacturing to services and knowledge-based industries. The recent, severe economic recession has profoundly altered the U.S. economy and with it the population of the Seattle area, but the full extent of these changes is not yet fully understood.

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 2010 when the growth rates began to reverse. In 2012 for the first time in 102 years, Seattle grew faster than its suburbs. It is not clear if this change is short term or a major demographic shift.

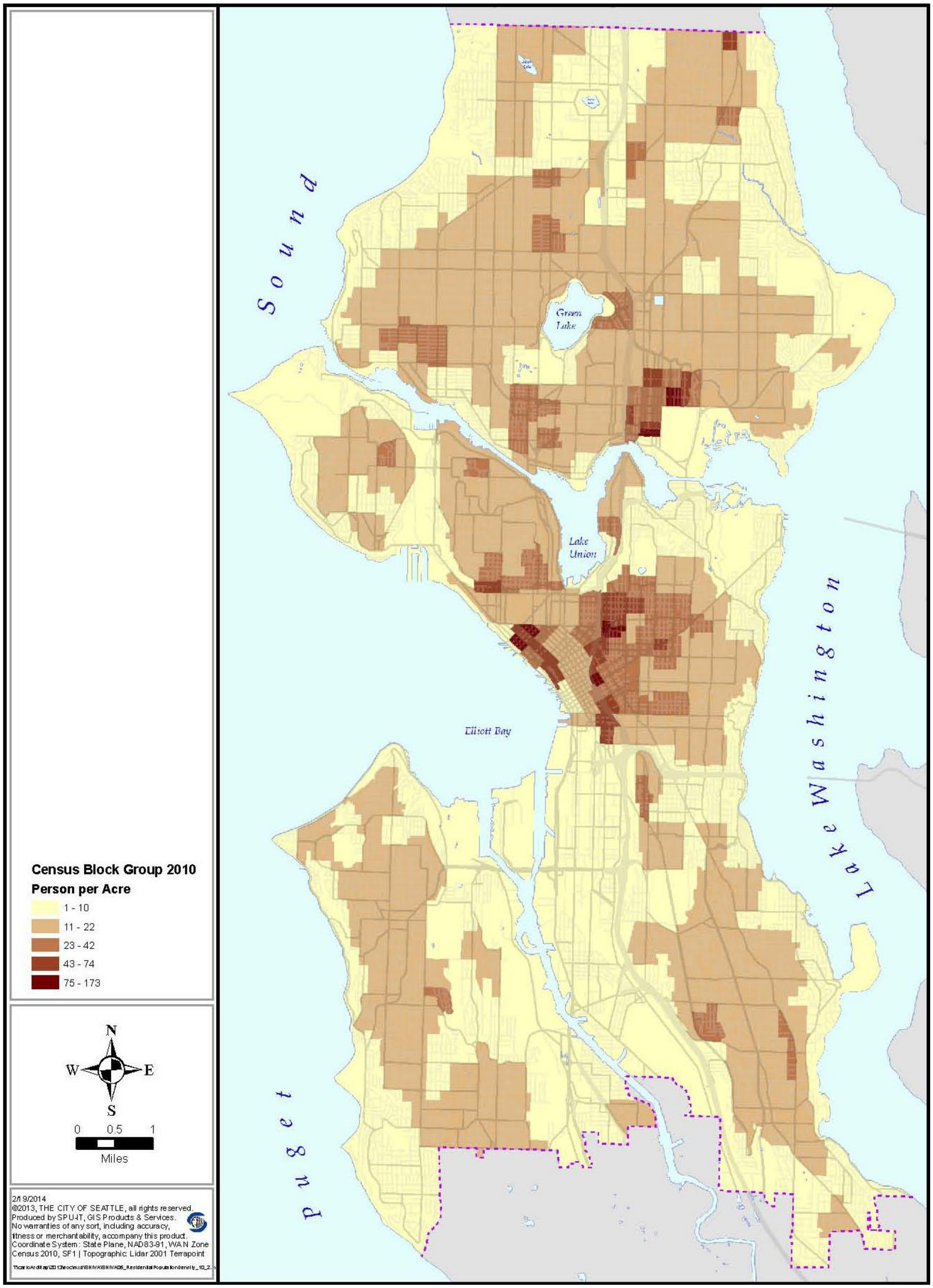
Seattle's share of regional jobs and residents has declined steadily. The local economy echoes the national economy with a shift from manufacturing to technology and services. While Seattle used to be centered on manufacturing (Boeing) it has diversified to include the technology and health sectors as 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 income gap in Seattle is growing and as the cost of living rises, those with lower income are finding it harder to get by.

Population and Demographics

In 2009, Seattle's population pushed over 600,000 for the first time and has kept growing[27]. In 2013 Seattle had an estimated 626,600 residents.[28] The population is now dominated by people in their 20s, 30s and 50s who live alone or with one other adult. The growing population is a good first order indicator that Seattle remained fundamentally healthy despite the recent recession. The overall picture painted by statistics is of community in which most people have been doing well but also where a

Figure 5. Residential Population Density 2010



sizable chunk of its population has not been able to share in the general prosperity and is experiencing challenges with 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[29].

2008 data comparing the largest 100 U.S. cities show that Seattle has:

- The lowest average household size (2.04). Over 40% of Seattleites living alone.
- The 2nd highest proportion of residents with college degrees (55%). Seattle is in first place among cities over 500,000.
- The second lowest share (20%) of people under 20 (only San Francisco had less)[30]
- Many new residents, especially around the downtown and University District. In 2000, three in ten residents had lived in Seattle for less than five years.[31] There are signs the in-migration is slowing, however. In 2008, Seattle ranked 18th among the top 100 among in-migration from out of state and 50th on in-state migration.

Seattle is a comparatively affluent city. Median household income grew in the 1990s and 2000s. By 2008 Seattle ranked 13th among the 100 largest cities, but was 4th among cities with a population over 500,000[32]. Like many other cities, household income is less evenly divided than in the country as a whole 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 late 2000s recession, Seattle ranked 3rd lowest in overall poverty among cities over 500,000.

Running counter to this trend was a rise in poverty among Seattle's elderly 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. This claim is supported by data showing that poverty among the elderly state-wide has been declining for many years[33].

While the overall decrease in poverty was good, it obscured difficulties with affordable housing. Rates of homeownership stagnated in the 1990s and rose only slightly during the housing bubble. At the same time, lower to middle income renters were being squeezed. In 2000, over half of this group reported paying over 30% of their income on rent. This rate is among the highest in the United States.

During the 1990s Seattle also grew more diverse, but the rate of diversification in Seattle was exceeded by that of the suburbs. As of 2008, Bellevue, Tacoma, and King County as a whole were more racially diverse than Seattle. Immigration has followed the same pattern, with rapid increases in Seattle exceeded by even greater increases in the suburbs. King County now has a slightly higher share of foreign born (19%) than Seattle (18.4%) and Bellevue has a much greater share (29.8%)[34]. Immigrants are now migrating straight to the suburbs in contrast with past patterns.

Table 5. Demographic Summary

Item	Seattle	Portland	Denver	San Francis	Minneapolis	Boston	Nashville	Atlanta	Tacoma	Bellevue	King County	U.S.
Total Population	**565,809**	541,550	576,842	757,604	362,513	600,980	586,214	439,275	193,920	117,521	1,832,835	298,757,310
Pop 25+: Bachelor's or higher	**52.50%**	38.20%	37.70%	49.80%	41.20%	40.30%	31.50%	41.20%	23.20%	58.90%	43.70%	27.00%
Average household size	**2.08**	2.26	2.32	2.3	2.22	2.43	2.38	2.45	2.41	2.37	2.39	2.61
Average family size	**2.94**	3.03	3.32	3.28	3.11	3.36	3.16	3.71	3.12	2.96	3.06	3.2
Disability Status	**13.8%**	14.3%	14.0%	13.9%	13.7%	15.4%	14.8%	15.0%	19.0%	9.8%	13.1%	15.1%
Non-English language at home	**21.4%**	18.6%	30.1%	45.5%	19.8%	35.3%	13.3%	9.3%	17.2%	32.0%	22.8%	19.5%
Foreign Born	**18.4%**	13.9%	18.3%	35.7%	15.3%	27.7%	10.4%	6.7%	11.7%	29.8%	19.0%	12.5%
FB - Asia	**9.6%**	4.9%	2.6%	22.1%	3.5%	6.7%	2.9%	1.6%	5.3%	18.4%	9.5%	3.3%
FB - Latin America	**3.0%**	3.8%	12.8%	7.4%	6.2%	13.6%	4.6%	3.2%	3.4%	3.6%	3.6%	6.7%
Means of Transport to Work												
Mean Travel to Work (minutes)	**24.5**	23.6	23.7	29.1	21.8	29.1	23.2	26.1	24.7	21.1	26.5	25.1
Car, truck or van - drove	**65.50%**	72.10%	80.20%	47.20%	72.40%	48.80%	90.60%	75.90%	88.50%	78.20%	77.60%	86.70%
Public transportation	**17.90%**	12.50%	7.20%	32.20%	13.10%	32.50%	1.90%	12.90%	5.20%	9.80%	10.20%	4.80%
Walked	**7.90%**	4.70%	4.50%	9.50%	6.60%	13.50%	1.90%	4.10%	2.10%	3.70%	3.90%	2.90%
Other means	**3.40%**	4.70%	3.10%	4.20%	3.60%	2.30%	1.60%	2.00%	1.50%	1.50%	2.10%	1.70%
Worked at home	**5.20%**	6.00%	5.00%	6.80%	4.30%	2.90%	4.00%	5.10%	2.70%	6.80%	5.30%	3.90%
Mobility (Lived last year in another state / country)	**5.80%**	5.10%	4.20%	3.10%	6.10%	6.10%	4.60%	5.70%	3.30%	7.20%	5.00%	3.20%
Income												
Per capita income	**$ 39,011**	$ 27,941	$ 28,534	$ 43,013	$ 28,515	$ 30,371	$ 25,682	$ 33,670	$ 24,575	$ 44,011	$ 36,747	$ 26,178
Families below poverty	**7.3%**	11.2%	13.6%	7.4%	15.8%	16.7%	11.6%	20.2%	12.1%	5.3%	6.0%	9.8%
Individuals below poverty	**13.0%**	16.6%	18.0%	11.8%	21.5%	20.8%	15.5%	23.3%	15.9%	13.3%	9.8%	13.3%
Housing												
Owner-occupied	**51.1%**	57.0%	55.6%	38.4%	53.8%	38.2%	59.5%	50.3%	54.8%	58.7%	61.9%	67.3%
Renter-occupied	**48.9%**	43.0%	44.4%	61.6%	46.2%	61.8%	40.0%	49.7%	45.2%	41.3%	38.1%	32.7%
Median value	**$ 439,500**	$ 257,100	$ 234,200	$ 789,400	$ 230,500	$ 426,100	$ 150,400	$ 235,200	$ 224,100	$ 511,900	$ 389,200	$ 181,800
Age												
Under 18	**15.6%**	21.3%	24.0%	14.2%	24.7%	19.1%	23.7%	21.1%	24.7%	21.5%	21.7%	24.7%
Over 65	**11.1%**	10.4%	10.6%	14.5%	8.4%	10.3%	10.7%	9.0%	12.5%	13.0%	10.6%	12.5%
Source: U.S. Cenesus Bureau, American Factfinder 2005-2007 American Community Survey 3-year Estimates												
date accessed: 8/7/09												

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. Census figures estimate the total number of people entering the city during the day, but not much beyond total numbers. The 2000 census found that 74% of employed Seattle residents worked within the city limits.

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. This report was released in August 2009. It connected demographic profiles to levels of preparedness, barriers to preparedness, and perception of risk. It found that individuals with college experience are "more aware, prepared, and confident in the benefits of disaster preparedness." This suggests that Seattle, with its high level of educational attainment, is (in aggregate) better prepared than many cities.

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 resultant disaster "bigger." Seattle's most vulnerable people tend to be clustered around Seattle's edges, Rainier Valley and south downtown.

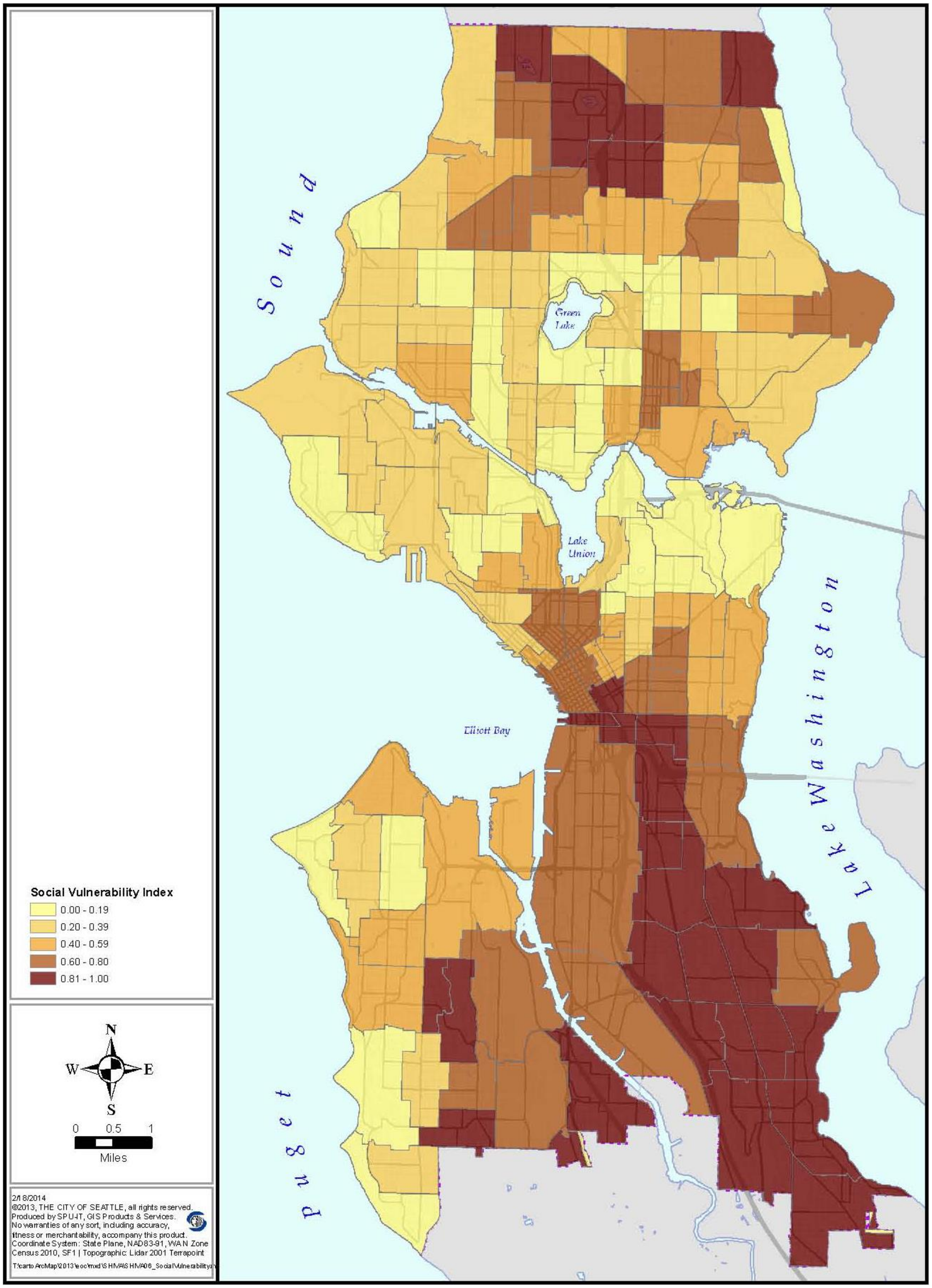
Social vulnerability affects all hazards. One of the most effective ways to reduce a community's overall vulnerability is to target social vulnerability.

The University of North 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 6 summarizes Seattle's Social Index of Vulnerability.

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 recently completed a project to develop an index for the medical community. This index includes the following:

- Physically Disabled
- Blind
- Deaf, Deaf-Blind, Hard of Hearing
- Seniors
- Limited English or Non-English Proficient
- Children
- Homeless and Shelter Dependent
- Impoverished
- Immigrant Communities
- Undocumented Persons
- Mentally Ill
- Developmentally Disabled
- Medically Dependent, Medically Compromised
- Chemically Dependent
- Clients of Criminal Justice System
- Emerging or Transient Special Needs.

Figure 6. Social Vulnerability Index[35]



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 502,000 jobs in 2013, up from a low of 463,000 in 2010[36]. Unemployment has dropped from 9% in 2009 to 4.7% in 2013. The University of Washington is Seattle's biggest employer, with 28,000 employees. Services account for 82% of jobs; manufacturing and construction account for the other 18%. These percentages reflect national trends away from manufacturing and into the service sector.

The aerospace industry has long been central to Seattle's economy. While Boeing is still a huge presence in the Puget Sound region, its influence is decreasing. While it still spends billions in the Seattle area. It has dramatically cut employment in Seattle proper. 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 smoother.

Seattle's manufacturing 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.

The growth of Seattle's healthcare industry, anchored by the University of Washington and the Fred Hutchinson Cancer Research Center, has made it a base industry in Seattle. Healthcare employs 96,400 people in the City of Seattle and produced $6.37 billion in output value in 2002. One in five jobs in Seattle is tied to healthcare. The Bill and Melinda Gates Foundation and the expansion of Vulcan's properties in the South Lake Union area are driving further growth in this sector. This sector is concentrated in First Hill (hospitals), South Lake Union (biotech and Fred Hutchinson) and the U-District (University of Washington).

The software and internet services industries centered around Microsoft and Amazon in Seattle employ 191,000 people regionally and 18,250 jobs in Seattle. While this sector slower after the 1990s, it continues to be a core industry. There are many linkages between the healthcare and software industries.

The Port of Seattle is one of Seattle's biggest employers. 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 destination for tourists. Spending on the arts by tourists and Seattleites is among the highest in the country. As a result tourism, the arts, music and sports are major contributors to the local economy generating revenues in the billions and employing thousands. The music industry alone contributes $1.3 billion and supports 8,700 workers.

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 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 is strong despite the setback of the recession. The economy is broadening with the long term outlook for many key industries strong.

Table 6. Total Employment[37]

Year	Seattle	King County	Greater Seattle Area*
1980	386,684	697,401	1,033,407
1990	469,802	972,567	1,445,243
2000	536,471	1,188,577	1,748,243
2006	470,698	1,125,197	1,615,507

Number of full-time and part-time positions (not including resource or construction)

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 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 17% of the city's area. Multi-family uses are just 5% of Seattle's area even though they account for 49% of the dwelling units. The reason is that most of Seattle's multi-family units are located in larger apartment and condo complexes rather that smaller 2, 3, and 4-plexes. Table 7 comes from the City's comprehensive plan and shows the breakdown of the city's land uses in 2004.

Land use drives population shifts on all time scales, from daily commutes to weekly recreation and long-term residential patterns. A US Census estimate found Seattle's daytime population grows by 27% every weekday to approximately 796,000 people[38].

Seattle has a majority of the region's biggest sports and entertainment venues as well as cruise ship terminals. 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.

Figure 7. Current Land Use

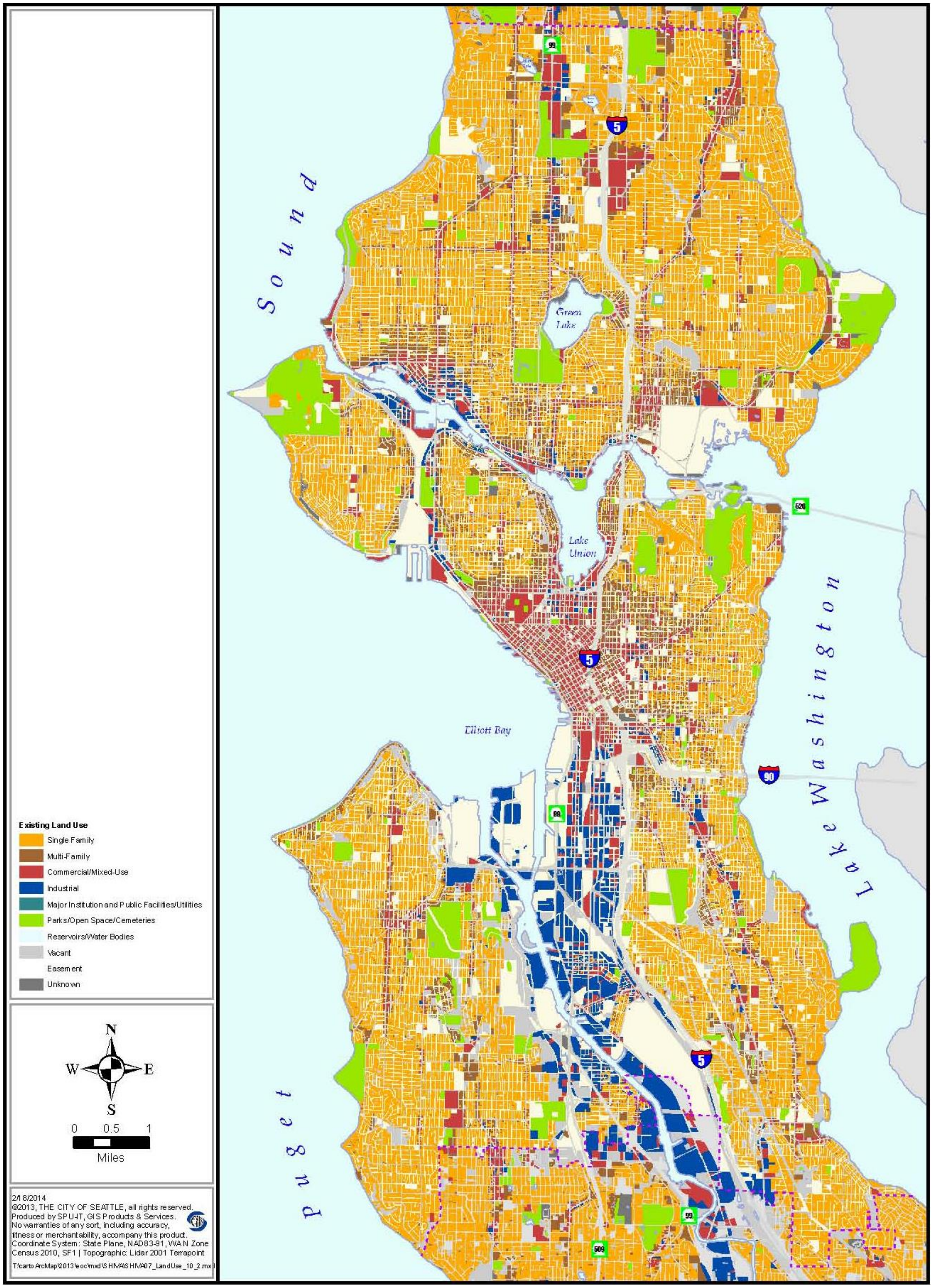


Table 7. Land Use, 2004

Category	Acres	% of total
Single Family	18,893	35%
Multi-Family	2631	5%
Mixed-Use / Commercial	2850	5%
Industrial	2077	4%
Major Institutions, Public Facilities & Utilities	4203	8%
Parks and Open Space	5514	10%
Water	349	1%
Right of Way	14108	26%
Vacant & Unknown	2888	5%
Total	53,513	100%

With over 7,000 people per square mile, Seattle seems to be in transition from a lower density city like Portland or Denver, dominated by single family neighborhoods, to a higher density city like Vancouver BC, San Francisco, and Boston. Portland and Denver have between 3,700 and 4,000 people per square mile; the later cities have between 12,000 and 16,000. The highest residential densities occur in older sections north of the I-90 Freeway and on Capitol Hill. Other dense areas include portions of the Denny Regrade, the south slope of Queen Anne Hill and parts of the University District.

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 particular disaster can vary more over short distances.

Washington State's Growth Management Plan (GMA) is having a huge effect on the City of Seattle. The Plan 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 center 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).

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.

In the late 2000s Seattle's transportation system saw big changes. In July 2009 Sound Transit light rail entered service and a multi-year debate about the replacement of the Alaskan Way Viaduct reached a conclusion with a decision to replace the Viaduct with a deep bore tunnel. Meanwhile, Seattle's urban village strategy, which seeks to reduce automobile travel by promoting the development of mixed use hubs near transit centers, started to see results with large new developments coming online. The last of these changes saw the Port of Seattle expanding to capture increasing cargo volumes.

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.

Passenger Transport

Like most American cities, Seattle's ground system has been dominated by the automobile and this dominance, while still strong, may be decreasing slightly as measures designed to reign in urban sprawl begin to take effect. In 2012, 14% of Seattle workers walked or biked to work (the highest percentage on the West Coast) while almost 20% used public transit[39]. 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.

While much of the transportation system is centered on direct economic activity, 83% of trips taken in Seattle are not work related[40]. The average King County household takes 12 trips per day, of which six are less than three miles. Although hard data for trip purpose is more difficult to obtain than total volumes, it seems that transit trips are proportionally more work related than car or non-motorized trips.

Unlike many other cities, marine transport plays a strong role in Seattle's passenger transportation. Washington State's Ferry system is the largest in the U.S. and Seattle is its busiest destination. Ferries connect Seattle with Vashon Island, Southworth, Bremerton, and Bainbridge Island. The Edmonds – Kingston run (operating north of the city) also serves Seattle residents and workers. These routes have an annual combined ridership of over 16,000,000[41].

Most passenger air transport is through Seattle Tacoma International Airport (SeaTac) located south of Seattle. Over 32 million passengers use SeaTac annually[42]. Boeing Field, located just outside the city limits handles a smaller number of passengers from small carriers, charters, and general aviation.

Freight Transport

Washington State's economy is the most trade dependent state in the nation and Seattle sits at the center of this economy[43]. 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 King County International Airport (Boeing Field).

Seattle's marine cargo terminals and rail yards are located close to downtown. They must contend with completing land uses and passenger transportation. Mariner's baseball games are punctuated by train whistles. While train whistles during ball games may be whimsical, the lack of grade separation is not. 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 a large number of designated truck streets serve the marine business.

The air cargo business operates under a different model than marine shipments. Time plays a bigger role causing the type of goods shipped via air to be different than 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 handled 290,653 metric tons of cargo in 2007. Port businesses are very sensitive to disruption because traffic can easily be routed through competing ports.

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 as passageways for motor vehicles, streets have many other important uses. Pedestrians and bicycles use them. They are home to a major part of Seattle's urban forest. They are the 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.[44]

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 progressive bigger arterials (collector, minor and principal) and finally to the Interstate Freeways.

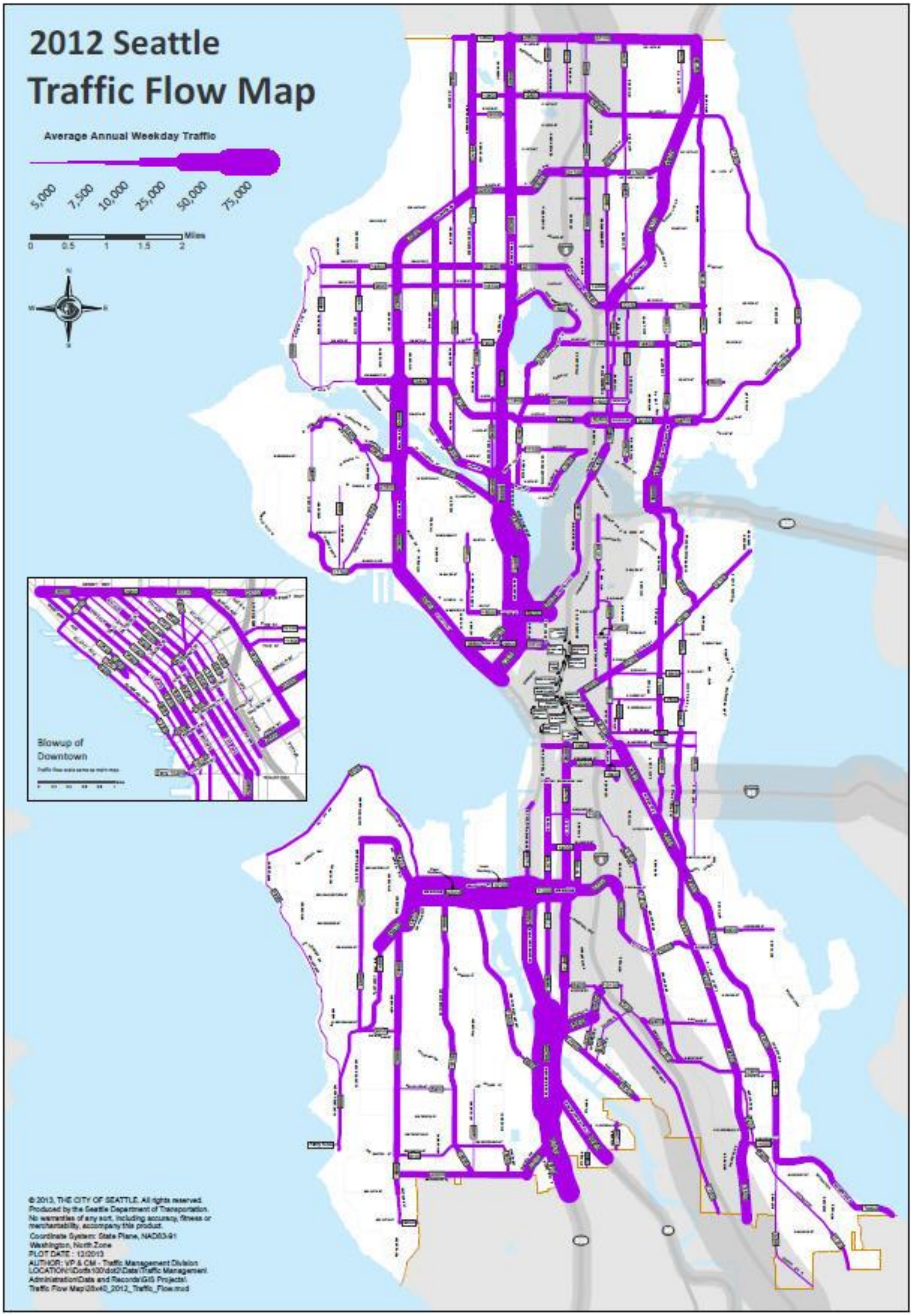
The backbone of motorized transport is the two Interstate Freeways (I-5 and I-90) and three principal arterials (SR-99, SR-520, and the West Seattle Freeway) that have large limited access portions. These five roadways handle by far the highest traffic volumes. I-5 and SR-99 run north-south and move 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. By far, the highest volumes in the city are found on I-5 around the Ship Canal Bridge.

The transportation data company, INRIX, ranked Seattle 8^{th} in the nation for traffic congestion.[45] This finding suggests that Seattle possesses little reserve capacity. A prolonged outage of a major roadway would shift traffic onto already overloaded infrastructure; however there is some evidence of mode shift.

Infrastructure: Bridges

Seattle depends on bridges. Seattle is an isthmus divided by waterways. To the west is Puget Sound. No bridges cross it and transport across it depends 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.

Figure 8. 2012 Traffic Flow Map



Two floating bridges, the SR-520 Bridge and I-90 Bridge (running over Mercer Island) cross Lake Washington. Together they bring over 192,000 vehicles into Seattle on an average weekday[46]. Washington State is replacing the Evergreen Point Floating Bridge. It has hollow support columns that are vulnerable to damage in earthquakes. [47] It currently handles 60,000 vehicles per weekday down from 96,000 a peak in 2010. Tolling to support new bridge has reduced usage of the current bridge.

The Ship Canal is spanned by seven bridges (six roadways and one rail). By far the most important is the I-5 Ship Canal Bridge, which at nearly 203,000 vehicles per day is the busiest roadway in the state. 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 53,000 vehicles per weekday.[48] 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.

Systems: Transit

Transit is a vital part of Seattle's transportation system for Seattle's residents, visitors and workers. Nearly 20% of Seattle residents use transit to get to work compared to fewer than 5% nationally[49]. Seattle is even more dependent on transit to bring workers into the key central employment areas. 35% of all downtown workers use transit to get to work. 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 118 million passenger boardings[50]. Trips involving Seattle make up the biggest share of this number. Sound Transit had 3,885,000 boardings in 2009. In July, 2009 Sound Transit began light rail service in Seattle. Ridership has increased steadily to 9.7 million boardings in 2013.[51]

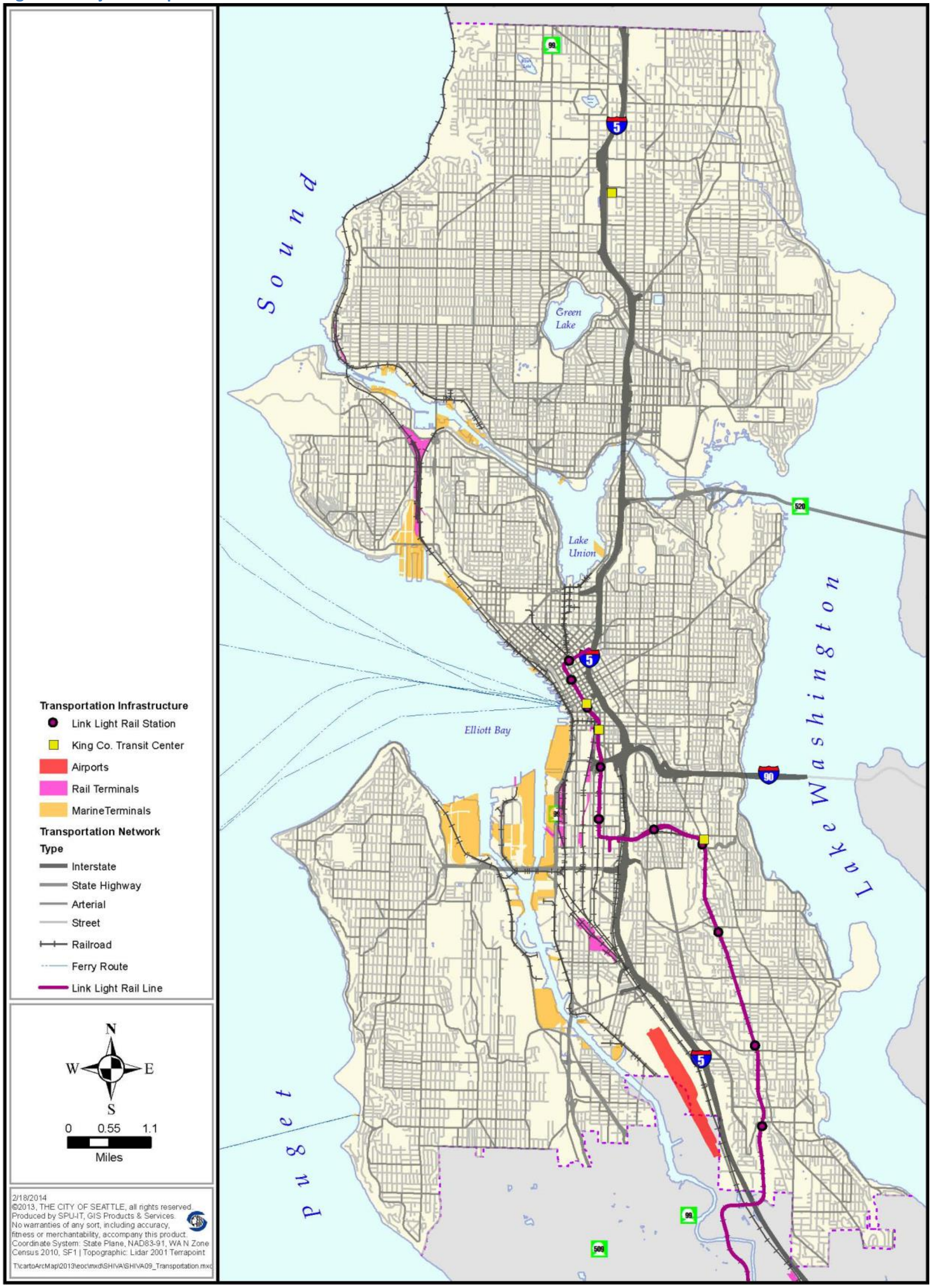
Paratransit (mostly vanpools) is gaining popularity in the Seattle area. Total boardings are less than for bus services (2,300,000 boardings in 2007) and growing quickly (up 18% from 2006 to 2007). Microsoft runs its own bus fleet, the Connector, to bring employees to its Redmond campus. The fleet has a capacity of 5,656 daily seats.[52]

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). 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.

Systems: Air

The Central Puget Sound area is unusual because it has a busy commercial hub *and* one of the country's key aircraft manufacturing areas. Seattle-Tacoma International Airport (SeaTac) and King County International Airport (Boeing Field) serve Central Puget Sound. SeaTac is the region's commercial hub and Boeing Field is one of the busiest non-hub airports in the country. The region has three other airports can handle large aircraft (important during large emergencies). They are Payne Field in Everett, Renton Municipal Airport, and Joint Base Lewis-McChord.

Figure 9. Major Transportation Infrastructure



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. Overall, SeaTac is the 15th busiest airport in the country with 317,186 air operations in 2013[53]. Boeing Field serves small carriers, general aviation (non-commercial), cargo carriers and Boeing.

SeaTac handles 65% of the regional air cargo traffic and Boeing Field takes the rest[54]. The biggest constraints on air cargo capacity are access to ground transportation and facilities to park aircraft. In 2012, SeaTac handled 283,500 tons of freight. This total is down sharply from a peak in 2000 when SeaTac handled over 400,000 tons.

Systems: Marine

Seattle has a strong maritime history. Travel by water is important for both passenger and freight traffic. Seattle is the center of the country's largest ferry system and the home to a diverse port that supports container traffic, bulk cargo, a major grain terminal, and a large fishing fleet. Cruise ship operations are a new and growing part of the economy that also creates demand for air and ground transport.

The Port of Seattle is the second busiest port in Washington.[55] Almost 800,000 shipping containers moved through Seattle's port in 2013. Seattle's bulk cargo terminal saw 1,420 vessel calls in 2013.[56] Most incoming goods are loaded onto trains and shipped to Chicago. While Seattle has a large marine port, it handles less than a quarter of the volume of the Port of Los Angeles. There is some indication that Seattle's cargo volume may grow as capacity at 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).

Systems: Rail

Seattle is a rail center. Both passengers and freight travel by rail in Seattle. Two major freight carriers operate in Seattle, BNSF and Union Pacific. Passengers use Amtrak for long-distance travel and Sound Transit commuter rail for short trips.

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 three-quarters of Seattle's commodities freight. Grain is the next largest commodity shipped through Seattle's grain terminal on Elliott Bay. 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.

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 route serving the corridor between Vancouver, B.C. and Eugene, OR. The other two are Seattle / Chicago and Seattle / Los Angeles. In 2013 the Amtrak Cascades route had 881,692 passengers. The number of passengers is declining due to competition with new bus service.[57] Seattle Ridership on the whole line has grown from 567,380 (1997) to 903,882 (2012).[58] 81% of riders are travelling for leisure[59].

Systems: 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.

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 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). Ninety percent of Seattle City Light's generated power comes from the Skagit River (North Cascades) and the Pend Oreille River (northeast Washington).

Seattle's heaviest electrical loads occur in the winter because by many Seattle buildings have electric heat.[60] Seattle's mild summer climate reduces the demand for air conditioning, allowing Seattle City Light to sell surplus power. Seattle's summer temperatures are projected to rise with climate change. This rise threatens creates financial risks for Seattle City Light.

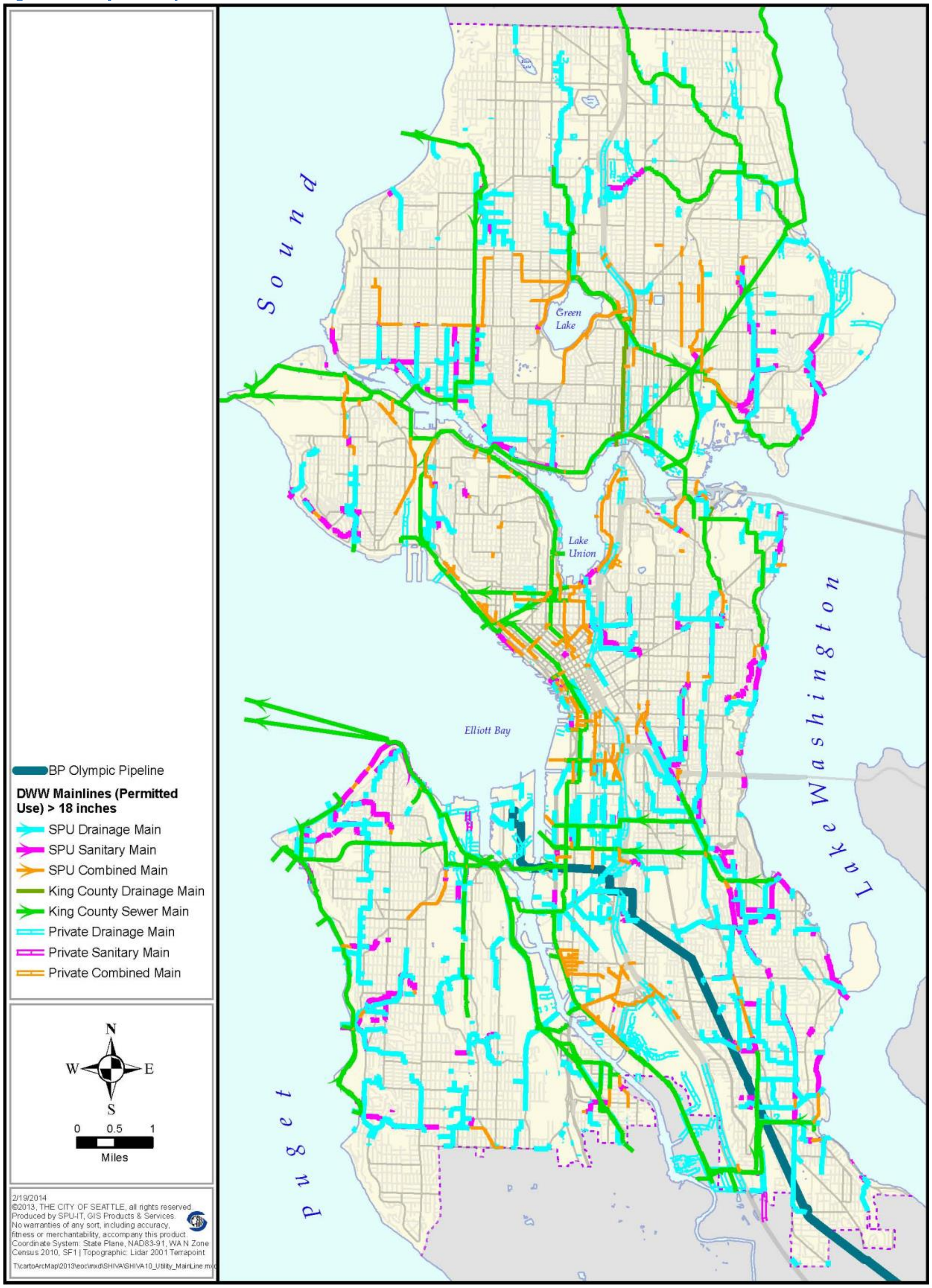
Seattle's use of hydroelectric power has meant that it is dependent on the snowpack in Washington's mountains. During years of low snowpack Seattle City Light has to purchase more power from BPA and other providers. Climate change may be reducing the Cascade snowpack. This trend is a major concern for Seattle City Light.[61]

Natural Gas

Natural gas is provided to 121,985 customers in the City of 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 pipe 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

Figure 10. Major Utility Infrastructure



the 1960s and early 1970s and the high cost of Canadian sources slowed the development of natural gas in the Pacific Northwest.

In Seattle, the use of natural gas has been slowly expanding and moderate growth is likely to continue. According to U.S. census statistics, 38% of Seattle residences are heated by gas.[62] The growth is linked to its price, which is driven by complex national factors. Regionally, the most significant factor is the use of gas to power electrically power plants. During the late 1990s and early 2000s, several gas fired plants were planned but subsequently moth-balled. This development shook up the gas market. This volatility acted as a brake on the expansion of natural gas service in Washington State.

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. Seattle Public Utilities controls supply, transmission and distribution of water within the City of Seattle and wholesales water to water districts in King County. 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 140 million gallons per day despite the population increasing from 1,100,000 to over 1,300,000. The main drivers for the change were the 1992 drought that led to higher water rates, a revised plumbing code, and improved conservation. Demand for water is lowest in the winter, at just over 120 million gallons per day. Demand spikes in late summer to nearly 220 million gallons per day.

Drainage and Sewer

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, Seattle Public Utilities 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 128 of them.

To update the public when CSO discharges are occurring, King County's CSO website shows CSO status in real-time for its 38 sites. Seattle Public Utilities maintains another 90 CSO locations, but this city utility does not have real-time monitoring of the sites. 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 less than 1.5 billion gallons (during the 2006 storms). Both King County and Seattle Public

Utilities 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. In Seattle, the Seattle Steam company's steam tunnels heat 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.

Seattle Steam generates its steam in power plants on Western Avenue. One is near Pike Place Market and the other is near Yesler Ave. 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 to damage in earthquakes because it is

Telecommunications

Seattle is widely viewed as a hi-tech powerhouse, but much of our city's telecommunications infrastructure remains rooted in older technology. Seattle's overall telecommunications infrastructure is a mix of broadcast media (television and radio), landline phone service, cellular networks, and cable television. The future of telecommunications is based on high speed connections, both wired and wireless. Washington State ranks 15th in the nation in Internet speeds; the U.S. as a whole ranks 25th in the world[63]. Many large organizations, including the City of Seattle, have high-speed connections and powerful private networks. Many locally, however, lack access to high-speed connections.

Telephone / Voice

Like everywhere else, phone service in Seattle is undergoing rapid changes as more and more customers switch to wireless, voice-over-Internet Protocol (VOIP) phones and smartphones with Internet access like the iPhone and others. The Center for Disease Control and Prevention found in 2013 that nearly 40% of American residents use only cell phones.[64] In 2013 PEMCO Insurance sponsored a poll that found that 32% of Washington residents do not have a landline telephone or were not sure if they had one.[65] Of the 68% that maintain a landline, 38% responded that they keep it in case of emergency. 65% of respondents reported that they do not have a family communications plan if their mobile service fails. Another 7% were not sure if their family had a plan.

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. Also, landlines are important as safety backups during power outages because they require no commercial power to work or charge.

All of 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.

Despite the explosion of cell use, traditional wired phone service is still the means by which the majority of Seattle residents have traditional phone service. In 2007 most basic phone service and Internet was provided by CenturyLink (80% share) but Comcast (13%) was growing[66].

Television / Video

Among Seattle residents, 69% subscribe to cable television, 11% use satellite systems and the remaining 20% rely on the traditional broadcast system. Comcast's 89% share makes it the dominant cable provider. Many cable subscribers get high-speed internet connections from their cable provider[67]. Many television viewers use their internet-based service to get video content, including television.

Internet / Data

The use of high-speed internet has expanded rapidly in the last decade. In 2000, only 18% of residents had high-speed connections; by 2009, 74% did. Most of these high-speed connections are over cable modems using a cable television connection or DSL, a phone-based technology. Comcast is now offering higher speed "premium" connection, but only 15% of households use this faster service. Clearwire offers a wireless Wimax high-speed Internet connection, but their market share is low.

The fastest way to connect to the Internet is with a fiber optic connect. There is almost no fiber optic service to residences and very little to businesses. Large institutions are the biggest users of fiber optics. The average download speed in Washington State is 5.3 megabits per second. With a fiber connection, speeds are often over 20 megabits per second.

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

High-speed internet has not been viewed as an essential service but this attitude appears to be changing. In a 2009 survey, the City of Seattle found that nearly half of all residents said that high-speed internet was "very important" and another 40% said it was "somewhat important." Underlying this response is the rapid growth is the number of people who use the internet to take care of essential business, take classes, and keep in touch with family and friends.

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. FEMA plans a new standard, a "P25" trunked radio system that permits greater inter-operability between agencies and jurisdictions. [68] Inter-operability is a commonly cited problem in emergency response.

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 have lower rates of access to technology.

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.[69]

Traditional broadcast and print media outlets are critically important because they are the dominate way that most people get their news. Over 60% of Americans prefer to get their news directly from news organizations.[70]

Written Media
Traditional media like newspapers are considered here along with newer tools like community blogs. Paper editions are still very important, especially for reaching the elderly, many immigrant and other communities that are underserved by the Internet.

Print 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.

Broadcast Radio
Broadcast radio remains a powerful medium. 74% of Americans listen to the radio every day[71]. Seattle is the 13th largest broadcast radio market in the U.S., with 57 stations. 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. A summary of 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, too. Fourteen 14 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[72]. Television sets are nearly universal, but only 69% of Seattle residents subscribe to cable television and most of these subscriptions are with Comcast. A smaller percentage of Seattle customers use satellite receivers. Most television news is now available on the internet either as a stream or in clips. EAS messages propagate to television.

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 1,329 sworn officers and 500 civilian employees, SPD is the largest law enforcement agency in the State[73].

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 there transfer calls concerning a fire or medical issue to the Fire Alarm Center; they evaluate calls concerning law enforcement issues and send them to dispatch, as necessary. 9-1-1 Center handles between 800,000 to 870,000 calls per year or over 2,000 calls per day.[74]

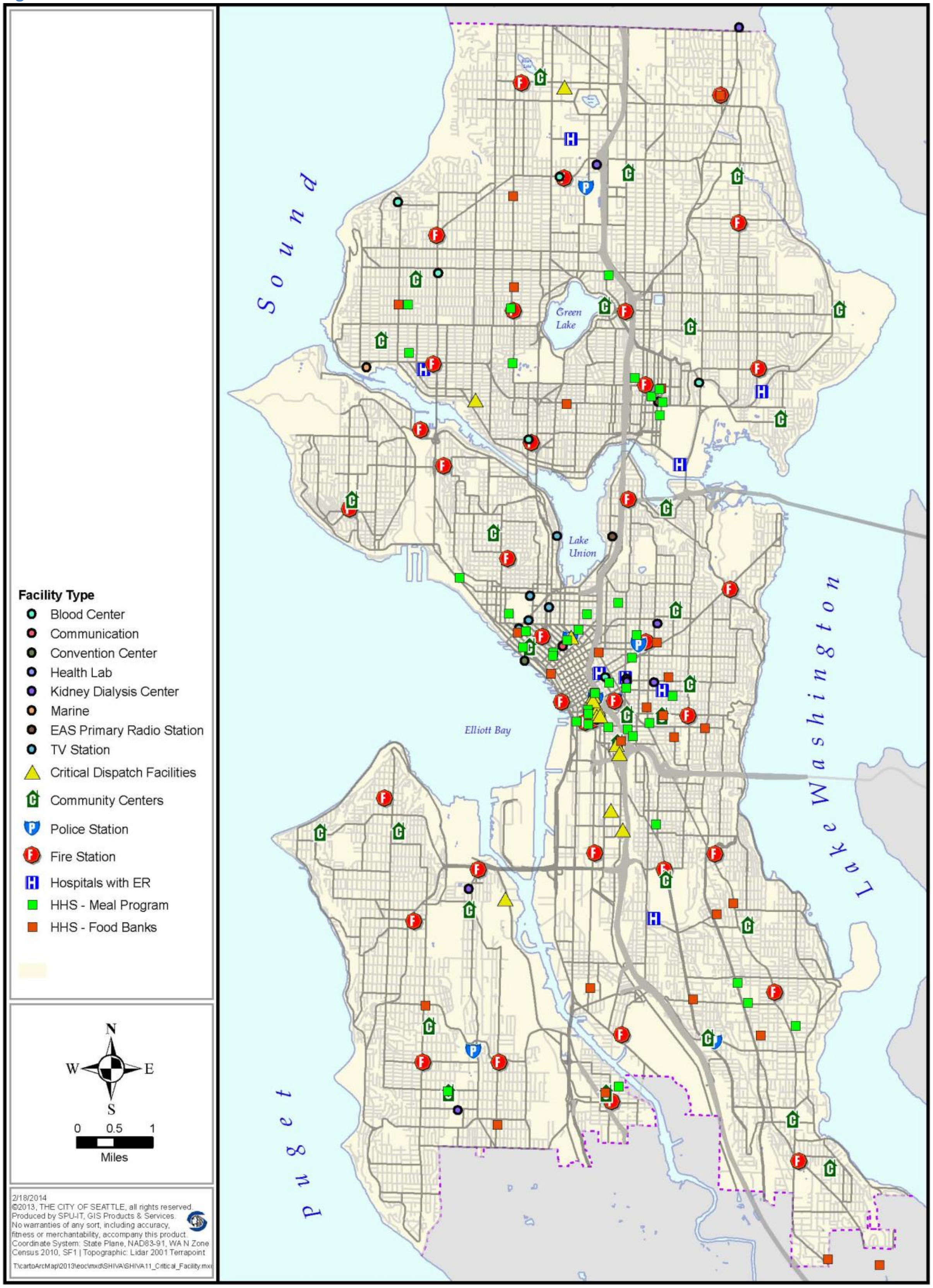
Overall, major crime has been on the decrease in Seattle but a disturbing rise in youth violence is also present in the overall statistics. Seattle's overall crime rate is comparable to or even a bit lower than cities of similar size. A 25 year review revealed a steady downward trend. In 1988 72,694 major crimes were reported. In 2012 34,607 such crimes were reported. This is a 52% drop.[75]

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.

King County maintains the two correctional facilities serving Seattle. The King County Correctional Facility is the primary detention facility in Seattle. It 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.

Figure 11. Critical Facilities



Fire Suppression
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 of 1,044 uniformed personnel has a duty strength of 207[76]. These personnel are divided among 33 fire stations, each of which house one engine company. SFD also operates specialized apparatus.

In 2003, voters approved a levy to improve fire infrastructure throughout the city. This nearly completed, nine-year project 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.

Between 1994 and 2009, Seattle had an average of 503 structural fires and 1,373 non-structural fires per year. Structural fires declined by nearly 50% from 1994 to 2008, from 784 to 387. The national average for cities of a similar size is 841. The trend for non-structural fires, e.g., vehicles, brush, and rubbish fires, has remained relatively flat.

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 casualties rates.

Emergency Medical Services (EMS)
SFD is Seattle's primary provider of emergency medical services provided somewhere other than healthcare facilities. All 981 Seattle fire fighters are certified EMTs, as well as about 100 police officers. To provide Basic Life Support (BLS), SFD maintains four 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. Seattle survival rate for cardiac arrest is 46%, compared with about 5% nationwide.[77] Medic One has 78 paramedics and 7 medic units.

Currently, SFD handles many more EMS calls than fire-related calls. In 2008, SFD handled over 69.000 rescue and EMS responses and 12,651 fire responses[78].

Healthcare and Human Services

Seattle's healthcare and human services systems are tightening 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[79]. 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, medical suppliers and the like—provide one in five Seattle jobs. 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 draws 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 10th 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 Director of Public Health – Seattle & King County serves as the Local Health Officer. This position 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; however, it is not known how many people are served in total. 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.[80]

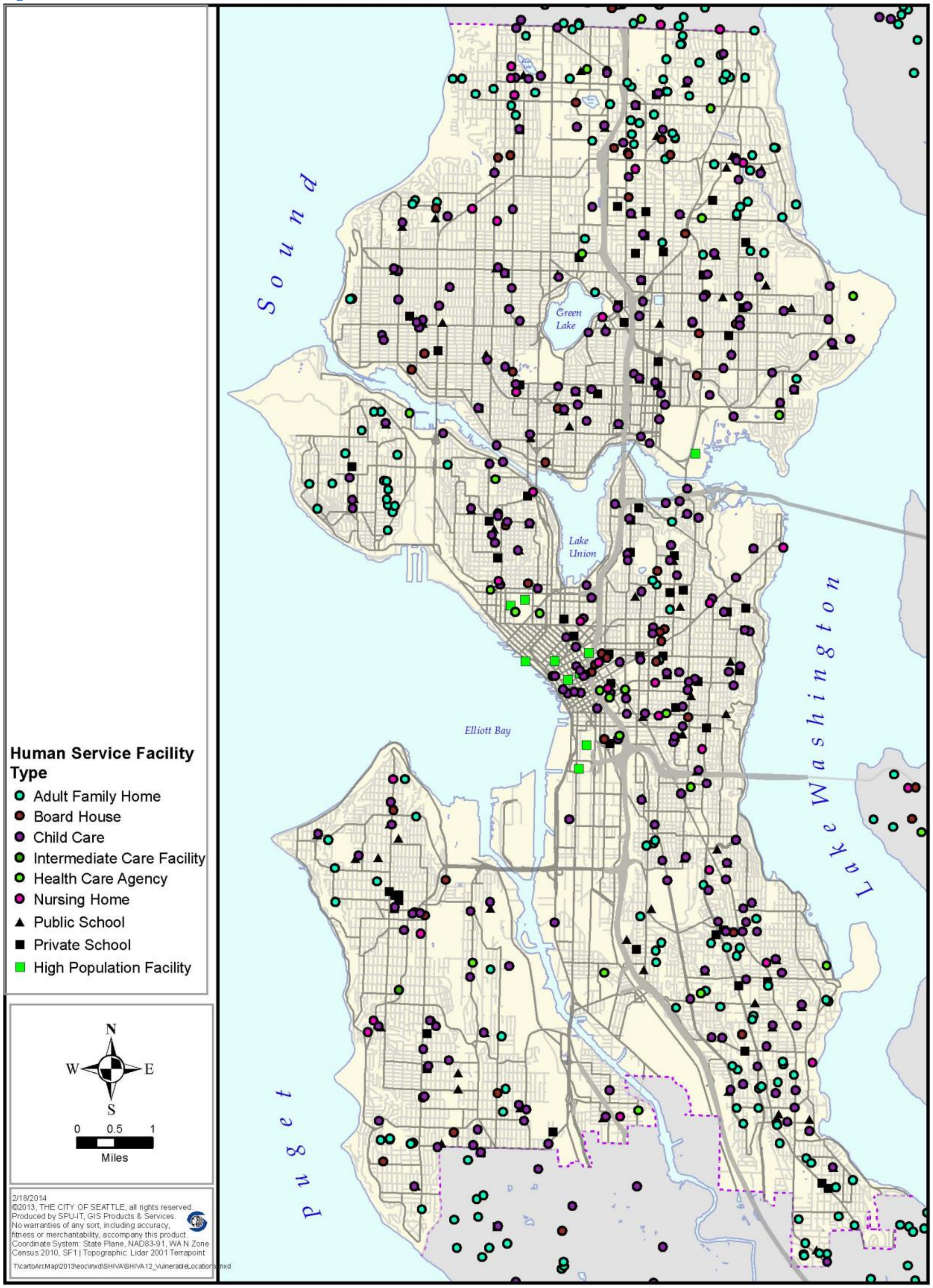
Seattle's human services sector is comprised of hundreds of public, quasi-public (e.g., Seattle Housing Authority) and private organizations. These differ so greatly is size, resources, scope, and capacity that it is impossible to make general statements about a "typical" organization. A relatively small 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 a large number of foundations that do not offer direct services but supply funding to providers.

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

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

- Enough food;
- Shelter;

Figure 12. Human Service Facilities



- 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[81]." Following the release of this report, the City of Seattle and United Way began a program to assist local nonprofits plan 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.

Structures

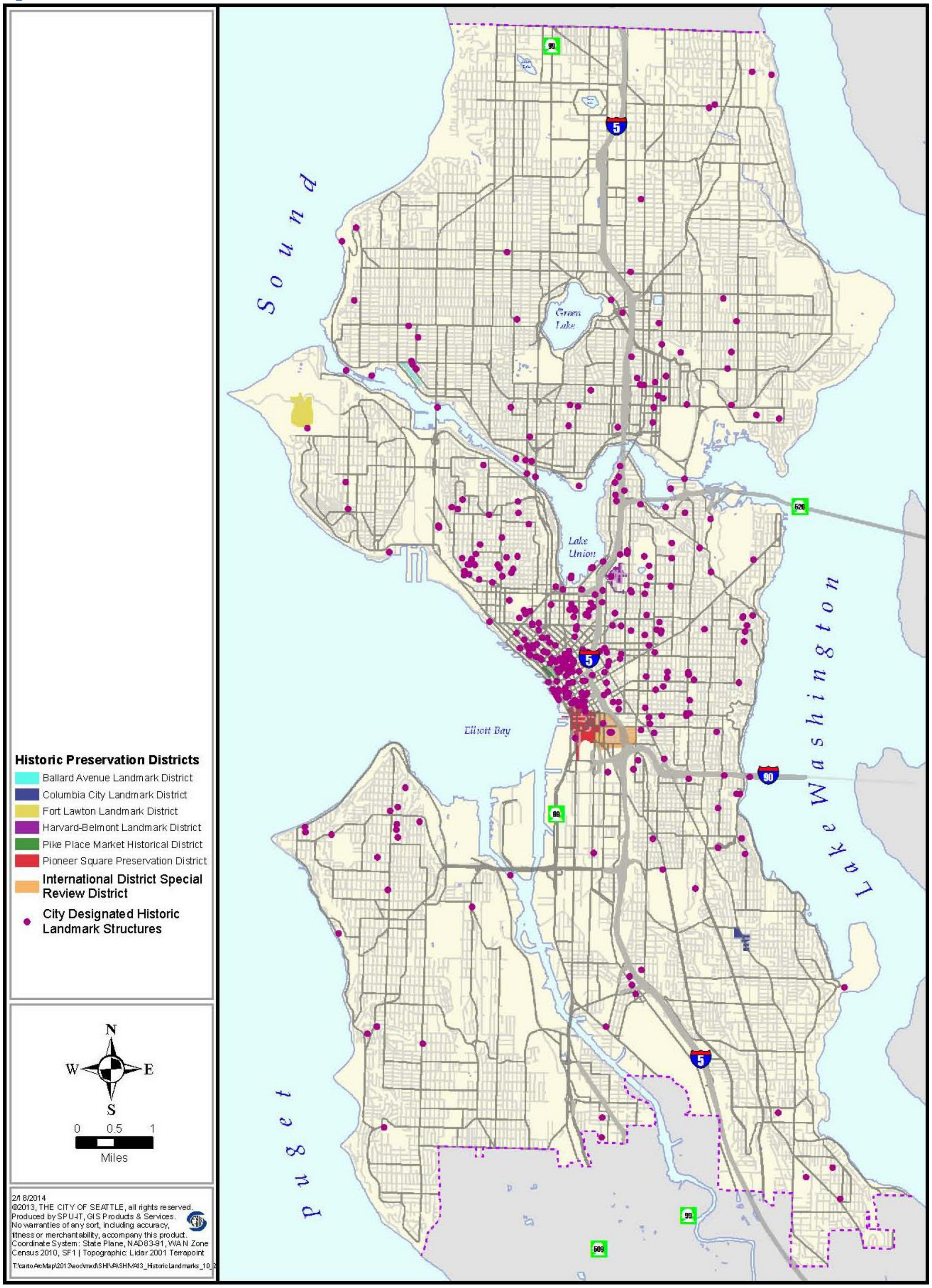
Seattle is a young city, but over half of its housing units were built prior to the 1949 building codes that introduced seismic standards or the city's 1992 upgrade of its seismic codes. The table below shows the age distribution of the housing stock.

Table 8. Age Distribution of Housing Stock.

Total housing units	**281,668**
Built 2005 or later	3,562
Built 2000 to 2004	19,228
Built 1990 to 1999	23,808
Built 1980 to 1989	23,824
Built 1970 to 1979	27,660
Built 1960 to 1969	28,943
Built 1950 to 1959	34,215
Built 1940 to 1949	31,135
Built 1939 or earlier	89,293

Source: U.S. Census.

Figure 13. Historic Districts and Landmarks



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. A Department of Planning and Development survey of the older areas of the city identified slightly more than 900 potential unreinforced masonry structures. 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.

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. As a consequence, 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.

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 Superstrom Sandy, many urban residents had to temporarily move out of their dwellings for this reason.

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.

Emerging Threats

This section recognizes new and long-term threats that affect the magnitude of hazards identified in the SHIVA. They are not additional hazards. They are an 'overlay' on the 18 hazards covered in the SHIVA. The 2014 SHIVA includes two emerging threats: climate change and cyber disruption.

Climate change a long term threat that will worsen over a period of decades. It is not a specific hazard. It is a factor that intensifies the effects of severe weather and flooding. Those factors are analyzed in the relevant hazard chapters: excessive heat, flooding, winter storms and water shortages. They are also collected along with an outline of climate changes causes and mechanics in this chapter.

Cyber disruption is the set of real world consequences due to massive computer failure regardless of cause. It does not cover cybercrime or cyber espionage. To be a cyber-disruption, a computer failure would have to produce deep, lasting, negative consequences for the Seattle community. It is an emerging threat because the world has not yet seen an actual significant incident although most security experts are very concerned. The SHIVA includes cyber disruption in the chapters on terrorism, power outages, transportation accidents and infrastructure failure.

Climate Change

Climate change is happening now and the rate of change is likely to increase. It 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 Carbon Dioxide (CO^2) would continue to contribute to warming temperatures.

Roughly half comes from burning fossil fuels for transportation. Another 30% comes from heating buildings and generating electricity. The rest comes from industry, agriculture, forestry and solid waste.[82]

At a Glance

- *3.2°F increase in average annual temperature in the Pacific Northwest by 2040.*
- *1-2% increase in annual precipitation with enhanced seasonal cycles (wetter autumns and winters and drier summers) by 2040.*
- *156 additional deaths on average per year due to heat and air pollution.*
- *Extreme precipitation leading to increased risk of urban flooding and landslides.*
- *40% decrease by 2040 in the mountain snowpack that provides Seattle's water and most of its electrical power.*
- *Increased power costs, especially in the summer.*
- *Rising sea levels leading to increased risk of landslides and coastal flooding. Rises range from 0.5 to 1.9 feet by 2050 and 4.2 feet by 2100.*
- *Degraded salmon habitat.*

The climate crisis presents Seattle with an extraordinary challenge —winter 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.

This section identifies climate change's direct effects, the implications for the SHIVA identified hazards and finally policy challenges that overlay emergency management but lay mostly outside it.

Direct Effects

Climate change is a complex process. It will not affect the Pacific Northwest uniformly. This section outline what the primary effects are expected to be. It summarizes the Climate Impacts Group's (CIG) findings. The CIG is an interdisciplinary group of scientists looking at climate change in the Pacific

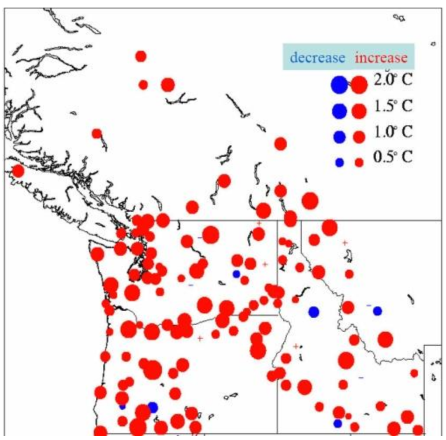
Northwest. Its assessments are the most rigorous and comprehensive for this area. In 2009 it published the Washington Climate Change Impacts Assessment, the most exhaustive analysis of climate change done to date for the Pacific Northwest.

A federal government assessment concluded in 2003 that "over the 20th century, the Northwest has grown warmer and wetter". Part of this increase is due to global climate change[83]. Historical data show that change has already happened and trends are measurably accelerating[84]. Average *global* surface temperatures rose 1.08°F during the 20th century[85].

Temperature

The average annual temperature for the Pacific Northwest has increased 1.5°F since 1920. Increases have not been uniform across the region and vary by time of year Figure 14. Temperature Changes in the 20th Century shows the temperature trends in the Pacific Northwest since 1920. Red marks an average annual temperature increase. Regional warming (3-5°F by 2040s) is likely to be faster than global warming (1-4°F by 2040s).

Figure 14. 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.

Sea Level Rise

The global average sea level has risen about 0.17 meters (6.7 inches) over the past century, about 10-times faster than the rate of sea level rise over the last 3,000 years. One Pacific Northwest study found a sea rising trend of 2.1 millimeters per year from 1898 to 1999. In Seattle, this sea level rise is compounded by land subsidence at a rate of about 1.4 millimeters (0.06 inches) per year, making the rate of sea-level rise roughly double the global average[86]. Seattle is projected to experience a 7 inch sea level rise by 2050 and 2 feet by 2100.[87]

Snowpack

Seattle's water and hydroelectricity are dependent on Cascade Mountain snowpack. Peak snow accumulation and snowmelt-derived streamflow across the West have shifted by 10-30 days earlier over the past half century[88]. According to the Washington State Climate Impacts Group the average snowpack in the North Cascades is about half of what it was 50 years ago, and we are likely to lose another 50 percent by 2050 if current trends continue. This drop translates into a 30-percent decline snow water equivalent (the amount of water contained within snowpack and usable as a water source) since 1945. The decline has been mitigated by a dramatic decline in per-capita water usage that has offset the decline in snowpack despite a rise in Seattle population.

Precipitation
The Puget Sound region will probably experience heavier peak discharges in the future. The Washington Climate Change Impacts Assessment included an analysis of historical precipitation at SeaTac. The study examined rainfall totals for nine durations (1 hour to 10 day totals) by examining the differences between the period of 1956 – 1980 and 1981-2005. The conclusion was that the "results suggest that urban stormwater systems in the Puget Sound region probably have already experienced substantially increased peak discharges over the past half-century"[89].

Air Quality
According to the Puget Sound Clean Air Agency, region-wide emissions increased eight percent between 1990 and 2000. And, within the next 15 years, they are projected to increase by 38 percent. The Washington Climate Change Impact Assessment estimates over 100 additional deaths will occur by 2050 due to decreased air quality.

Effects on Hazards
Climate change will affect all Seattle's weather hazards, fires, landslides, disease outbreaks, power outages and infrastructure failures. It will affect both the likelihood and the consequences for most hazards.

Landslides
Water is a trigger for landslides. Increase ground water beyond a given threshold and landslides will increase. Climate change is expected to increase winter rainfall and with it the number of landslides.

Disease Outbreaks
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?

Fires
Climate change will mean potential increases in the number of forest fires, but less so in the western Cascades than in the eastern Cascades. A large fire in the City of Seattle watershed could degrade Seattle's water quality.

Infrastructure Failures
High heat causes steel to expand which can damage some older structures. During excessive heat SDOT must cool its drawbridges to ensure they can be opened and closed.

Power Outages
Climate change will increase demand for power in the summer. This increased demand will not make power outages more likely, but it will increase their negative consequences especially if one happens during an excessive heat event.

Excessive Heat Events
Many cities are already experiencing more very hot days in the summer, contributing to increased smog and health problems, particularly for vulnerable populations. Hotter summers could raise smog levels that already have exceeded health standards in recent years.

Flooding
Climate change will probably increase winter flooding. If rainfall falls harder over shorter periods of time as is expected, 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 may also increase. Low-lying areas fronting Puget Sound could be subject to flooding, especially when winter storms coincide with high tides. Though changes to coastal wildlife habitats are expected, limited effects are predicted for the Seattle area because our coast is highly developed. Long term, 300-400 hectares (741-988 acres) of dry land is predicted to be at risk of being converted to transitional marsh, salt marsh and tidal flats. In addition, 55 percent of estuarine beach could be lost by 2100.

Water Shortages
Existing water resources should still be sufficient to meet the forecasted water demand through 2053, assuming no decreases in yield after 2040. Seattle Public Utilities supplies drinking water to more than 1.45 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. Given the projected climate changes in the Cascades (reduced snowpack, earlier snowmelt, higher air temperatures) the impacts for the water utility could be significant. Seattle Public Utilities contracted the CIG to model impacts on the Tolt and Cedar watersheds. By 2020, CIG projects about a 7% less reliable yield in water supply. This equates to about 12 million gallons a day, which would not affect the utility's ability to meet projected demands. By 2040, the study projects a reduction in yield of approximately 24 million gallons a day. Seattle Public Utilities is continuing to evaluate new water supply alternatives and to track climate science developments in the event that conditions indicate new supplies are needed sooner.

Seattle City Light's 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). To better understand and plan for the hydroelectric impact scenario, Seattle City Light supported research at the University of Washington's Atmospheric Sciences Department to model the effects of climate change specific to the Skagit watershed. Seattle City Light will continue to support research of this kind and integrate the information into its planning for operations and future resource needs. In the long term, Seattle City Light will look at the potential need to modify operation on the Skagit. To be consistent with National Energy Reliability Council requirements, Seattle City Light 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. Seattle City Light 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 Skagit.

Windstorms
How climate change affects the frequency and intensity of storms and extreme precipitation events in the Pacific Northwest is unclear. Research and modeling is underway at the CIG to develop greater certainty in this area, especially with windstorms. One thought is that, in the late 21st century, intensification, widening and shift of the Pacific storm track could result in 1) increases in winter precipitation and 2) fewer but more violent windstorms.

According to modeling currently underway, increased temperatures at higher elevations in the atmosphere could yield more energy and water vapor in the atmosphere, potentially giving storms more strength. A westerly shift of the storm track could also enhance the “mountain effect,” leading to greater precipitation on the western side of the mountains and less on the eastern side.

Slow Onset Challenges

Besides intensifying hazards, climate change will produce a unique set of challenges that will be difficult to handle because they will happen slowly enough that the community will not see them as special events that call for immediate attention. Although these risks are outside the traditional emergency management framework, it is important to recognize them. The possible consequences are listed below as policy questions for our community.

Urban forestry

How will native conifers in parks and green spaces respond over the long term to warmer temperatures and fewer winter freezes? Will the trees be more prone to insects and diseases?

Sea level and water temperature rise

What will be the impact on Seattle shorelines and how will that affect development regulations, the location and design of shoreline facilities, and habitat restoration projects? What will sea-level rise in the Sound mean for the integrity of critical shoreline infrastructure such as seawalls, the Port of Seattle, and King County’s wastewater treatment facilities? What will a warmer Lake Washington and Puget Sound mean for the cherished wild salmon runs that we are spending hundreds of millions of dollars to restore? Some sea level rise projections even 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?

Food Systems

Climate change impacts to agriculture will affect our food and nutrition sources. Temperature changes and increased competition among irrigators for a potentially smaller water supply will affect our regional agricultural economy. Warmer summers may cause some pest species to increase, while causing others to decrease.

Coastal Ecology

Already unavoidable 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.

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. One of the biggest concerns is how sea-level rise might affect the region’s already-beleaguered 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.

Projected changes from sea level rise and other climate changes would fundamentally alter the region’s coastal habitats and the species they support. Some species may be able to respond to changes by finding alternative habitats or food sources, but others will not. Coastal habitats such as marshes, tidal flats, and beaches and the fish and wildlife that depend on them are at great risk. 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, 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.

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 climate change that is already here. Building on efforts underway at Seattle Public Utilities and Seattle City Light, the city is continuing to develop and implement a comprehensive strategy to ensure that climate impact scenarios are integrated into city policies, operations and services.

In September 2006, the City of Seattle finalized the Seattle Climate Action Plan. This document is the roadmap for the City of Seattle's goal of reducing global warming pollution by 7% below 1990 levels by 2012. The city government, led by Seattle City Light's program to achieve "zero net emissions," has reduced its own contributions to global warming pollution by more than 60% below 1990 levels. The Seattle Climate Action Plan details other opportunities to limit climate change by:

- Reducing our dependence on cars.
- Increasing fuel efficiency and the use of biofuels.
- Conserving and using cleaner energy in our homes, businesses, and institutions.

The city has implemented waste reduction and water and electricity conservation programs. For example, in response to varying weather conditions over the years, Seattle Public Utilities has developed and applied strategies to enhance the water supply system while also meeting stream flow needs for fish. Additional options to adapt the water supply system to climate change have also been identified. Total water usage in the Seattle area is now less than it was 30 years ago, despite a 25 percent increase in population.

Cyber Disruption

Cyber disruption is the set of real world consequences resulting from a computer or network outage. The US has not yet experienced a catastrophic cyber disruption but we know that 1) the US and the rest of the world has become dependent on networked computer systems to maintain public safety, quality of life, the economy and the environment; 2) that these systems can be severely damaged by a variety of events: cyber-attacks, electro-magnetic pulse (natural or man-made) or physical damage as a secondary impact from another hazard; and 3) a prolonged outage to critical infrastructure could have catastrophic impacts.

The City is also vulnerable to cyber espionage and crime: the unauthorized access of computer systems and data for criminal purposes. The City experiences attempted attacks on a daily basis but has avoided a major compromise. Espionage and data theft could degrade public safety, expose the City to financial risk and the public to identity theft.

Causes

This section outlines the four most likely causes of large-scale cyber disruptions.

Cyber-attack

The US intelligences services are concerned about cyber-attacks but judge that "there is a remote chance of a major cyber-attack against US critical infrastructure systems during the next two years [2013-2014] that would result in long-term, wide-scale disruption of services" (2013 Worldwide Threat Assessment). The same report states that the most sophisticated cyber actors such as Russia and China are unlikely to launch attack outside of military conflict. It goes on to state that less skilled but more motivated actors could cause disruptions, but that "systemic disruptions will probably be limited". The report hedges its assessment by warning that even unsophisticated attacks can get lucky if a high value target is unprotected.

2008 marked a cyber-attack turning point when the US 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.

Electromagnetic Pulse (EMP)

Electromagnetic pulse is burst of electromagnetic energy from natural (e.g., lightning, solar storms) or man-made (e.g., nuclear explosions, electric motors) sources. Both types can destroy or damage unshielded electrical equipment. Natural sources typically do more damage to power grids while man-made sources, especially nuclear weapons do more damage to integrated circuits like those in computers. 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 of an outage caused by EMP could vary considerably based on the size of the device and where it detonated. It is possible that devices up to 400km away could be affected. Some analysts have questioned why a small enemy state or terrorist group would use a nuclear weapon to cause EMP when it could be used much more dramatically to kill people and destroy buildings.

Physical Damage

Cyber disruptions can also happen as secondary effects from other kinds of hazards. 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.

Indirect Effects

One of the most probable impacts of a disaster will be the temporary disruption of networks due to overwhelming utilization. Power outages will also 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.

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 are also deeply connected with the machines that control our infrastructure and embedded many everyday devices from vehicles to coffeemakers. Most of these computers are connected via networks. Some of these networks are private, but most are connected to the Internet, the de facto common communications backbone for the world and therefore 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 (e.g., engineering drawings). They are built from standard commercial off-the-shelf (COTS) 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

These are computers built to do one thing. A computer that assists in the control of 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. There are 10 billion embedded systems world-wide. They have a wide range of applications from consumer electronics, industry, transportation, medicine, facility management to defense. Miniaturization is pushing their spread to smaller and smaller devices. Often these devices have been isolated from the Internet which reduces their exposure to hacking. Many of the companies that make embedded systems have been casual about security due to the past lack of exposure to hacking.[90] If these devices become connected to the Internet (to make them more convenient to manage) they become much more vulnerable to hacking.

Supervisory Control and Data Acquisition (SCADA) Systems

SCADA is a class of industrial control system that can include embedded systems, general purpose computers and communications equipment. There are many specific types of SCADA systems. They are used in power generation, transmission, and distribution; traffic control; water treatment and distribution; oil and gas transmission; dams; wastewater treatment; 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 behave appropriately given the status of the whole system.

Many SCADA system components are not patched on a regular basis making them vulnerable to attack. Only about 10 to 20 percent of organizations install patches that SCADA vendors release.[91] These components are especially vulnerable if they are connected to the Internet. 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 to the Internet and it is easy for staff to mistakenly connect to the Internet. The major reasons operators are not patching systems are 1) patching can necessitate system outages, 2) fear that a bug in the patch itself will crash the system, 3) lack of urgency because systems are not directly connected to the Internet and 4) the equipment is so old that there are no patches available. Even if SCADA systems remain disconnected from the internet Stuxnet demonstrated that it is possible to deploy malicious code to computers that are not connected to the Internet. Stuxnet spread via infected thumb drives.

Effects on Hazards

Computer outages manifest themselves through hazards that the SHIVA covers, mostly those that are human caused. Natural hazards can cause cyber disruption by physically destroying key components or indirectly by cutting power or causing overloads.

Infrastructure Failure

Computers and data network failures are a type of infrastructure failure. The consequences would depend on 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. Most if not all of these cases would involve an attack. For example, false instructions sent to a motor can cause it to run hard enough to fail. To be most effective most experts conclude that physical attacks and sabotage would have to accompany cyber-attacks.

Power Outages

Experiments have demonstrated that it is possible to destroy electrical generators by sending them instructions that cause them to overheat. Attacks or accidents could also damage turbines in power generation facilities. Losing generation facilities would reduce capacity and could lead to brownouts especially if the outage occurred during peak demand (during the winter in the Pacific Northwest).

Transportation Accidents

As more and more of our transportation systems become 'intelligent' we incur a greater the risk that computer malfunctions will cause disruptions to our transportation system or worse: accidents that hurt people. All modes of transport: roads, rail, air and marine all have major computerized components. These computers run signals, communications, controls and vehicle subsystems.

Terrorism

Groups and individuals who seek to harm the US may turn to computer-based attacks as a means to pursue their goals. Although some researchers question whether terrorists are likely to use computers to attack when conventional attacks are more directly destructive and easier to stage, critical systems are exposed and capable of being attacked. 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 an attack in order to make the attack more successful.

Water Shortages

Most water shortages result from dry weather, but the loss of control over the water SCADA system could force Seattle to rely on manual backup systems that would reduce overall efficiency. Seattle's transmission and distribution system is 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.

Geophysical and Weather Hazards

Computers problems cannot cause the earth to move or rivers to rise, but these natural hazards can cause physical damage that triggers cyber disruption. The cyber disruption could feed back into the consequences of the primary hazard. The effects can range from the physical destruction of facilities like server farms and network hubs to the saturation of networks following a big event. 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. The City of Seattle is in the process of building a new data center. The plan calls for a secondary center outside the Puget Sound region to provide for continuity of operations.

Conclusion

Institutions in the Seattle area face hacking attempts every day. The vast majority of these are not successful, but it only takes a few to cause a major compromise. Moreover, due to the interconnected natural 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. Despite the fact that computer compromises and data theft pose a significant threat, the world has not yet seen a major disaster precipitated by computer malfunction whether accidental or intentional. Analysts are divided on the likelihood of a large scale cyber disruption. Some point to the vulnerability of critical computer systems. Others conclude that catastrophic attacks are 1) still beyond the means of those most motivated to carry them out and 2) less attractive to these same groups than conventional attacks. The scope and depth of this threat is still emerging.

Geophysical Hazards

This section groups together some of Seattle's most common hazards, such as landslides, and its most severe, earthquakes. This section also includes the chapter on tsunami because they are caused by either earthquakes or landslides.

Earthquakes

Key Points

- 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 three very different 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. Shallow quakes are the type expected on the Seattle Fault zone, which is the primary but not only source for shallow quakes in Seattle.
    - **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 ground motions are attentuated. The 2001 Nisqually Earthquake was a deep quake.
    - **Subduction Zone or Megathrust Quakes** occur on the interface between the North American plate and the San Juan de Fuca plate, a small plate extending from northern California to British Columbia. These are the largest type of earthquakes in the world.
- An earthquake on the Seattle Fault poses the greatest risk to Seattle.
    - The Seattle Fault Zone extends east-west through the middle of the city.
    - A Seattle Fault quake could be as large as magnitude 7.5[92], but less than 7.0Mm 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 6.0Mm occurred in 1909, 1939, 1946, 1949, 1965 and 2001.
- Megathrust earthquakes are the greatest risk to the region as a whole. A megathrust earthquake could reach M 9.0+ and affect an area from Canada to northern California. Shaking in Seattle would be violent and prolonged, but not as intense as a Seattle Fault quake. This area has a megathrust earthquake about every 500 years.
- 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 an estimated 819 Seattle unreinforced masonry buildings that perform poorly in earthquakes. These older brick buildings tend to be concentrated in areas expected to experience the strongest ground motion during earthquakes. Other vulnerable building types exist, too.

- Seattle is heavily dependent on its bridges. Damage to them would impair emergency services and the economy. The city has launched a multi-year effort to retrofit them to a life-safety standard so they won't collapse. Despite the retrofits, many will not be usable after a strong earthquake. Most of the critical bridges were retrofitted by 2009.

- 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, and hazardous materials releases could become disasters themselves. In many earthquakes more people die from fire than building collapse.

    - 2013 research finds that Seattle is at risk of *thousands* of landslides following a strong (magnitude 7) Seattle Fault earthquake. Estimates range from 5,000 if soils are dry to 30,000 if soils at saturated.

    - A large Seattle Fault earthquake could trigger a 16ft tsunami that would strike the Seattle shoreline within seconds of the earthquake and flood it within 5 minutes. Although megathrust and deep earthquakes will not directly cause tsunamis in Seattle these sources could initiate landslides that result in local tsunamis.

    - A magnitude 7 Seattle Fault earthquake could cause dozens of fires. Suppressing the fires would be more difficult because damage to the water system would reduce water pressure in many parts of the city.

    - Structural failure and fires would probably causes multiple hazardous materials releases. They could range from minor spills to major incidents.

Context

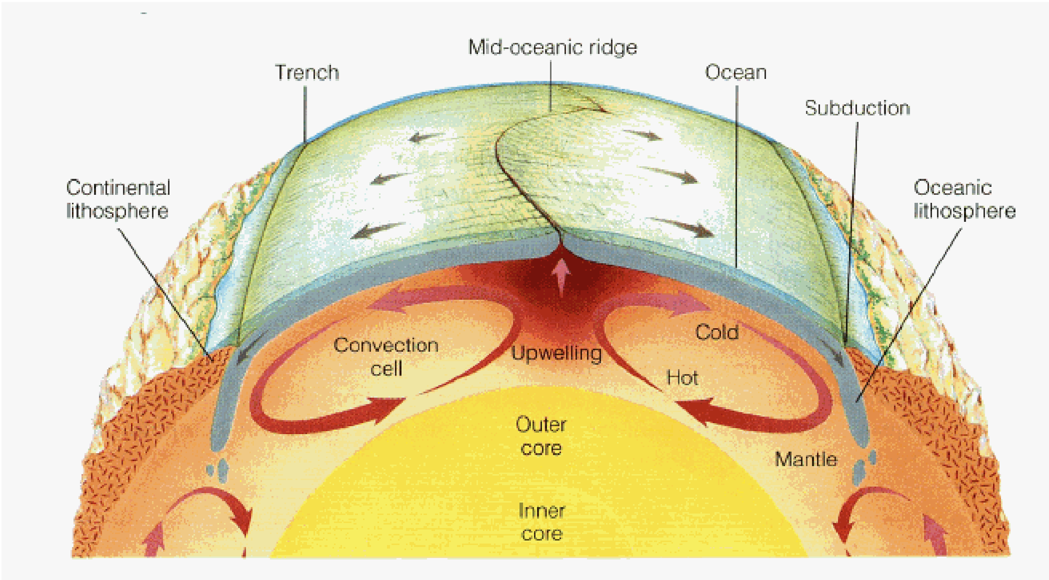
This section provides a very brief overview of the causes of earthquakes and the pattern of seismicity in the Pacific Northwest. Also included are explanations of the major metrics used to describe earthquake power and intensity.

Causes

Earthquakes are caused when the strain accumulating in rock due to the movement of large parts of the earth's crust called plates 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. 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 dense Pacific Plate is moving northwest and it rotating the small San Juan de Fuca plate clockwise under the lighter North American Plate. This process is known as subduction. It usually occurs in a jerky manner. 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. When the strain is too great, the plates slip, suddenly causing a megathrust earthquake.

Figure 15. Convection in the Earth's Crust



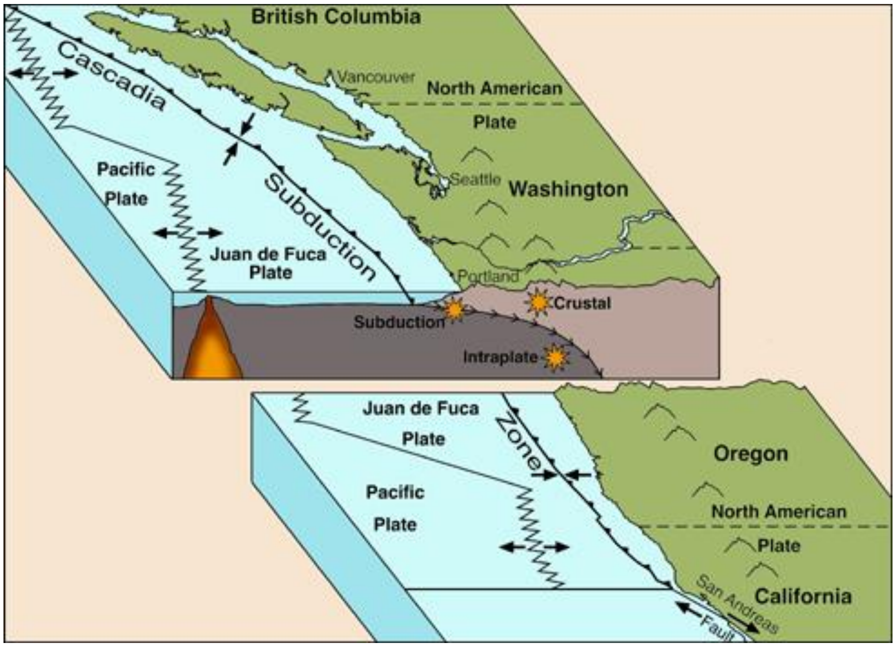
Source: http://www.dstu.univ-montp2.fr/PERSO/bokelmann/research.html under "driven by mantle convection. Accessed 12/21/2009.

Types of Earthquake

Pacific Northwest has a complex seismic profile, but ultimately all are driven by subduction. Quakes in this region fall into all three categories: shallow, deep and megathrust.

- **Crustal or Shallow earthquakes** occur in the North American Plate as it adjusts to the build up of strain along the interface of the North American and San Juan de Fuca Places. Depths vary from 0 to 30km (about 21 miles). They are usually felt very intensely near their epicenter, but their effects usually diminish relatively quickly with distance. There is an active shallow fault system running through the middle of Seattle, the Seattle Fault Zone.
- **Intraplate or Deep earthquakes** at depths between 35 and 70km (about 21 miles to 43 miles). Since they are farther from the surface, they are not felt as intensely, but are experienced over a wider area than shallow quakes. The 1949, 1965 and 2001 Western Washington earthquakes were deep earthquakes. They are the most common type of large earthquake in our region.
- **Megathrust or subduction earthquakes** result when pressure at the interface between the San Juan plate and North American plates unlocks. They occur along a sloped plane from where the plates meet off the Washington coast to just under the coastal area. This fault is over 1,000 km (620 miles) long. Megathrust earthquakes are the largest type of quake, with magnitudes from 8.0 to over 9.0. They have occurred at about 500 year intervals ranging along the Pacific Coast[93].

Figure 16. Types of Pacific Northwest Earthquakes



Source: http://www.oregonshowcase.org/index.cfm?mode=resources&page=earthquake.

Measures

Three of the most common measures of earthquakes are Movement Magnitude, Modified Mercalli Intensity (MMI) Scale and Acceleration.

Moment Magnitude is the best single measure of the total energy released, i.e., the size of the earthquake. Movement Magnitude measures three things: the size of the area that has slipped, how far is has slipped 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 5 are considered “moderate;” above 8, they are considered “great.”

Many people, including some in the press, confuse Richter and Moment Magnitudes. The Richter scale was designed in 1935 for earthquakes in California and intending for medium sized earthquakes (between 3.0 and 7.0). Because of these shortcomings, Moment Magnitude is the most commonly used scale used by the United State Geological Survey (USGS).

Modified Mercalli Intensity (MMI) Scale is a subjective measurement of earthquake effects and damage. The Mercalli scale uses twelve steps to describe damage to structures. Each step is a stronger intensity. Maps drawn from reports of what people felt are useful in determining areas of damage concentration. Because effects differ in across areas, an earthquake has multiple intensities.

Acceleration measures the effects of ground shaking on structures. It is the rate of change of velocity at which a reference point moves during ground motion and is expressed as a fraction of gravity (g): typically the higher the acceleration, the more stress on a building. 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. Typically, acceleration is measure over periods of 0.3 and 1.0 second. Acceleration varies with distance from the epicenter and local conditions like soil type.

Table 9. 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.

In 2007, the United States Geological Survey developed a series of maps that estimated the maximum acceleration Seattle neighborhoods would faces in the next 50 years. They are explained below.

Sometimes duration is also used as a measure because the long shaking occurs the greater the likelihood of damage, especially in soft soils. Megathrust earthquakes last an especially long time (2-4 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[94]. As seismic waves become less powerful moving away from the epicenter, the waves can change amplitude as they move through different types of soil and rock. Soft soils, especially those that overlay hard rock amplify seismic waves, causing more vulnerable soil farther from the epicenter to shake more intensely than less vulnerable soils closer to the epicenter. Notice how in Figure 17 that the Duwamish Valley experienced more intensity shaking than the surrounding hills even though they were the same distance from the epicenter.

Local geology also 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. Once liquefaction has occurred, the muddy soil will often flow laterally (laterally spreading) and cause severe structural damage.

Earthquakes can trigger landslides by shaking unstable or steep slopes. Wet conditions can exacerbate slide potential because waterlogged soils are less able to resist sheer pressures in slopes. A 2013 study by UW researcher Kate Allstadt examined the potential for shallow (less the 2.8 meters deep) landslides following a magnitude 7.3 Seattle Fault earthquake. The results were sobering. She found that the quake could cause 5,000 landslides in dry conditions and 30,000 in extremely wet conditions (i.e., like New Year's 1997 when Seattle had 225 landslides without the help of an earthquake). The study did not model deep seated landslides which can cause whole hillsides to fail. More information about landslides can be found in the Landslides chapter.

History

The Puget Sound region has fewer earthquakes than California but they can be just as powerful. From the time record keeping began, the Puget Sound region has been the most seismically active area in Washington[95]. Of the earthquakes recorded, ten quakes of magnitude 4.9 or greater occurred in western Washington. Eight of these ten were centered in the Puget Sound region:

Around 900. Magnitude 7.5 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 mucho of the low lying area around the mouth of the Duwamish River. It is estimated that the Seattle 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[96].

Jan. 1700. Magnitude 9.0 megathrust earthquake. One of the world's largest earthquakes struck the Pacific Northwest coast. Coastal areas dropped 1.5 meters as the undersea thrust fault ruptured along 1000 km. It generated a tsunami that struck Japan.

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

Jan. 1909. Magnitude 6.0 deep earthquake centered in the San Juans.

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

Apr. 1945. Magnitude 5.5 (no data on depth)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. Magnitude 6.3 deep earthquake centered under mid- Puget Sound. Damage in Seattle mainly limited to the Duwamish Valley and structures built on pilings.

Apr. 1949. Magnitude 6.8 deep earthquake centered near Olympia. The earthquake had a peak lateral 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 (measured in 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. Magnitude 6.5 deep earthquake with the epicenter closer to the city than the 1949 quake. The earthquake's acceleration was lower, .2g. While it did cause type VIII MMI damage, most of its effects were limited to type VII MMI. As in 1949, many ground failures occurred in the Alki and Harbor Island areas, but they were not as concentrated as in the 1949 quake. Six people were killed, mostly by falling debris. Damage was $104 million (2010 dollars). Based on these records, one report estimates that 6.5Mm events have a repeat rate of 35 years and 7.0Mm events have a repeat rate of 110 years[97]. However, these rates are highly speculative.

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

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

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

Feb. 2001. Magnitude 6.8. Large deep quake under South Puget Sound, the Nisqually Earthquake.

Figure 17 indicates the location of ground failures resulting from the 1949, 1965 and 2001 Puget Sound area earthquakes.

Effects of the Nisqually Earthquake

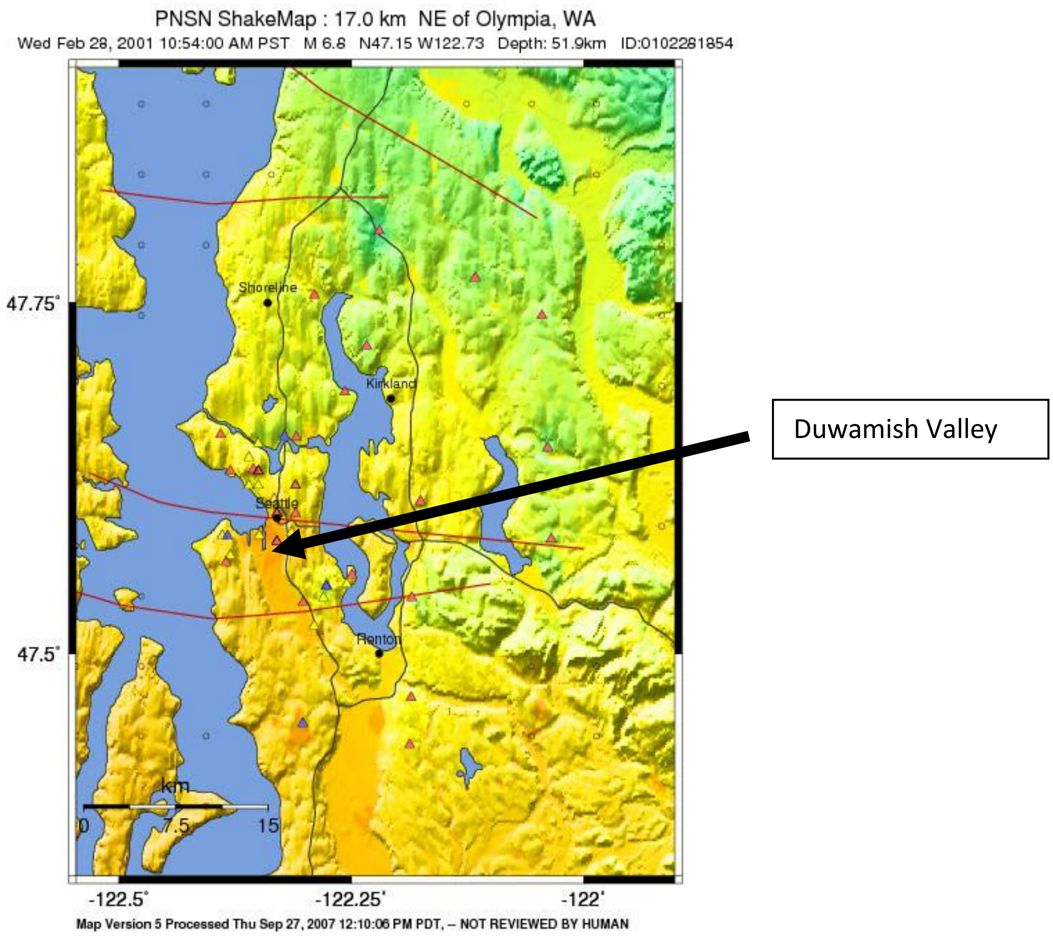
Significant public and private damage occurred as a result of this deep quake. The northern end of the Boeing Field runway was closed for two weeks after the earthquake. As stated earlier, in Seattle the Nisqually Earthquake caused in excess of $20 million in response costs and repairs to city-owned facilities and systems, plus costs for damage to arterial roads and bridges.

The quake's damage to structures serving vulnerable populations raised concerns. Seattle's Office of Housing (OH) did a post-Nisqually assessment of 45 non-profit assisted housing properties serving low-income residents. Only properties that sustained notable damage appeared on the report. Among them were several buildings located in or near downtown. One structure serving the homeless, the Compass Center, was red tagged and its 75 male residents were forced to vacate. The building was repaired and seismically upgraded in 2005. Seattle Housing Authority buildings, which house low-income people, suffered damage to elevators.

The earthquake impacted many businesses. The National Federation of Independent Business sent a survey to randomly selected members in an effort to document the impact of the Nisqually Earthquake on small business owners[98]. The survey revealed three areas with the most identifiable, concentrated small business damage: 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

Figure 17. Nisqually Shaking Intensity



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+

Map of Nisqually Intensity measured by the Modified Mercalli Intensity Scale (MMI).

Harbor Island firms had direct losses exceeding $20,000. They also suffered high rates of indirect losses from disruptions to operations[99].

Likelihood of Future Occurrences

The USGS estimates the frequency intervals for the types of earthquakes the Puget Sound experiences. Frequency intervals are the most reliable for deep earthquakes. The frequency intervals are *estimates* - not predictions. Deep earthquakes with a magnitude of 6.0 or greater occur *about* every 30 to 50 years. Shallow Quakes with a magnitude of 6.0 or greater occur about every 500 years. Megathrust earthquakes occur every 200 to 1,100 years, or *average* every 500 years.

Figure 18. Seattle Fault Zone, Liquefaction Areas and Ground Failures

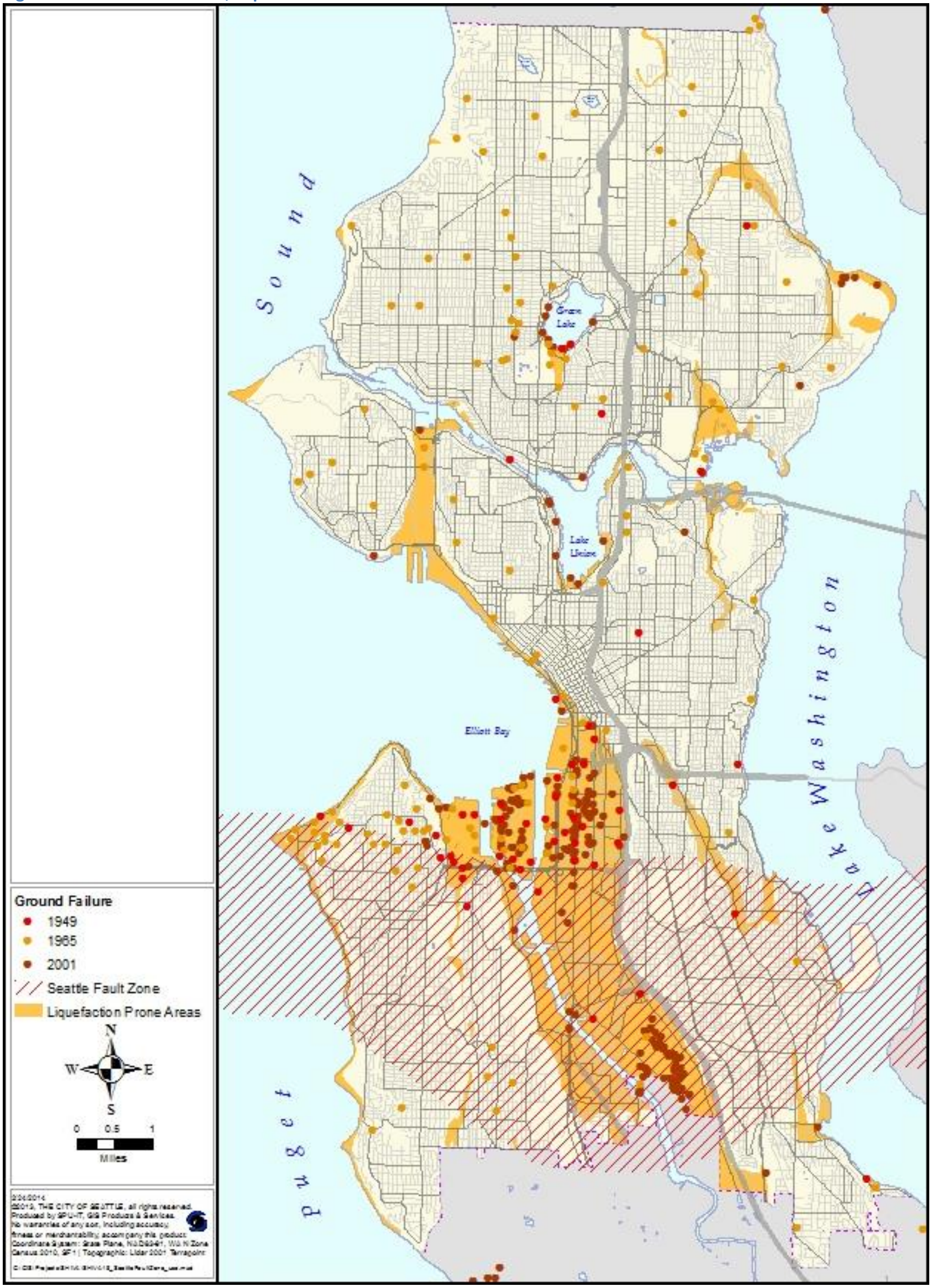


Table 10. Earthquake Type and Estimated Frequency

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 100 years
Seattle Fault	Over 6.5	Every 1000 years
Seattle Fault	7.5 (biggest quake possible)	Every 5000 years

A megathrust earthquake occurred in 1700 and the Seattle Fault produced a powerful earthquake 1,100 years ago, but neither type has occurred in Seattle in modern times. With 3 -4 events in the past 3,000 years, the very rough estimate is that the Seattle Fault is active about every 1,000 years.

Based on the type of research described in this document and other seismological input, the USGS has produced a series of earthquake hazard maps for Seattle (Figure 20). These maps show the amount of earthquake-generated ground shaking that, over a specified period of time, is predicted to have a specified chance of being exceeded. Ground shaking caused by earthquakes is often expressed as a percentage of the force of gravity. For example, many earthquake hazard maps show contours of the percentage of the force of gravity that has a 10% chance of being exceeded in 50 years. Based on such a map, if you were living in the same house for 50 years, and that house was in a zone labeled "5% g", then there would be 1 chance in 10 that (at some point during those 50 years) an earthquake would shake your house at a level of at least 5% of the force of gravity.

To appreciate why these values of ground shaking are expressed as a percentage of the force of gravity, note that it requires more than 100% of the force of gravity to throw objects up in the air. In terms of felt effects and damage, ground motion at the level of several percent of gravity corresponds to the threshold of damage to buildings and houses (an earthquake intensity of approximately V on the Modified Mercalli scale). For comparison, reports of "dishes, windows and doors disturbed" corresponds to an intensity of about IV MMI, or about 1.4% – 4% of gravity. Reports of "some chimneys broken" correspond to an intensity of about VII MMI, or a range of 18% to 34% of gravity[100].

Vulnerability

This section provides the specific physical and social vulnerabilities present in the Seattle community that are unique to or especially important for earthquakes.

General vulnerabilities described in the Community Profile section combine with earthquake-specific vulnerabilities that can be analyzed with geographic information systems (GIS). Generally speaking, the most vulnerable parts of the city 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.

The following sections breakout several earthquake specific vulnerabilities that can be overlaid to develop a composite picture of earthquake vulnerability in Seattle.

Ground Shaking
Not all areas of the city are likely to experience the same level of ground shaking. The USGS has created seismic hazard maps (Figure 20) that show the probability of exceeding a defined level of shaking (shown as acceleration as defined above) within the next 50 years. For example, downtown Seattle has a 5% chance of experiencing shaking in the 70-90%g range within the next 50 years[101].

These maps are valuable because they give us a nuanced view of the level of shaking each area of the city can expect to receive. One can see clearly that Seattle's liquefaction and landslide-prone areas experience more severe ground motion than other areas. Southeast Seattle is likely to experience serious but comparatively less shaking than the rest of the city.

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, Interbay area, University Village area and along the Puget Sound. Ground failures caused by previous earthquakes in Seattle have primarily been located in these areas of fill (see Figure 18). The Duwamish area is considered the best site in the nation to study liquefaction[102]. The tables below summarize land use in liquefaction prone areas. They are areas that have a heighten earthquake risk.

Table 11. Land Use in Liquefaction Prone Areas

Area	Acres	% of Seattle	% of Zone
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 19. Land Use in Liquefaction Prone Areas.

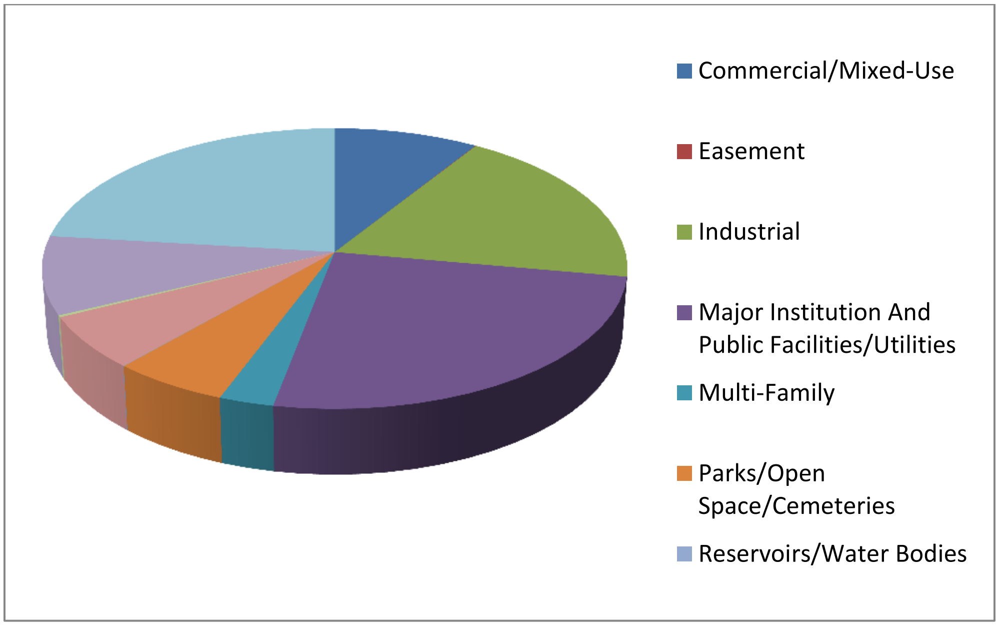


Table 12. Estimated Population, Structures, and Assessed Value in Liquefaction Prone Areas.

Number of Buildings	9,300	Est Pop
Number of Single Family Units	4,156	8561
Number of Multi-Family Units	12,591	25937
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		34499

Table 13. Critical Facilities in Liquefaction Prone Areas.

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 14. Facilities with Concentrated Vulnerable Populations in Liquefaction Prone Areas

Adult Family Homes	4
Boarding House	3
Child Care Centers	17
Nursing Home	1
Intermediate Care Facility	0
Total	***25***

Table 15. 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 16. Growth Centers in Liqufaction 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 17. 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%

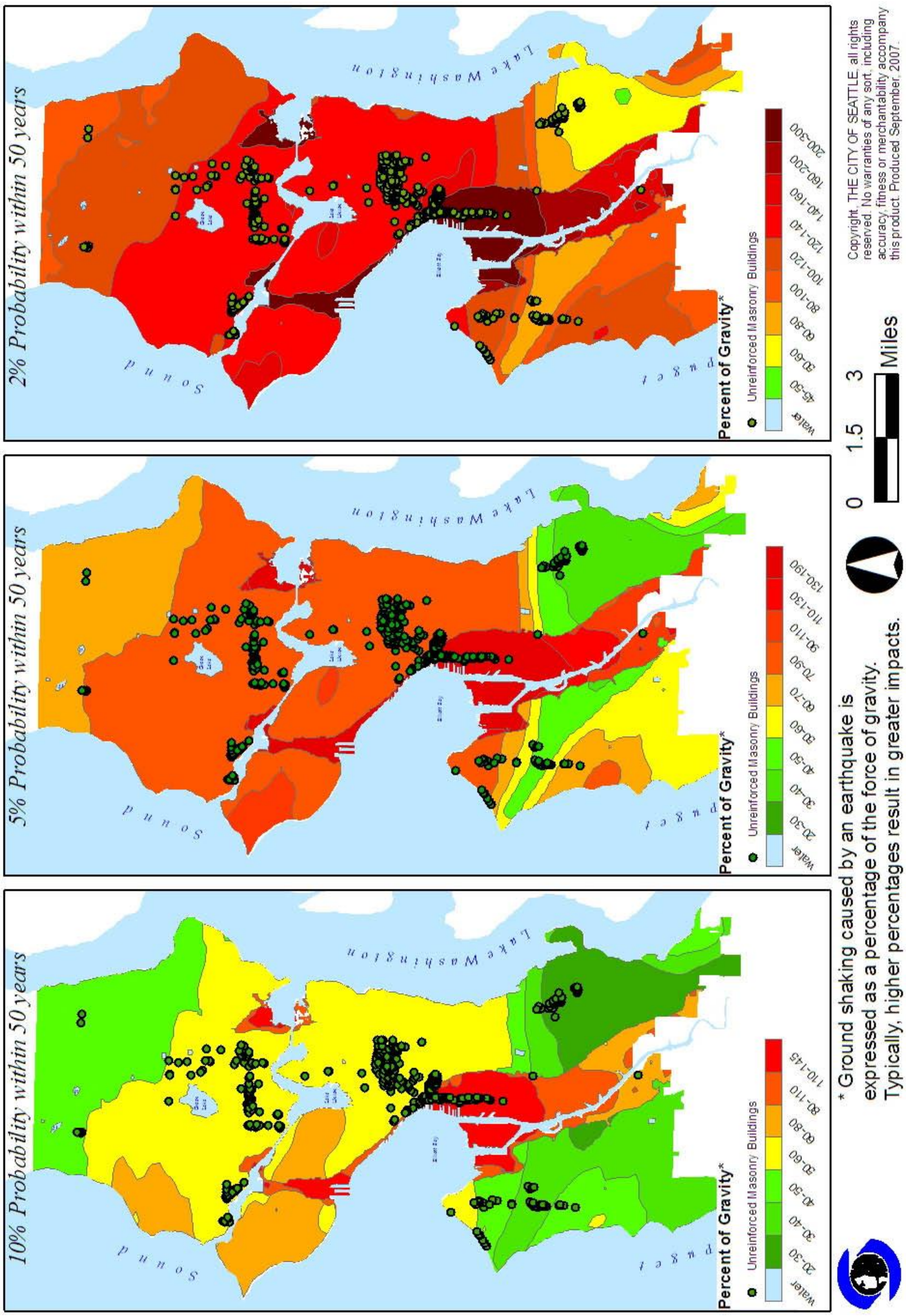
Structures

Vulnerable structures are not evenly distributed throughout the city. Those constructed with unreinforced masonry (URMs) are the most vulnerable, followed by concrete frame structures with masonry infill and tilt-up structures. Seattle has 819 URMs, mainly in the older areas of the city, i.e., downtown, Ballard, Capitol Hill, Columbia City and the University District. The number of concrete frame and tilt-up structures is not known; however, these construction types are fairly common in the Pacific Northwest. 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 "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. The City of Seattle has sponsored a program since the mid-1990's to promote these retrofits.

Our multi-family structures are vulnerable, too. Taller buildings experience more lateral force during an earthquake and more people occupy them. Many built in the late 1950s and early 1960s have "soft" stories were 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.

Figure 20. Probabilistic Ground Motions



Isolation Vulnerability
One of Seattle's major vulnerabilities is its dependence on its bridges. All the overland routes to and from North and West Seattle go over bridges. In 1992, the city began studying its bridges and found that 13 of the first 19 surveyed had a high probability of catastrophic failure[103]. By the end of 1999, all city-owned bridges were assessed; since that time, most have been upgraded. The improvements should save these bridges from catastrophic collapse, but many will not be useable after a strong Seattle Fault or megathrust earthquake.

Bridges maintained by the Washington State Department of Transportation include such critical bridges as the I-5 Ship Canal Bridge and the Aurora Bridge. The Loma Prieta, Northridge and Kobe quakes showed that even modern freeways and overpasses can collapse. Large parts of I-5 and I-90 rest on columns and run near slopes prone to failure. The Alaska Way Viaduct, which is similar to the one that collapsed in Oakland, is in a liquefaction zone and is at risk of failure in a major earthquake. The 2001 Nisqually earthquake damaged it enough that the public became motivated enough to replace it.

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
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 it as well as key bridges and elevated structures, the Alaskan Way Viaduct, the West Seattle Bridge, the First Avenue South Bridge and approaches to the end of I90. The King County International Airport is completely in the liquefaction zone as are most of the city's rail and marine terminals.

Utility Vulnerability
Most earthquakes damage utility networks. Underground systems and older storage tanks are the most prone to trouble. The city's water system was evaluated in 1990. Most parts have been given good marks, but there are still sections of the city with brittle cast iron pipes that will break with even moderate ground motion[104]. Seattle Public Utilities has been replacing this pipe with seismically resistant pipe when street repairs are made. In 2007, a vulnerable section of the three Cedar River pipelines, carriers of two-thirds of the City's water supply, was retrofitted. Seismic retrofits are included as part of a comprehensive asset management program.

Power, sewer, and telephone systems have not been recently studied. Their vulnerability must be 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[105]. This performance is quite good, but the epicenters in these quakes were far from the areas studied. Puget Sound Energy has replaced most of its brittle cast iron pipe with more flexible plastic pipe.

As with transportation, liquefaction is a danger to most utilities. Seattle's water supply lines cross liquefactions zones in the Rainier Valley and the University Village area. The Olympic BP Pipeline and sewer main lines cross the Duwamish liquefaction zone. City Lights South Service Center and two of its substations are in the liquefaction zone, but all sit on pilings. The biggest danger for these facilities is the potential loss of access due to transportation system damage.

Secondary Hazards

Direct losses from ground motion are just one aspect of earthquake vulnerability. Secondary events can be even more disastrous than the initial earthquake. The most important are fires, landslides, hazardous materials releases, tsunamis, and seiches. Each of these hazards is described fully in its own chapter.

Fires

Fires are the most dangerous of the secondary events. More people died in the 1995 Kobe earthquake than from building collapse. Most of the 28,000 buildings destroyed in the 1906 San Francisco earthquake were lost in the conflagration that followed it. Multiple ignitions are the most dangerous post-earthquake fire hazard. In 1992, the Council on Tall Buildings and Urban Habitat estimates the type of ground motion produced by a moderately large earthquake would produce approximately 5.4 serious ignitions per square kilometer, or about 450 ignitions in an area the size of Seattle. Some of these fires would be in crowded high-rise buildings. Under the same conditions, the Council estimates that each high rise has a 10% chance of ignition.

Normally, the city would call on neighboring cities 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.

Hazardous Materials Incidents

A serious secondary effect of ground shakings is the spilling of hazardous substances. Most of these spills will be small and contained within structures. They are serious hazard to people in these buildings. 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. A megathrust zone or shallow Puget Sound fault could generate a tsunami. The most dangerous source is the Seattle Fault. Although there is no direct 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[106]. In 2001, the National Atmospheric and Oceanic Administration (NOAA) modeled a Seattle Fault-generated tsunami. It is covered in full in the Tsunami section. The low-lying areas around the downtown sports stadiums, Harbor Island and Interbay are the most at risk from a tsunami. Because a tsunami generated inside Elliott Bay would strike within minutes of 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

Landslide prone areas are spread more evenly throughout the city. The land use in these areas is mostly open space or residential. North Seattle has less slide-prone areas than the central and southern areas. The major northern slide 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 slide areas.

Consequences

Earthquakes have wide ranging consequences. They cause widespread physical damage across the whole city with higher damage rates on areas that were once valley bottoms or estuaries. The physical damage can cause in turn high casualties, transportation blockages, utility outages, hazardous materials accidents and fires. If the earthquake is powerful enough it can trigger landslides, tsunamis and seiches.

When calculating earthquake exposure in 2008, FEMA ranked Washington second to California. Among metropolitan areas, FEMA ranked Seattle fifth, behind four metropolitan areas in California. [107].

FEMA's methodology involved producing series of estimated of annualized earthquake losses for the United States. They calculated the probability of future earthquakes for the entire U.S. along with the expected damage they would cause. FEMA then "annualized" the losses by dividing the total estimated losses by the number of years covered by the estimate: the bigger the number, the bigger the problem. The FEMA study provides a powerful first order indicator of the extent of our region's exposure, but it is only a rough estimate. A more detailed analysis is required.

Seattle has not experienced a shallow Seattle Fault or a megathrust earthquake since its founding, but either could happen and would be more damaging than the deep Nisqually Earthquake. A megathrust earthquake would cause several times more damage than the Nisqually Earthquake. Damage locally would be just small fraction of that extending up and down the whole Pacific Northwest coast. A Seattle Fault earthquake would be a catastrophe for Seattle, but response and recovery resources would be easier to obtain because damage would be not extend as far as 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 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[108]. Estimates are 1,600 dead regionally. Despite the enormity of the 2005 scenario, the Seattle Fault is capable of causing earthquakes up to magnitude 7.3, but earthquake of that size are probably much rarer.

An effective earthquake response begins with the transportation system and it would be severely impacted by either megathrust or Seattle Fault earthquakes. 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 patients 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 long time. Another deep quake would probably cause only minor interruptions, but these impacts could be severe if the epicenter were closer to Seattle.

Fire suppression is critical after earthquakes. It is highly probable that Seattle's water distribution system would be damaged, limiting the ability to fight post-earthquake fires. The 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 could be enormous. A successful recovery would depend on local, regional and national political and economic conditions. 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 what it wants to be post-disaster. A recovery would also depend heavily on favorable economic conditions. Overall community and economic health status and trending at the time of an event can impact recovery.

Some specific issues worth mentioning are the impacts of structural damage to commercial buildings and the transportation infrastructure. Many of the city's most vulnerable, unreinforced masonry structures house commercial uses. Seattle's businesses are vulnerable to disruption in the transportation and telecommunications network. 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 there.

The 2005 Seattle Fault earthquake scenario estimated that 46,000 households would be temporarily displaced. About half will be need short term shelter (less than 2 weeks) but the rest will need housing for months. 15% or 6900 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 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 were still intact in 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.

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. 40 have to be red tagged and 120 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 business 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.

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 transition to showers. The earthquake generates a 16ft tsunami, triggers thousands of landslides 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 7) shaking extends north to Edmonds and south to Tacoma.
Duration	4	This event devastates the Central Puget Sound region. Immediate recovery (e.g., service restoration) takes a month. Full recovery takes years. Major 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 1200 deaths and 15000 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 more than 6 months. Fans in stadium and tourists are stranded in Seattle.

Category	Impact (1- 5)	Effects
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.
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.

Alternate Scenario

Because earthquakes are so complex, it is impossible to convey the earthquake hazard consequences without briefly mentioning megathrust earthquakes. 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 rated as ‘Very Strong’ (7 MMI) on the Modified Mercalli Intensity scale. Well engineered structures would survive with minimal damage, but 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.

Conclusions

Earthquakes are both high probability and high impact events in Western Washington, making them the most likely cause 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, landslides, conflagrations, seiches or even a tsunami. Each of these would cause additional damage and casualties. Response to and recovery from a large earthquake would be the largest challenge this community has confronted.

Landslides

Key Points

- Seattle has a lot of steep hills, very wet winters and geology that is prone to landslides. As a result slides occur frequently, especially in the winter. January has the most landslides.
- 8.4% of the city's surface is covered by areas identified as slide prone in the city's Environmentally Critical Areas Ordinance.
- Landslides can be any size. Most are shallow happen on undeveloped land and have minor consequences. A small percentage of landslides are deeper seated. Deep seated landslides are usually bigger and therefore more dangerous that shallow slides, but any slide can be deadly.
- Occasionally swarms of landslides occur within a few days, especially during winter storms. While most of the slides in these swarms are small, some cause extensive damage.
- The response to landslides becomes more difficult when they are part of a larger event like a winter storm.
- Any landslide can be dangerous. A shallow 1997 slide on Bainbridge Island killed a family of four.
- Most insurance policies do not cover damages from landslides making property owners extremely vulnerable to economic loss.
- Most of the land use in potential slide areas is open space, single family residential and right of way. The City of Seattle is the largest owner of landslide prone slopes.
- Landslides can precipitate secondary emergencies, most notably 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 of Seattle.

Context

Nationally, landslides cause over 25 deaths and cost about $1-2 billion per year in the U.S. They are a common natural hazard in Seattle[109]. In parts of the developing world single landslides have killed hundreds of people. In parts of the United States they have destroyed whole neighborhoods. The collapse of Mt. St. Helens during its eruption was one of the largest slides in the world. In understanding that landslides are a very serious class of hazards, it is important to examine the kinds of slides we have in Seattle and what kind of damage they can do.

Causes

Every slope experiences two forces: gravity and forces resisting gravity, such as the nature of the material or slope angle. The ratio of these forces is constantly changing. These changes are usually gradual, but sometimes sudden shifts throw the slope out of balance triggering a landslide. The most frequent triggers for Seattle's landslides are human alteration and groundwater saturation of the slope

Types
Four kinds of slides occur in frequently in Seattle[110]:

- 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 pervious (sand) and impervious (clay) soil units causes a catastrophic groundwater and soil burst. Between 5-6% of all slides.
- Deep-seated Landslides – deep, rotational or translational slides and slumps caused by groundwater pressures within a hillside. Between 18-19% of all slides*. These are the most dangerous type of slide*.
- Shallow Colluvial (Skin Slide) – shallow and rapid slides on a slope, which may result in a debris flow. Over two-thirds (69%) of all slides are shallow colluvial.

Size
The most common landslides are the shallow colluvial slides; the largest are the deep-seated landslides. About two-thirds of landslides are small, isolated events that cause little or no damage. The largest landslides usually occur on slopes that already have a low margin of safety, often due to weathering and erosion. When these slopes are then struck by a sudden event such as an earthquake, rain or human alteration of the slope, slides occur.

The size of a slide correlates poorly with fatalities. Most fatalities have occurred in relatively small slides, many of which happened at construction sites. Landslides can happen in swarms. These events are often associated with a storm further complicating response.

Timing
Late winter and early spring are the most common times for slides, although most of the documented slides in Seattle have occurred in January[111]. According to Tubbs the probability of sliding rises after a wet, cold winter, especially if a freeze occurs in late winter and early spring[112]. 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. Nearly all landslides in Seattle occur when the ground is saturated and most include a human component[113].

Literature and Research
The understanding of Seattle's landslide hazard increased significantly between 2006 and 2008 when eight new papers were published on the geology of Seattle's landslides. Together they were included in a publication called, *Landslides and Engineering Geology in the Seattle, Washington Area*. They all refined Tubbs original work and examined specific types of slides are their triggers.

Of special interest for responders is a tool to estimate when groundwater saturation is reaching the point at which landslides are most common. This tool can be found online at http://landslides.usgs.gov/monitoring/seattle/rtd/plot.php. This work also produced a map of shallow landslide hazards that shows relative likelihood of shallow colluvial slides (i.e., from low to high).

Figure 21. Landslides and Landslide Prone Areas

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 1966/67, 1985/86 and 1996/97[114].

1921 Six major slides occur during one weekend[115].

1934 More than 400 Seattleites battle slides in ten areas of the city. These slides prompted numerous repair projects[116].

1941 Several slides occur during December around Sand Point[117].

1947 Several children die when a slide destroys their home[118].

1948 Multiple slide events in Magnolia and Yesler Terrace[119].

1950 Many slides occurred in the spring. They may have been connected with heavy snowfall as the 1997 events were[120].

1961 Slides occur in many areas of the city during the spring[121].

1965 SR 520 threatened, one lane closed, Roanoke interchange closed[122].

1969 Large slides occur on Magnolia Bluff[123].

1971/72 Slides destroy homes in Madrona causing about $1.8 million in damage. These slides were also probably connected with snowfall[124]. 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[125].

1983 Queen Anne slide closes Aurora for a day. Mud travels as far as Lake Union[126].

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.

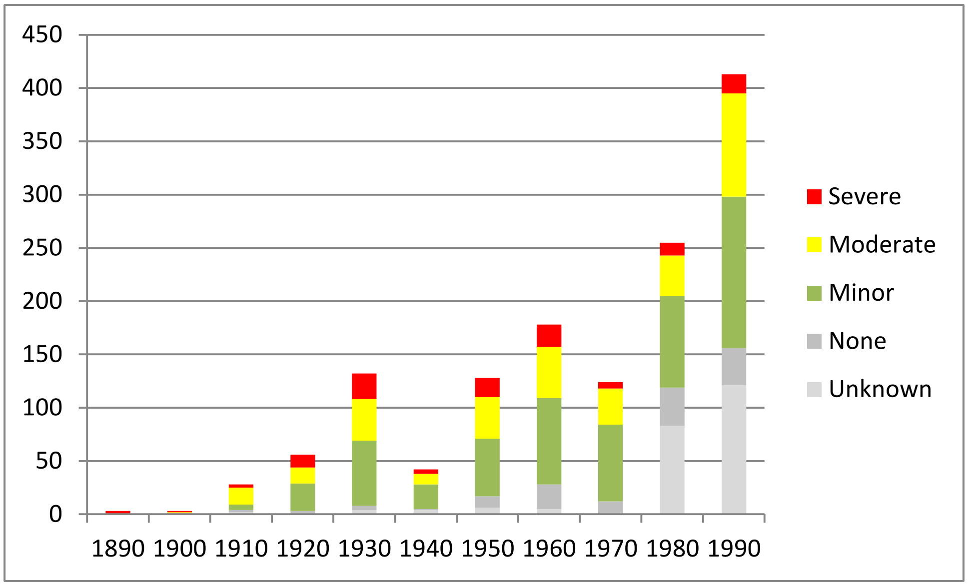
There have been several noticeable historical trends. The first is the occurrence of landslides related to major construction projects, especially the construction of Interstate 5. Newspaper accounts document several landslides along Beacon and Capitol Hills during this time. The second is in a decline in slides in some areas, like the southwest side of Yesler Hill, presumably as a result of its transformation into a dense urban neighborhood.

Geologists have discovered that earthquakes have led to massive landslides in Lake Washington. Whole hillsides have slid into the lake leaving tall Douglas Fir standing upright at the bottom of the lake.

Likelihood of Future Occurrences

The number of landslides recorded by the city is increasing dramatically. Aggressive data collection in the modern era is one reason why; oscillations in weather patterns is another. Development of slide prone slopes probably accounts for much of the increase. Slides on undeveloped property went underreported, whereas now that property is developed and property owners are reporting slides to the city.

Figure 22. Landslides Increasing By Decade



The number of landslides is increasing, and so is the number causing moderate and severe damage. There is simply more property to be damaged. Looking at the percentage of each damage category by decade adds to the picture. It shows that the percentage of severe landslides dropped after 1950 and is holding steady. It also shows a decline in the percentage of slides doing moderate damage from 1950 through the 1980s followed by a sharp increase through the 1990s into 2002. The reasons for these trends are examined below.

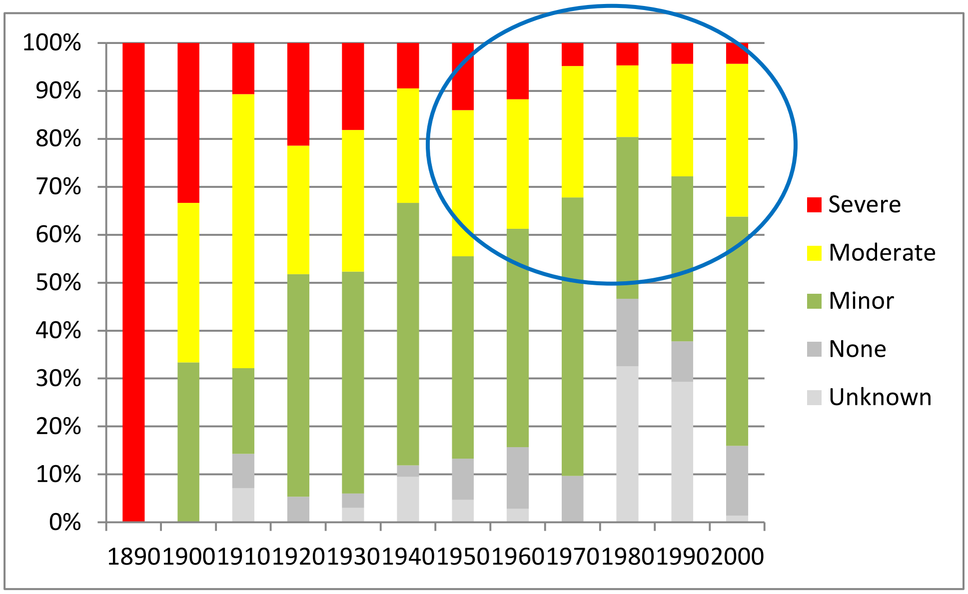
Vulnerability

Understandably, areas within the city's mapped Landslide Prone and Steep Slope areas are more likely to have landslides. What are the conditions that increase the vulnerability of people and property within these mapped areas?

Location and Causation

Landslides are prone to occur on 8.4% of Seattle, near the edges of steep and predominantly linear hills. Eighty-eight percent of the documented landslides in Seattle have occurred either within a steep slope area or potential slide area already mapped by the City of Seattle[127]. The areas with the greatest number of previous occurrences of landslides are along Alki Avenue in West Seattle and Perkins Lane North in Magnolia, with over 100 documented occurrences each. Other areas with large numbers of recorded slides include Beach Drive Southwest, Pigeon Point, Madrona, Rainier Avenue S.E., Interlaken, Magnolia and Northwest Seattle[128].

Figure 23. Share of Damage By Decade



Landslides in certain parts of Seattle are increasing, most notably along the slopes along northwest and northeast Seattle, Perkins Lane and 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.

The most frequent landslides in Seattle are the shallow colluvial slides, especially after intense, short duration storms. Although not as frequent, deep-seated landslides are larger and more destructive in Seattle. The deep-seated landslides are located in Southwest Magnolia, Northwest and Southwest Queen Anne, East Queen Anne, Alki, Admiral Way, West Beacon Hill, Interlaken, Madrona and Pigeon Point[129].

Human alteration of the slope is at least a partial cause in 84% of Seattle's landslides. This finding strongly suggests that development, especially non-engineered development, had been playing a big role in driving vulnerability.

Property

Many areas prone to landslides are attractive and expensive property with great views close to the water. As a result, nearly one third of the area designated as landslide prone is single family residential, making those homes vulnerable. A home built underneath a bluff on Bainbridge Island was buried in a landslide in 1997, tragically killing a family of four.

While the City requires new construction to mitigate the landslide hazard, Seattle is largely built out and it is not known how many properties conform to current standards. Furthermore, many mitigation practices are designed to prevent loss of life and not property loss, which is frequently uninsured. The amount of construction in landslide prone areas, especially residential construction, is a vulnerability to the Seattle community.

Transportation / Right of Way

Landslides are mostly a danger to transportation corridors. Air, marine and rail terminals need flat ground and are not in landslide prone areas (although some are adjacent to them). Public right of way, such as roads, railways and trails, accounts for one-quarter of the land within the slide prone areas.

Table 18. Land Use in Landslide Prone Area

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 24. Summary of Land Use in Area

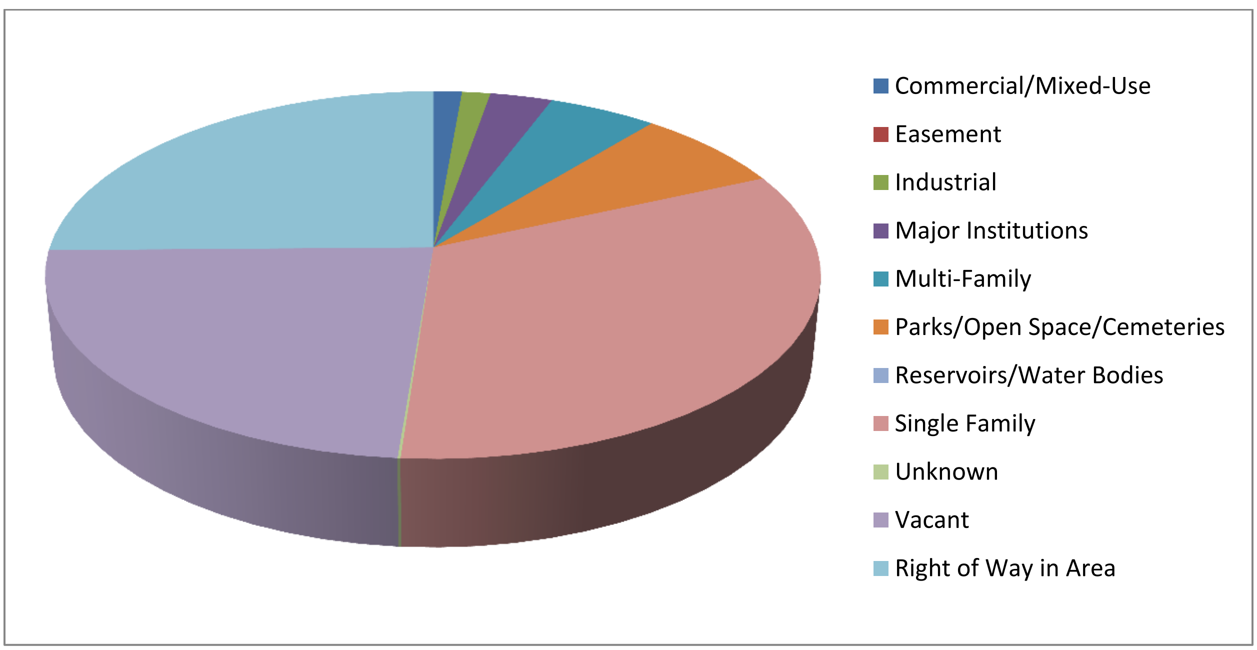


Table 19. Estimated Population, Structures and Assessed Value in Area

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 20. Critical Facilities within 50ft of Landslide Prone Area.

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 21. Facilities with Concentrated Vulnerable Populations within 50ft of Landslide Prone Area

Adult Family Homes	13
Boarding House	0
Child Care Centers	5
Nursing Home	1
Intermediate Care Facility	0
Total	***19***

Table 22. 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 23. Growth Centers in Landslide 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%*		
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 24. Wildlife Area 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%

(Transportation Continued…) About one-quarter of the slides affect a right of way. Slides can either go over the right of way or they can undermine it or, rarely, both.

The most vulnerable right of way is parallel to the slope. Seattle has many such locations. Some of the more important are the railroad tracks running along Puget Sound in north Seattle, I-5 along parts of Beacon and Capitol Hills and SR 99 Aurora along Queen Anne. Since 2011 two trains have been derailed by landslides in the Seattle-Everett corridor (12/18/2012 and 4/7/2013). In late 2013, BNSF and the State of Washington began a $16 million, multi-year project to mitigate landslides in this corridor.

Most of the time a slide 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.

Slides 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 its closure 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 underground, are vulnerable to landslides. Drainage systems, because they are often close to slopes by necessity, are the 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 water leak sometimes causing the slide 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 mainlines that run parallel along the base of many landslide prone hill sides, especially in West Seattle, the east side of Queen Anne Hill and in Carkeek Park.Sewer mainlines cross landslide prone slopes in more than seven locations. Seattle water supply lines cross landslides prone areas in three locations: southeast Seattle, the north end of Beacon Hill and the Interlaken area of Capitol Hill. Power transmission lines cross landslide prone areas in southeast Seattle.

Consequences

History and increasing development in slide prone areas indicate that landslides will continue to be a threat to public safety and property. The 1997 deaths of a Bainbridge Island family underscored the human costs, but threats to property are far more common.

Property damage from the 1974 and 1997 slides was shared roughly equally by the public and private sectors. While too much can be drawn from just two occurrences, 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 residential. Historically, the most frequent private damage was to residences. There is little information about severity (i.e., how many homes were destroyed and how many were only damaged). Newspaper articles making frequent reference to "destroyed homes" yield only anecdotal evidence.

Other significant impacts could include the interruption of lifeline services such as water, sewer and transportation. The city's water, gas, sewer, and power lines all cross areas prone to landslides, particularly in Highline, the east side of Beacon Hill, and the east side of West Seattle. Of these areas, Highline is generally the most critical because many of the utility networks have trunks that run through the area. All 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 slide area around Beacon Hill. Aurora has been blocked by slides along the east face of Queen Anne Hill several times. Since each one of these routes handles thousands of vehicles every day, slides 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 house 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.

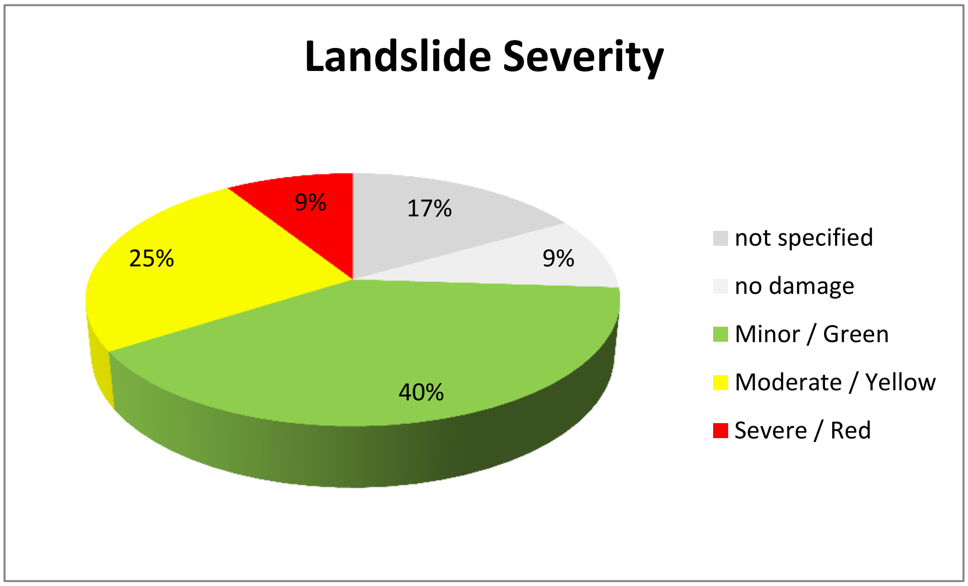
Landslides can induce other disasters. Landslides can cause flooding by blocking rivers, streams and storm drains and lead to releases of hazardous materials by destroying waste and storage sites. Hazardous materials are housed or transported close to potential slide areas in West Seattle, Interbay or along the Burlington Northern tracks running through the Golden Gardens area. Several trains have been derailed by slides in the Puget Sound area, including two in the 1997 slides alone.

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

With landslides ranging from insignificant to massive, they are a hazard whose overall consequence is best analyzed by looking at cumulative impacts. This approach permits the consideration of events that fall below the level of a city emergency but still have a negative effect because of their frequency and their combined effect.

Figure 25. Landslide Severity



Most Likely Scenario

The most likely scenario is an event similar to the 1996/7 landslide event. In this scenario 227 mostly shallow landslides occur over 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 major slide.

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 five days.
Health Effects, Deaths and Injuries	1	The landslides cause no deaths or injuries. Tension cracks appear at the top of most slopes before they fail allowing residents and businesses to close before the slides occur. Three slides occur without warning and strike buildings, but the residents escape. (SUGGEST increasing to '2')
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.

Category	Impact 1 = low 5 = high	Narrative
Economy	1	Although 72 buildings are affected and the property owners incur severe loss, the losses do affect the greater Seattle economy in a measureable 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	8 buildings are red tagged including 1 childcare center. The latter was unoccupied when the landslide struck it. 27 buildings are yellow tagged.
Transportation	2	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.
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
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.

Maximum Credible Scenario

Seattle certainly has the potential to have big, dangerous and damaging landslides that exceed the destructiveness of 1996/97 event. In this scenario three large deep-seated landslides occur within 72 hours during a storm along with hundreds of smaller slides. The slides occur at night without warning. They destroy multiple structures, destroy roads, start fires and release hazardous materials. A City Light transmission tower coming into Seattle from the south slides. Many lives are lost as the slides crush homes in the night. Massive slides into Puget Sound and Lake Washington cause tsunamis. A freight train is knocked into Puget Sound. Tanks of oil are ruptured.

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.

Category	Impact 1 = low 5 = high	Narrative
Displaced Households and Suffering	3	240 people are displaced from their homes. Of these 54 need shelter.
Economy	2	Multiple businesses are affected with concentrations of damage in two areas. The overall City economy suffers minor impacts, but the effects at the neighborhood level are severe.
Environment	3	The landslides strip hundreds of acres of hillsides of vegetation, break numerous sewer lines and knock a train carrying fuel 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	3	Due to bridge and arterial outages, emergency services are delayed reaching Magnolia and parts of West Seattle. Commuters experience long delays.
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 incident and triggered a tsunami.

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, a number of 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.

Volcano Hazards, including Lahars

Key Points

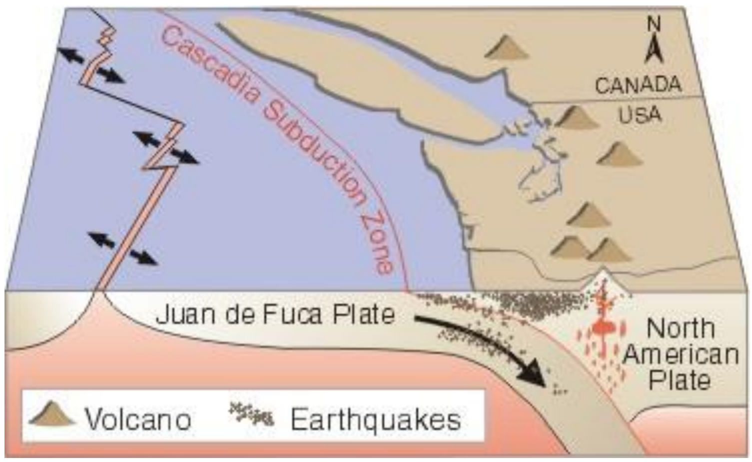
- Washington State is home to five active volcanoes located in the Cascade Range east of Seattle: Mt. Baker, Glacier Peak, Mt. Rainier, Mt. Adams and Mt. St. Helens. Washington and California are the only states in the lower 48 to experience a major volcanic eruption in the past 150 years.
- Major hazards caused by eruptions are blast, pyroclastic flows, lahars and ash fall.
- Seattle is too far from volcanoes, including Mt. Rainier, to receive damage from blast and pyroclastic flows.
- Ash falls *could* reach Seattle from any volcano, but prevailing weather patterns would *probably* blow ash away from Seattle. Mt. Rainier and Glacier Peak are closest volcanoes to Seattle and therefore the most likely ash sources. To underscore this uncertainty, ash deposits from a pre-historic eruption were recently found in Seattle. The deposit’s source could not be identified.
- The City of Seattle depends on power, water and transportation resources located in the Cascades and Eastern Washington where ash could fall. Seattle City Light operates dams directly east of Mt. Baker and in Pend Oreille County in eastern Washington and would be in the likely path of an ash cloud. Seattle water comes from two reservoirs located in the Central Cascades. They are outside the probable path of an ash cloud.
- If ash were to strike 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.
- The United States Geological Survey defines lahars as “mudflows and debris flows that originate from the slopes of a volcano.” Lahars contain high concentrations of rock debris and can travel tens of meters per second. Most, but not all, are preceded by volcanic and seismic activity.
- Of the five Cascade volcanoes, Mt. Rainier is the most significant threat. Lahars from Mt. Rainier have buried the Kent Valley, but there is no evidence a lahar has reached Seattle in the past 10,000 years. An USGS analysis states that it is possible for a lahar to reach Seattle, but would be extremely unlikely.
- Although the risk of lahars seems quite small, some uncertainty exists because the last lahars occurred thousands of years ago before development. It is not understood whether or how the development will affect a lahar.
- Seattle has a high probability of “post-lahar sedimentation.” A lahar is likely to stop in the Kent Valley, then the next big storm transports loose material from the lahar down the Green and Duwamish Rivers, causing problems for the maritime community.

Context

Washington has five active volcanoes. They are part of the same tectonic motion that gives the Pacific Northwest its seismic activity. As the earth’s continent and ocean-sized plates move, the heavier ocean plates slip under the lighter continental plates. This process is called “subduction” and it causes friction along the plate faces. 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 the plates into magma. The hot, molten rock forms reservoirs near the surface. As the rock melts it seeks to expand.

Under normal conditions, the constraining pressure of the surrounding rock keeps the expansive force of the molten rock 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.

Figure 26. Subduction in the Pacific Northwest



Source: United States Geological Survey website. http://pubs.usgs.gov/fs/2000/fs060-00/

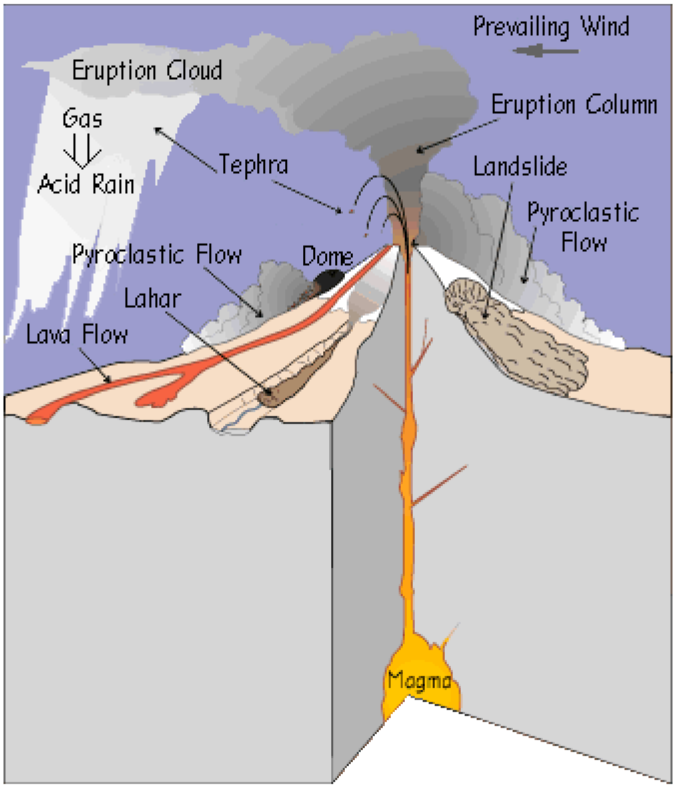
Washington's volcanoes are capable of producing very explosive eruptions. In addition to being dangerous, they are also very complex. Volcanic hazards are very a collection of related hazards. They include pyroclastic flows, landslides, gases, lava flows, tephra (ejected ash and rock) and lahars. The major hazards to Seattle are ash falls and lahars.

Pyroclastic Flows
Lateral explosions contain deadly clouds of debris called pyroclastic flows. These hug the ground flattening most everything in their path. The ejected material often heats up and mixes with the glaciers and other snow covering the volcano. The combined material is even more dangerous since it increases the size of the pyroclastic flow and enables it to move farther. This type of flow caused the mudflows that raced down the Toutle River following the Mt. St. Helens eruption.

Volcanic Landslides
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.

Figure 27. Volcano Hazards.



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

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. Collapsing lava flows can trigger pyroclastic flows, however.

Ash falls

The most widespread eruption impact is ash, which can cover hundreds of square miles. It is not nearly as dangerous as some of the other volcanic hazards, but ash is a health risk to people with respiratory problems. Ash also has many indirect effects on health by causing hazardous driving conditions, damage to mechanical equipment, and interference with wireless communications. Ash flows can also interfere with aviation, as planes cannot safely fly through ash.

Lahars

Lahars are a hazard directly related to volcanoes, *but they can be triggered without an eruption*. They are especially important in areas of Western Washington along rivers originating on the slopes of volcanoes. Sometimes called mudflows, lahars are slurries of water and at least 60% sediment by volume. Lahars 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.

Not all lahars are triggered by eruptions. Some have been caused by rapid melting of glacier ice. Though spontaneous lahars are possible, a lahar would likely be preceded by volcanic and seismic activity.

Although there are multiple ways in which a lahar can be generated, most of the largest ones are a mix of eruptive material, unstable rock water from glaciers from the sides of the volcano.

Lahars can travel tens of miles from their source, making them extremely dangerous to communities close to volcanoes. After a lahar initially stops, it can still be a hazard. “Post-lahar sedimentation” is the incremental transport of excess sediment from the headwaters of a river to lower river reaches that occurs days, weeks even years after a lahar occurrence. The resulting rise in sediment is a risk to navigation and the environment.

History

Since 1780, four of the five active volcanoes near Seattle have erupted. These are Mt. Baker, Glacier Peak, Mt. Rainier, Mt. St. Helens and Mt. Hood[130]. Only Mt. Adams has been inactive. There was a flurry of small-scale activity in the 19th century. 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.

Each volcano has its own character and history.

Mt. Baker has been active with small scale events since pioneer settlement. Large volume events have occurred about once every 150 years during the past 600 years [131]. Several post-ice age eruptions have produced mudflows but only light ash falls near the mountain.

Glacier Peak generated a sequence of nine 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. Glacier Peak’s more recent eruptions, including one just 220 years ago, have not been as violent but have sent mudflows down to the Skagit on several occasions. Some of them reached the Puget Lowlands[132].

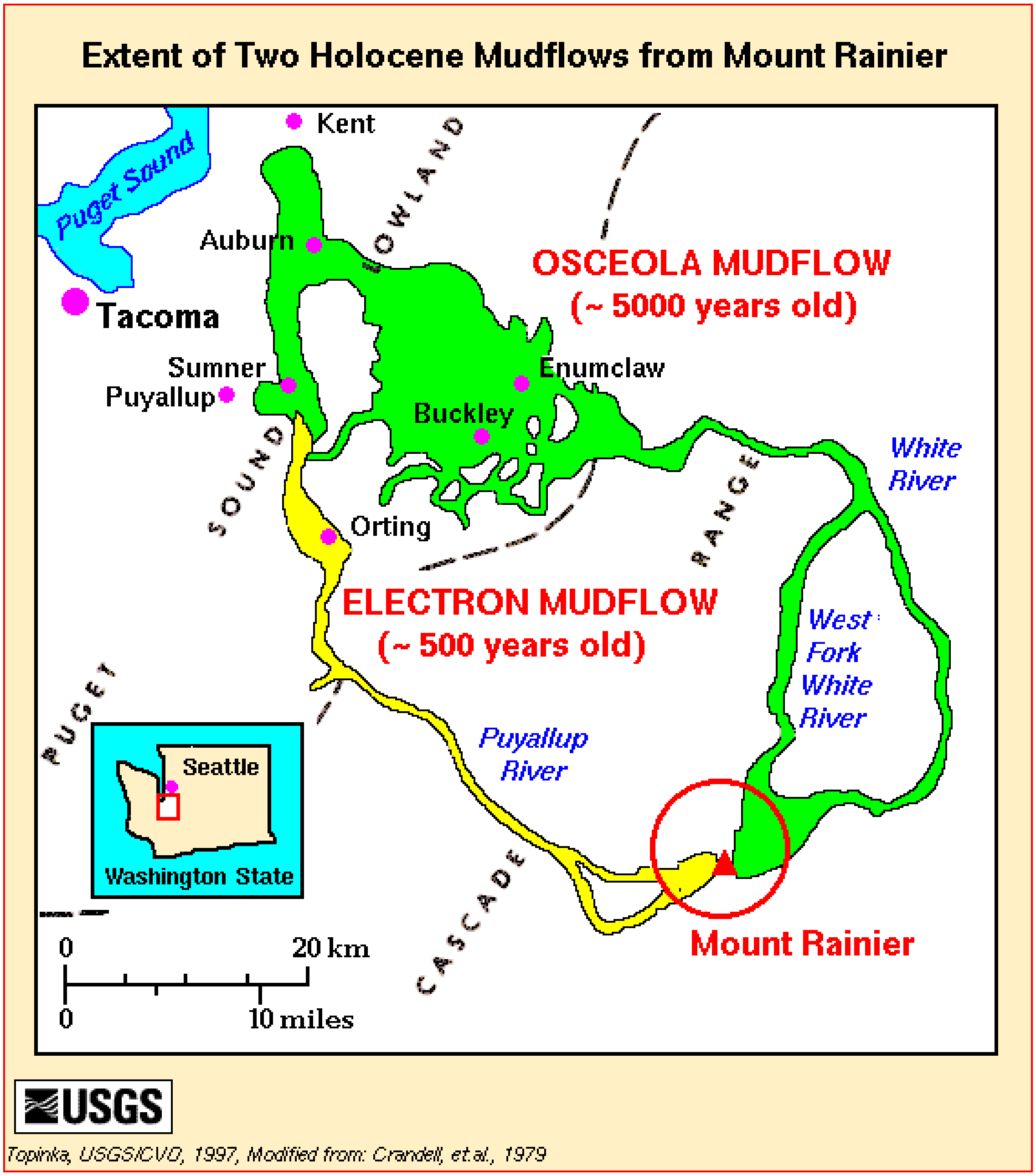
Mt. Rainier has erupted in the historic period. Explorers and pioneers tell of smoke and earthquakes near the mountain, but there is no historical evidence of major mudflows or ash falls. Stephen Harris investigated these stories and suspects most were steam eruptions and not the more violent Plinian type[133]. Geologic records show Rainier was active 6,500 to 4,500 years ago and again 2,500 to 2,000 years ago. Most of this eruptive activity produced little ash but large mudflows, also known as lahars.

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[134]. The largest lahar originating at Mount Rainier is the Osceola Mudflow that occurred about 5,000 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.

In 1963 and 1967, large landslides crashed down the slopes of the mountain. Increased heat was responsible, suggesting renewed volcanic activity[135].

At least six smaller debris avalanches have spawned lahars in the past 5,600 years. As recently as 500-600 years ago, the Electron mudflow nearly reached Puyallup[136]. 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 28. Osceola and Electron Mudflows



Source: United States Geological Survey website:
http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Maps/osceola_map.html

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.

Mt. St. Helens. The 1980 eruption was the largest in the Cascades in historic times but only produced trace ash dustings in Seattle. Mt. St. Helens has been consistently the most explosive of the Cascade volcanoes, with earlier, smaller eruptions in 1800, 1831, 1842 and 1857[137]. Mt. St. Helens is the most prolific tephra (ash) producer of the past few thousand years because of the frequency of its eruptions.

Mt. Adams has erupted in recent geologic time although not since written records began. Most of these eruptions were fairly quiet with little ash or pyroclastic material. Some observers speculate that it is dormant or extinct, but the Cascades Volcano Observatory thinks it could have minor eruptions again[138].

Mt. Hood has been very active recently, with eruptive periods between 1,500 - 1,800 and 200 - 250 years ago. Harris concludes there were small eruptions in the 19th century. The ash fall and pyroclastic flows have been limited to Oregon and southern Washington[139]. Mt. Hood is more of a threat to Portland than Seattle.

Likelihood

The USGS estimates that Seattle has an annual probability of 10 centimeters or more accumulation of 0.01% (1 in 10,000). The USGS has produced a map showing annual probabilities of 1cm ash accumulation. Seattle is more likely to receive ash from Mt. Shasta, in California, then volcanoes in Washington State.

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. 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 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. Despite all the suggestive evidence, these changes are so new the effects have not been studied comprehensively and many gaps in understanding remain to be filled.

Vulnerability

Seattle is vulnerable to two volcano hazards: ashfall and lahars. Seattle could be affected by only one or both.

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. The whole city 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. A lahar could reach Seattle, but geologists have not found evidence that they have. It is most likely that a lahar would stop in the 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 inundation. Containing the sediment depends on its volume, its speed, the time of year, and the levees' condition. If

Figure 29. Potential Post-Lahar Sedimentation Area with Key Transportation Infrastructure

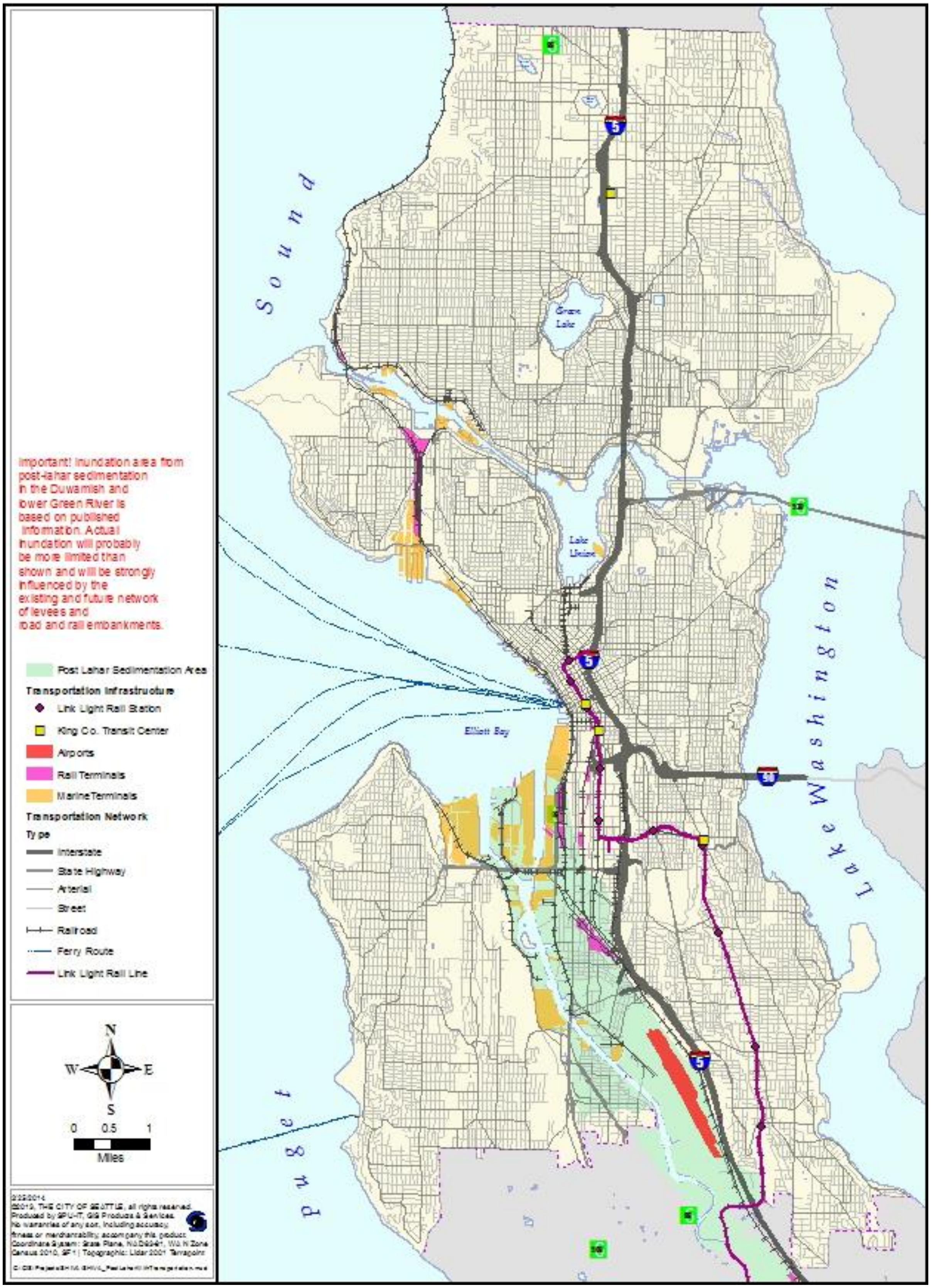


Table 25. Land Use in Post-Lahar Sedimentation Area.

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 30. Summary of Land Use in Post-Lahar Sedimentation Area

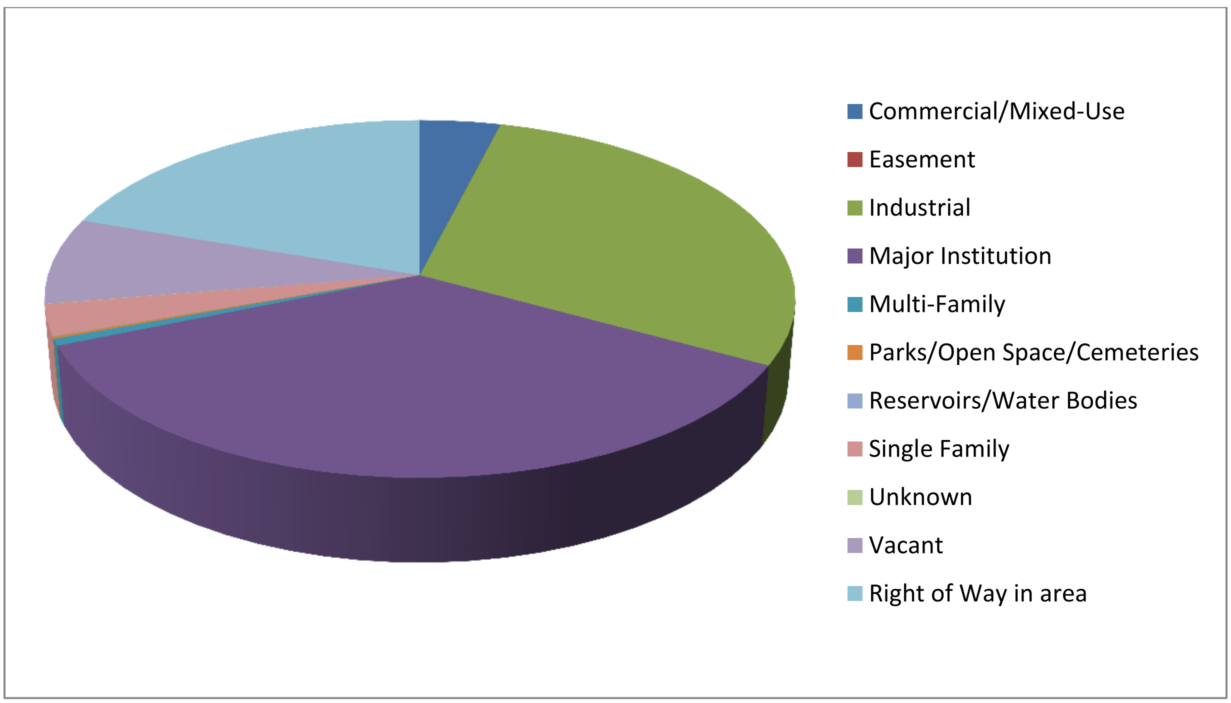


Table 26. Estimated Population, Structures and Assessed Value in Post-Lahar Sedimentation Area

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 27. 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 28. Facilities with Concentrated Vulnerable Populations 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 29. 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 30. Growth Centers in Post-Lahar Sedimentation Zone

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 31. 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%

(Continued from page 120) sediment overtops levees or they fail, low-lying areas along to the river could be inundated. The USGS has developed maps that show areas at risk of post-lahar sedimentation.

Seattle's transportation and utility lifelines would be exposed to post-lahar sedimentation in a worst case scenario. All major utilities cross the area susceptible to post-lahar sedimentation. They include electrical transmission lines, water supply lines, sewer mains and the BP Olympic Pipeline. The area houses key transportation corridors, including I-5, SR99, SR509, and SR599. It includes the King County International Airport, 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 the Valley or use it to get to work.

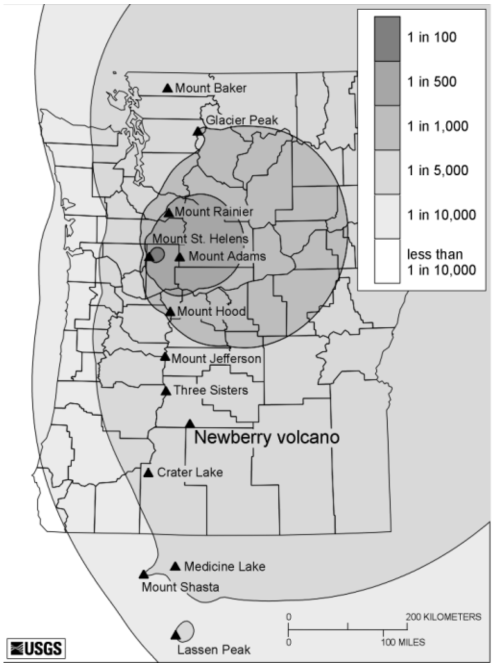
This indirect vulnerability due to exposure of lifelines outside the city extends to the whole Puget Lowland region. All the Cascade volcanoes are capable of generating lahars that could reach Puget Sound crossing many transportation and utility trunks along the way.

Ash Vulnerability

Seattle is exposed to ashfall, but the likelihood of a large one is remote. 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 blow ash into Seattle.

Seattle is made more vulnerable due to its reliance on watersheds and hydroelectric facilities in the Cascades. In fact, Seattle is more likely to be impacted by ash falling into its watershed that by ash falling directly on the city. When ash falls into a reservoir it can affect its chemistry and turbidity (clearness). It is difficult to assess the vulnerability of the hydroelectric power generation system because there have been so few instances of this happening.

Figure 31. Annual Probability of 1cm Ash Accumulation.



Source: United States Geological Survey website: http://vulcan.wr.usgs.gov/Volcanoes/Newberry/Hazards/OFR97-513/OFR97-513_inlined.html

Consequences

Volcanoes pose two hazards to Seattle: ashfall and lahars. Each has its own set of consequences. Seattle is too far from the Cascade volcanoes to be directly affected by blast and pyroclastic flows.

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 on areas outside Seattle and, in the case of a Mt. Rainier lahar, post-lahar sedimentation in the Duwamish waterway.

In a post-lahar sedimentation event, sediment could wash down the river for years. The consequences would be primarily economic and environmental.

Lahar material from the Kent Valley would introduce more polluted debris into the waterway which is 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 $13,000,000 (2009 dollars) when its port closed after the 1980 Mt. St. Helens eruption[140].

Sedimentation could possibly alter the course 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 cause increase water volume and 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 is predominantly commercial and industrial but includes residential areas and 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 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. 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. They are exposed to danger only from a lahar reaching Seattle, not from post-lahar sedimentation.

Ash

Prevailing winds blow toward the east, making tephra or ash much more likely to fall in eastern Washington than in Seattle. City owned resources in the Cascades and eastern Washington are more likely to receive ashfall than the city itself.

The smaller the amount ash, the more likely it is to occur. Seattle received a trace amount of ash from the 1980 Mt. St. Helens eruption and would likely receive trace amounts in a future eruption. These dustings do not create emergencies.

The experiences of Yakima and Spokane in 1980 reveal a "typical" case of an ash fall emergency. Yakima received about 3 inches; Spokane got 2 inches. Both communities were shut down for days. The ash falls caused a "midnight at noon" effect in Eastern Washington that lasted for 18 hours. While both cities are well prepared for snowstorms, both were overwhelmed by the ash. Seattle would likely be severely affected by less ash than these cities received.

An ashfall would have five potentially large impacts:

- Ash would irritate people's eyes and throats, especially those with existing respiratory trouble, but it would rarely cause death[141]. 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 generation facilities prompting expensive emergency power purchases[142]. Wireless communications and public safety would be impeded.

- The city would incur huge clean-up costs. Yakima, a city much smaller than Seattle, had to pay at least $1.1 million to get the ash off the streets[143]. These problems would be worse if it were to combine with water and fall from the sky as mud. The weight could lead to roof collapses throughout the city.

A heavier ash fall 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.

Volcanic ash damages human health, buildings, communication equipment, power, transportation system, water supplies and drainage infrastructure. Seattle is the densest collection of people, buildings, and infrastructure in the Pacific Northwest and is naturally more exposed than less dense areas.

The costs of a heavy ash fall would include the halting of economic activity for several days or weeks, property damage, and cleanup costs. Since an ash fall 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.

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 Southpark and Georgetown are displaced and Seattle hosts many people who are displaced from South King County.

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.
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 on 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.

Maximum Credible Scenarios

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 ash fall. 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. (Chang, 2007). Only one ash deposit has been found in Seattle and it was far less than 6".
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.

Category	Impacts 1 = low 5 = high	Narrative
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	1	Despite the heavy physical damage, the incident causes no casualties due to timely warning provided by the USGS.
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	4	The ashfall brings transportation to a halt. Air traffic is interrupted while the ash is airborne. Roads are impassible and ash clogs vehicle air filters. 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.
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 causes insulators to flashover.

Conclusion

Casualties are likely to be small compared to the economic effects. The most deadly phenomena will probably not 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 could have time to prepare itself. Early warning signals of seismic activity and the rate of change of post-lahar sedimentation allow time for evacuation. Mitigating sediment loads through dredging and sediment retention dams might make evacuation unnecessary. Displacement of water bodies pose more of a challenge, particularly if the White River were diverted back into the Duwamish/Green River valley

Planners should not assume that the prevailing westerly winds will keep ash out of the Seattle area. During the Mt. St. Helens eruption many cities were caught unprepared because they assumed they would not be hit. When they were, accurate information to help them was not readily available.

Tsunamis and Seiches

Key Points

Tsunami

- *Definition*: Tsunamis are waves caused by earthquakes, volcanic eruptions or landslides. In deep water they have long wavelengths and travel very fast. They slow down but can build to great heights as they enter shallow water near shore.
- Damage is caused by the wave's kinetic forces and the flood that follows.
- Tsunamis generated in the open ocean would not have a great effect in Seattle because a tsunami wave has to make a 90 degree turn to reach the city and the complex coastline of Puget Sound acts as a baffle. The most likely effect of a tsunami from the Pacific in Seattle would be strong currents.
- Tsunamis can be generated within Puget Sound by landslides or earthquakes. The most frequent cause of Puget Sound tsunamis is landslides.
- The 1949 Olympia earthquake triggered a landslide into the Tacoma Narrows that causeds a 6 – 8 foot tsunami three days after an earthquake. An earthquake on the Seattle Fault about 1,000 years ago produced a 16ft tsunami.
- The Seattle Fault, which runs through Seattle's midsection and through Puget Sound to Bainbridge Island, caused a tsunami around 900 AD.
- If a tsunami like the one in 900 AD happened again it would be devastating. 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 areas up to a mile inland.
- The 900 AD tsunami was probably a worst case. It is more likely (but not certain) that the next Seattle Fault tsunami will be smaller.

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) from an earthquake epicenter. Because they are *standing* waves they move vertically more 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 SR520 bridges. A large seiche could strain cables anchoring the bridges. The new SR 520 bridge is designed to take about 12' of upward motion and 8' of downward motion from a seiche. Based on models the most damaging seiche would probably be caused by a Cascadia subduction zone earthquake.

Context

A tsunami is a sea wave 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, such as across the Pacific, 2) Cascadia Subduction Zone megathrust earthquakes, 3) local faults, such as the Seattle Fault, and 4) landslides.

Tsunamis are hard to detect in the deep, open ocean. The wavelengths of these tsunamis are very long, between 93 and 155 miles, with amplitudes of one foot or less and travel at speeds of about 500 miles per hour. 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 nothave any cliffs nearly that size, it does have steep sea bluffs along enclosed bodies of water.

Most tsunamis have more than one wave, with a distance between crests of 60 or more miles. These waves interact with each other and are 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. Magnitude 6.5 to 7.5 earthquakes are probably the most common trigger of tsunamis[144].

Some tsunamis break when they reach land. Some just 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[145].

Tsunamis rarely crash ashore without warning. Coastal flooding frequently comes first, followed by a recession of the water and numerous waves. This effect is dangerous since many people assume the trouble is over after the first wave breaks. Unaware of the looming danger, they venture too close to shore and are swept away by subsequent waves. During the Indian Ocean Tsunami, a ten-year-old girl who had studied tsunami saved more than 100 people when she recognized this phenomenon.

Three main factors could influence the size, shape, volume and potential destructiveness of a tsunami generated by the Seattle Fault. These are shallow waters, steep seabeds and the contours of Elliott Bay.

- Since Elliott Bay and Puget Sound are shallow, there is less water to displace; therefore, the resulting tsunami would be slower and have less volume than those generated in the deep ocean[146].
- Puget Sound's steeply sloping sea beds tend to increase the chance that a tsunami will break on the shore, thus enhancing the tsunami's destructiveness[147].

- The shape of Elliott Bay could increase damage by funneling waves together, thereby increasing wave height[148]. The net result is unclear, since not much is known about the offsetting relationship between the depth of Elliott Bay on one hand and its shape on the other[149].

Seiches
Seiches are related to tsunamis. A seiche is the sloshing of water in a waterbody like water 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[150]. The biggest danger is from subduction zone or megathrust earthquakes that cause powerful, low frequency ground waves[151].

History

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

Tsunami deposits have been found in four locations in Puget Sound, including Seattle[152]. It is not known if they are the result of one event or several, 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 here, causing a sea rise of 0.8 feet. It had more of an impact on the coastal communities of Washington, Oregon and California. Friday Harbor and Neah Bay recorded maximum rises on the order of 2.3 feet and 4.7 feet, respectively. Despite this dramatic change on the coast, the tsunami's effect was negligible in Seattle because the complicated shoreline in Puget Sound acted as a baffle for incoming ocean waves. The protective effects of Puget Sound are probably one reason why the 1700 megathrust earthquake that caused a tsunami in Japan was not detected here.

Landslides have causes 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 no evidence has been found yet that they caused tsunamis.

The 1964 Alaska megathrust earthquake and 2002 Denali earthquake caused seiches in Lake Union[153]. 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, but seiches have not caused extensive damage so far. In 1891, an earthquake near Port Angeles caused an eight-foot seiche in Lake Washington, big enough to endanger people along the shore[154]. Both Lake Union and Lake Washington experienced seiches during the 1949 earthquake, but they did no damage[155].

Likelihood of Future Occurrences

Tsunami

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

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 be but limited historical evidence suggests at most 6 to 8 feet high.

Tsunamis originating in the Pacific Ocean are a certainty but they will probably have only minor effects on Seattle because they have to 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. A tsunami generated by a magnitude 8.5 Cascadia subduction zone earthquake would lose much of its velocity and be only 1.3 feet high when it arrived in Seattle[156].

The worst tsunami for Seattle would be triggered by a Seattle Fault earthquake[157]. The Seattle Fault runs through Puget Sound, through West Seattle, Sodo, Beacon Hill and then across to Bellevue. (See Figure 18 for a map). The biggest earthquake possible on the Seattle Fault is magnitude 7.3. It is roughly estimated to have a 1 in 5000 chance of occurring each year.

It is more 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 much 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[158].

The size of a tsunami depends on the amount of uplift caused by an earthquake. The earthquake 1,100 years ago caused over 15 feet of uplift. If the fault movement is purely vertical, a magnitude 6.7 earthquake would likely cause about 1 m (3 feet) or less of displacement on the fault plane, which translates to about 0.5 m (1.5 feet) of uplift on a 40 degree thrust fault. A tsunami generated by a 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 7.3 earthquake or the earthquake-generated tsunami of 1,100 years ago.[159]

A two meter wave is not expected to overtop the Elliot Bay Seawall, but a wave could propagate up the Duwamish[160]. The primary impacts are likely to be from the earthquake itself. The impact to bridges is expected to be minimal, since the Washington State Department of Transportation anticipates that storm-generated wave forces would exceed the forces from a small to moderate-sized tsunami. Regarding the possibility of liquefaction impacting bridge support, bridge design assumes seismic effects to govern.

Other faults capable of producing tsunamis run though Puget Sound: the South Whidbey Fault, the Kingston-Edmonds and Tacoma.

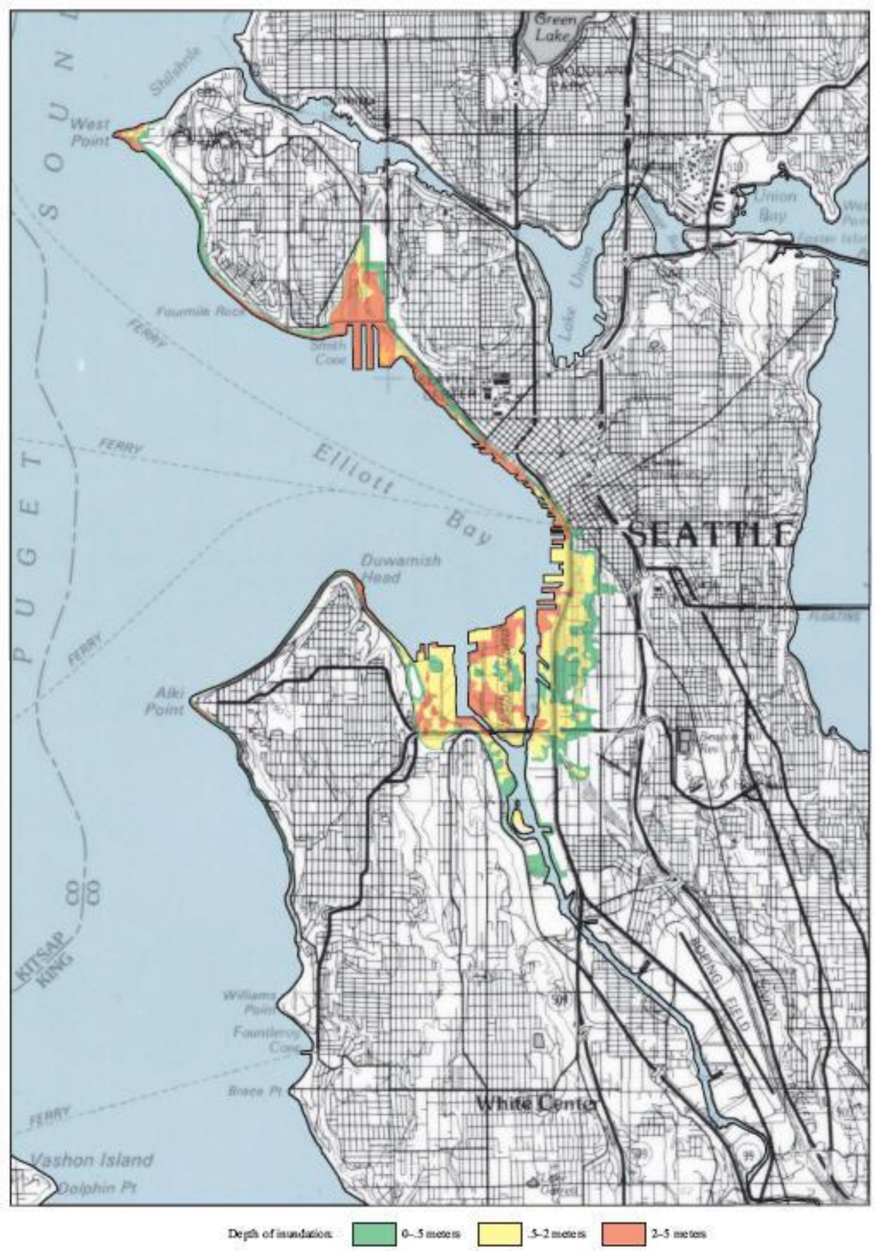
Seiches

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 similar seiches will happen again. A Cascadia megathrust earthquake would probably cause a much more dangerous seiche in Lake Union and possibly Lake Washington[161]. Washington megathrust earthquakes happen every 400-600 years. See the chapter on earthquakes for more details.

Vulnerability

Seattle has a long and highly developed shoreline that makes it highly exposed 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, parks and museums.

Figure 32. Worst Case Tsunami Inundation Area. Source: Washington State Dept. of Natural Resources.



The exposure is enhanced because the short time between a triggering event (earthquake, landslide) and arrival of the wave train (30 seconds to 5 minutes) would not permit many people to escape[162]. The only possible escape is running upstairs in multi-story buildings. These buildings are likely to be severely damaged if the trigger is a Seattle Fault earthquake. Most engineered structures performed fairly well in

Table 32. 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 33. Summary of Land Use in Worst Case Tsunami Inundation Area.

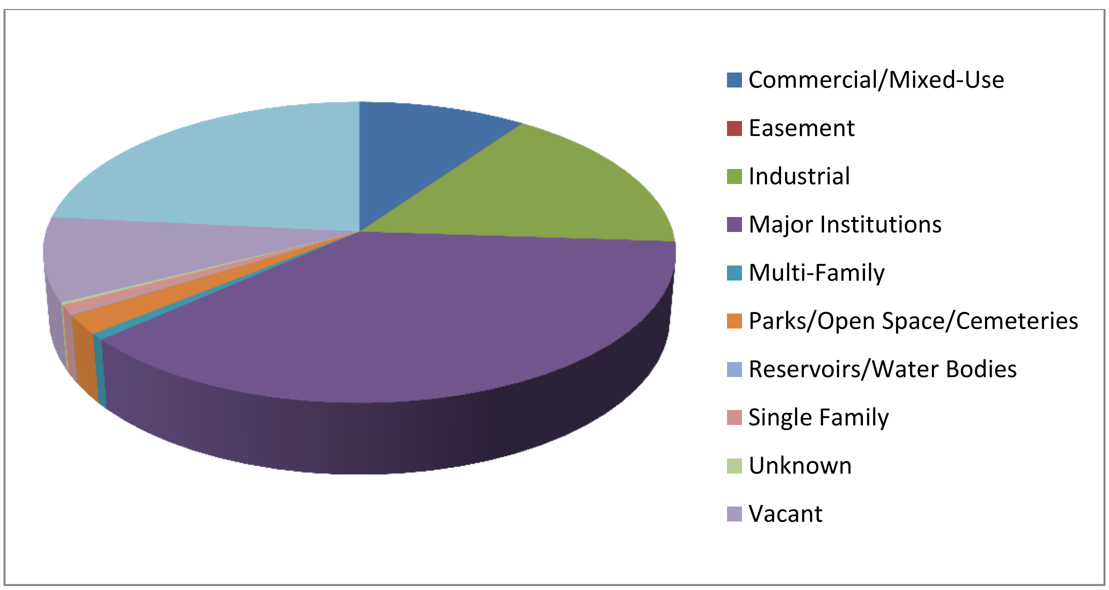


Table 33. Estimated Pop., Structures and Assessed Value in Worst Case Tsunami Inundation Area.

Number of Buildings	1,339	Est. Pop
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 34. 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 35. 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 36. 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 37. Growth 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 38. 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%

recent tsunamis, structures already damaged by a landslide or earthquake would be especially susceptible to more damage from a tsunami.

In any event involving incidents on Puget Sound, the tide is very important. A tsunami or seiche riding on a high tide is more dangerous than one occurring at low tide.

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 wave, 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 add debris into storm water. The tsunami modeled for Seattle does not include the effects of the built environment. Seattle's downtown seawall is very weak and will be replaced by 2017. There is a high probability that the existing sea wall would not survive a 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.
- City Light power transmission lines enter the area near Port of Seattle. 30 transmission towers are in the area.
- Sewer mains run through the area in 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 Duwamish Head.

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 yard are in the area; all Seattle's north-south rail corridors touch the area.
- The southern entrance to the new SR99 tunnel is in the area. See the paragraph below for more on its exposure.
- SR99, 1st Ave S and the West Seattle Bridge cross the area.
- The King County International Airport is *not* in the inundation area.

Consequences

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 waveheights 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 effect means that major flooding would probably not occur.

The likelihood of a seiche on other local waterbodies is not as well understood, but a seiche's magnitude on them would probably be smaller than those on Lake Union. The consequences of a seiche on Lake Washington could include casualties resulting from people near the shore being knocked into the water, residential and commercial property damage and damage to the floating bridges. A seiche on Elliot Bay could include damage to port and industrial facilities.

Seiches could precipitate landslides, fires and hazardous materials releases. Seiches can erode the base of steep slopes causing them to fail. The northeastern side of Lake Union, the south side of Magnolia, and four locations along Lake Washington have landslide prone hillsides near the shoreline (See Figure 20).

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). The model is a worst case scenario. It assumes a maximum of 7 meters of uplift on the Seattle Fault's south side (on Bainbridge), 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 the wave 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 still water line). 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 28 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[163].

Figure 34. Area Exposed to Lake Union Seiche

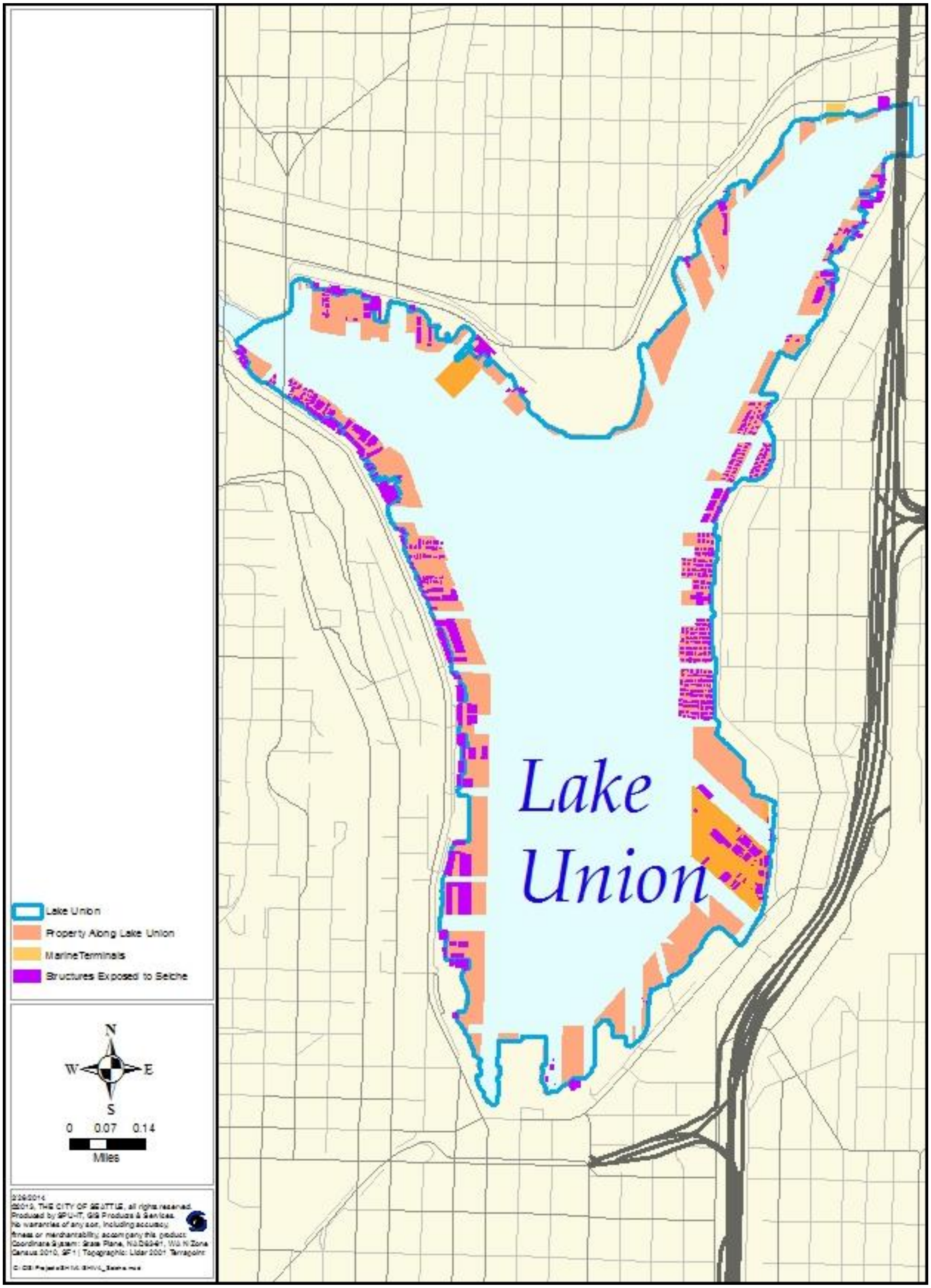


Table 39. Land Use in Lake Union Seiche Area

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 35. Summary of Land Use in Lake Union Seiche Area.

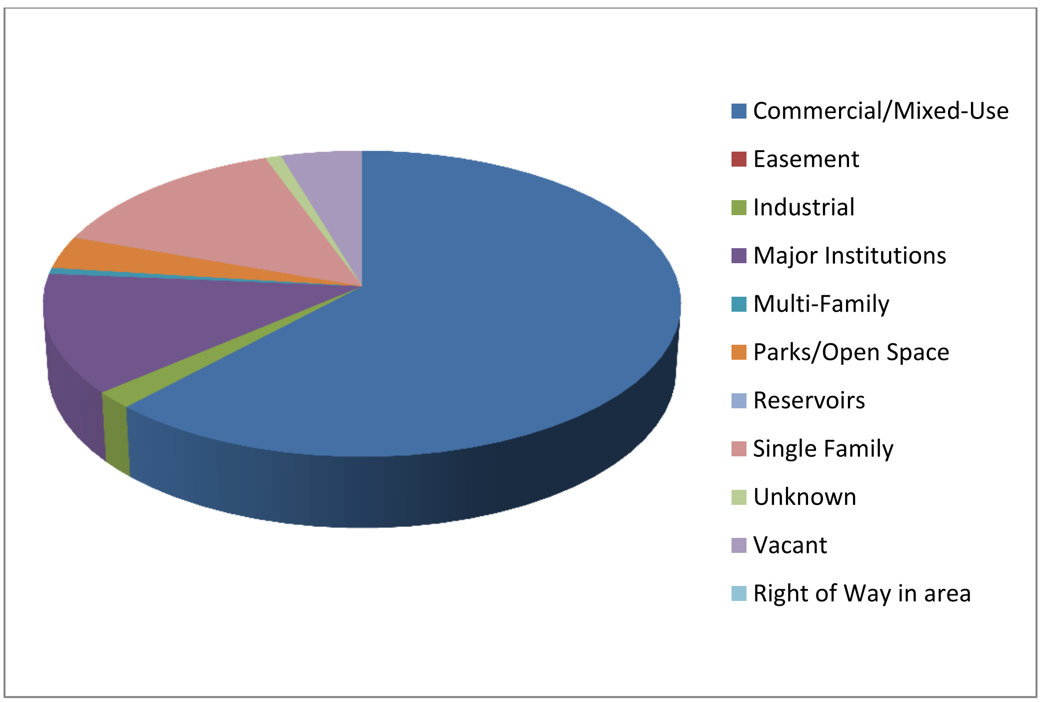


Table 40. Estimated Population, Structures and Assessed Value in Lake Union Seiche Area

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 41. 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 42. 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 43. 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 44. 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 45. 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%

The consequences of this 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. It would also inundate major roadways (SR 99, Elliott Avenue and the area under the West Seattle Bridge) and railways. If the tsunami occurs before the replacement of the downtown seawall and viaduct, it is likely that both would fail.

The SR99 tunnel is scheduled to open to traffic in late 2015. The effects of this tsunami on the tunnel have not been studied, but the area around the south entrance is shown to have six feet of inundation. The extent of flooding 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 coseismic subsidence. If the tunnel were to flood the consequences would be severe. People would be trapped underground; flooding would make escape harder and hamper rescue efforts. The tunnel will automatically close when strong earthquakes occur, but because the tsunami would arrive within minutes after the earthquake, it is unlikely that everyone inside during the earthquake would get out before it floods.

The tsunami would probably cause many landslides on the south side of Magnolia and the area each 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 Seattle Steam. If Seattle Steam loses generating capacity Seattle's major hospitals would lose their ability to sterilize medical instruments.

Most Likely Scenario: Seiche following Cascadia Megathrust Earthquake

During a Cascadia Subduction Zone earthquake (see the Alternate Earthquake Scenario) the water in Lake Union begins to oscillate. Waves that move more 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. 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
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.
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 seawalls 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.

Maximum Credible Scenario: Tsunami following Magnitude 7.2 Seattle Fault Earthquake

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 there is no chance for many people 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 out doors.
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 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 resources 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. The tsunami floods the SR99 tunnel as it is under construction. The tsunami further damages the downtown seawall and viaduct with have partially collapse due to the earthquake that preceded the tsunami.
Critical Services and Utilities	3	The tsunami occurs before the downtown seawall is replaced. This collapse breaks utility lifelines: water, 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

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 tsunami are the greatest overall risk to Seattle. Landslide-caused tsunami can be very large and can be triggered by many relatively common events like moderate earthquakes and storms.

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. This type of event happens only about once every 5,000 years; the last such event occurred 1,100 years ago.

Biological Hazards including Bio-Terrorism

Key Points

- Throughout history disease outbreaks have changed and shaped society. The impact of these diseases varies based on the virulence of the disease, duration of the illness and spread within the community.
- The most threatening emergency management situation is the outbreak of a new disease with high rates of morbidity (illness) and mortality (death). New disease outbreaks can quickly overwhelm local hospitals, healthcare providers and decrease society's ability to maintain critical services.
- An outbreak can be characterized by the extent of spread of the disease. An outbreak is considered a pandemic if the disease spreads throughout the world. The outbreak is considered an epidemic if it is above normal disease levels within a geographical area. More common diseases are classified as endemic, as they are at or below normal levels within a community. Brand new diseases can quickly become an epidemic/pandemic if there is little or no immunity in the population.
- Common disease outbreaks include influenza, Pertussis, hepatitis, Salmonella, E. coli and Tuberculosis. New strains of influenza are a great risk to King County, due to the low immunity in the community, the potential for severe symptoms, and the speed at which the virus can spread 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.
- For King County, the Communicable Disease Epidemiology & Immunization Section within Public Health – Seattle & King County investigates and coordinates the Public Health surveillance of disease outbreaks.

Context

Disease has been one of the most influential factors in human history. On many occasions disease has shaped civilizations and altered the course of history. Throughout the 20th century great strides in medicine have produced many treatments and cures for the most deadly diseases. Many of these medical advances have given 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.

Virulence: The ability of a pathogen to cause disease.

Severity: The seriousness of the effects of the disease.

Duration: The symptoms of a disease can either be acute or chronic. Acute diseases have a rapid onset causing severe disease (e.g., influenza, Salmonella, Pertussis). Chronic disease persists for a longer period of time (e.g., heart disease, diabetes, cancer).

Scale: The scale of the disease is described by the extent of the spread of disease in the community. An outbreak can be classified as an endemic, an epidemic, or a pandemic depending on the prevalence of the disease locally and around the world.

Some diseases, such as Salmonella and E. coli, can be spread quickly through food and water sources. Though these diseases are treatable they can lead to severe symptoms or death if not addressed quickly.

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

West Nile virus is an emerging pandemic that has affected numerous communities across the country. West Nile is transmitted through mosquito bite only and can be spread to humans, horses, and birds, causing severe symptoms or death.

Many potentially devastating diseases are spread through physical contact, ingestion, insects 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.

History

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

Influenza. 1918-1919: The influenza pandemic of 1918 was especially virulent, killing 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.

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

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 health populations as well as those with chronic diseases. This increase in morbidity caused strain on the local healthcare system. Although there were not nearly as many fatalities as previous pandemics, the outbreak caused a larger than usual amount of disease in the community.

Likelihood of Future Occurrence

Although it is impossible to predict the next disease outbreak, history has shown that outbreaks are not uncommon and can produce devastating effects on a community. While the revolution in medicine in the past century has increased our ability to counteract disease, increases in the number of people without adequate healthcare, the evolution of antibiotic resistant bacteria and globalization help make outbreaks spread more quickly and increase their severity. Disease outbreaks not only cause increased morbidity and mortality in the community, but also put a greater strain on the healthcare and infrastructure system that could prevent the operation of critical services.

Vulnerability

In many epidemic and pandemic situations, disease spreads quickly throughout a community. There are many factors that can increase Seattle's vulnerability to disease spread. Since many of the potential disease outbreaks involve close contact or inhalation of the pathogen, locations where large numbers of people gather in a close environment are perfect circumstances to spread disease. Seattle has the largest population density in Washington, over 7,000 people per square mile. The city is also a transportation hub with SeaTac airport to the south and numerous railway and bus stations. Many large social events routinely occur in the city including sporting events, parades, and concerts.

Disease often affects those most vulnerable in our communities. Young children, the elderly, the poor and those with underlying health conditions are often the hardest hit by disease.

Seattle has a large concentration of healthcare resources, but in an epidemic or pandemic these resources can be stretched or overwhelmed by the outbreak situation. The Seattle area also provides specialized medical care for a large geographic area, including one of the areas 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.

Other resources, such as food and water, are also a concern when planning for disease outbreaks. Seattle has many open reservoirs that provide water to the city. These reservoirs can be vulnerable to contamination and disease spread. Food sources can become quickly contaminated from improper handling and cooking methods. Continual surveillance is done by Public Health to protect against widespread food-borne illness outbreaks. Assessment

Seattle will surely be struck by epidemics and pandemics. The question is how severe these outbreaks will be. Communicable diseases impose a cumulative burden on the community, but significant outbreaks bear additional costs.

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. Sickness is the most visible consequence of an epidemic, but they can severely affect 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.

Epidemics are not uncommon in King County. Seattle / King County Public Health monitors dozens of communicable diseases. Some of these, like seasonal flu, inflect many people but most cases are mild. Other epidemics, like whooping cough, are very severe but inflect only a small segment of the population. These epidemics are handled within the normal health care system.

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 listeriosis 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[164]. A large outbreak centered in 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 kill large numbers of them. Pandemic influenza is the disease most likely to cause this great a disaster. It poses a great threat to health of our local community as well as the national/international community. Beyond the human morbidity and mortality pandemic influenza can have 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 outbreak showed how potentially easy it is to overwhelm the healthcare system, even though, as it happened, H1N1 was an influenza that caused less disease than a typical seasonal flu. 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 46. 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
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

Source: Public Health - Seattle & King County. (2008). *PANDEMIC INFLUENZA RESPONSE PLAN*[165].

Bioterrorism is another potential cause of on a catastrophic disease outbreak. This scenario is included as the maximum credible scenario under terrorism.

Most Likely Scenario

Seattle is the center of a severe listeriosis that kills 10 people and makes hundreds severely ill. The emergency is complicated because public health officials have a difficult time isolating the cause of the emergency. Public Health officials must use available resources to address the need.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Seattle has experienced disease outbreaks many times in its history. Six events stand out for their complexity and severity: influenza in 1918, 1957, 1968 and 2009; E. Coli in 1993; and Pertussis from 2002 to 2005. The scenario here envisions a food borne illness that is similar but more complex and severe that the 1993 event.
Geographic Scope	5	The disease strikes the entire Central Puget Sound region.
Duration	5	It takes health officials two months to contain the illness and for patients to recover.

Category	Impacts 1 = low 5 = high	Narrative
Health Effects, Deaths and Injuries	4	Ten people die but 11,456 become ill and 1833 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	Restaurants, stores and other places suspected or later found to have sold contaminated food suffer sales losses, 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.

Maximum Credible Scenario

A severe pandemic flu 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. 3600 people die including many young adults. 2809 people require ICU care and 1404 require mechanical ventilation.

Category	Impacts 1 = low 5 = high	Narrative
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 cause 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.
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.

Conclusions

Disease outbreaks can be severe and unpredictable. Many diseases can cause epidemics and pandemics such as influenza, Pertussis, hepatitis, Salmonella, E. coli, West Nile 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.

Intentional Hazards

This section includes human caused hazards in which a group deliberately seeks to harm the community. It includes civil disorders, terrorism, and active shooter incidents.

Social Unrest

Key Points

- Social unrest includes civil disorders, acts of mass civil disobedience and strikes differ in their legality, morality 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 (e.g., a lynch mob) and those in which the perpetrators are focused more on crimes against property. Most of Seattle's disorders have been the later type.
- Civil disobedience is the nonviolent refusal to obey certain laws as an act of political protest. Civil disobedience has been associated with some of America's most admired figures, such as Dr. Martin Luther King, Jr. Even so, it is an effort to put pressure on a governmental body and often does so by disrupting the functioning of society. 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.
- The lines between civil disorder, civil disobedience and strikes are fuzzy. The World Trade Organization (WTO) protests began with acts of civil disobedience then spiraled into civil disorder.
- The World Trade Organization unrest was Seattle's most damaging disorder. 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.
- Disorders often occur in dense areas where people naturally gather and crossroads areas. In Seattle, downtown, Capitol Hill and the University District have seen the most frequent civil disorder.
- Looting and arson are the most common crimes in Seattle's civil disorders.
- Rock-throwing, sniping and other severe personal assaults have not been common in Seattle disorders, but they have occurred. They are not expected to be frequent threats in the future.
- Reputation damage has been a major impact to some areas hit by civil disorders, but Seattle has not seen major, lasting reputation damage.

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 as 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. Communal riots involve direct battles between two or more ethnic groups. They 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[166].

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[167]. But the 1992 Los Angeles riots demonstrated that something more complex might be developing. They challenged the distinction between communal and commodity riots. In keeping with the theory of commodity riots, the main targets were stores and structures symbolic of authority, but the ethnic diversity of the arrested persons was something new. There seems to be a new element of interethnic and interclass conflict involved that makes recent disorders much more dangerous. These developments suggest that cities should monitor intergroup tensions seriously.

The 1992 LA riot challenged the established theory. It began not 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 (an announcement of a verdict) that allowed crowds to gather quickly. Unlike the 1960s, rioters used more firearms and assaulted fire department personnel more frequently. When it was over, 55 people died. 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[168].

Most of the municipalities that suffered severe disorders were reluctant to activate their disaster plans and sought to downplay the events until it was too late[169]. The official studies of the mid-1960s riots, the LA riots, and the Crown Heights riots all noted this tendency. It seems harder for local government to admit that damage caused by citizens has gotten out of their control than if the damage had been caused by natural forces.

Protest and Civil Disobedience

Organized protest has long been a cherished right of Americans and a hallmark of the right to freedom of speech. The vast majority of 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 as a means 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. 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. Sometimes, this pre-planning does not work because one or both sides will not or cannot control its people on the street.

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.

A general strike is a work stoppage by a critical mass of workers in a location. There has not been a general strike in the United States since the Great Depression. They are very hard to organize and maintain.

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[170].

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 here, but it was minor compared to other trouble spots[171]. 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 trouble. 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 closed I-5.

1992 Rodney King Verdict
Following the early 1970s, there were no major incidents of civil disorder until the Rodney King verdict and the disturbances that ensued. The night of the verdict, small groups of people roamed the downtown streets smashing windows, lighting dumpster fires and overturning cars. The next day, there was a rally 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 of its mutual aid. Another protest occurred in the University District. That protest was largely peaceful, but protesters did occupy I-5 for a while, shutting down traffic[172].

1999 WTO Protests
From November 29 to December 3, 1999, Seattle hosted the World Trade Organization (WTO) conference. Despite several months of preparation, protests quickly got out of control. During the first day of the conference, a large confrontation lasted all day in the area near the convention center. This confrontation quickly turned ugly. 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). Over 500 people were arrested. There were no deaths; 89 people were treated at local hospitals. 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, but the night saw a police action on Capitol Hill.

The number of protesters (over 30,000), 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 protest organizers divided downtown into thirteen wedges. Each group was given one wedge. Their use of the Internet, cell phones, radios and other technologies combined with a very loosely structured 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.

2001. Mardi Gras
In February 2001, chaos erupted for two nights in a row 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 in the melee. Damage was estimated between $100,000 and $200,000. This was a pure riot. There was no element of protest involved. An after action review recommended intervening to disperse the crowd sooner.

Likelihood of Future Occurrence

Disruptive social activity has regularly occurred in Seattle and will definitely happen again, yet the form that future events will take cannot be reliably predicted. Each of the major historical events revolved around different issues and took a different form. The most significant events seem to occur when Seattle is the primary focus of a conflict rather than a secondary site. This helps explain why the WTO event was larger than the Rodney King Incident. It suggests that the next large incident will be centered on an event happening in Seattle. Seattle's emergence as a leading cultural and economic center increases the chance that controversial events like WTO will occur here in the future.

Vulnerability

Seattle is the social hub of the Puget Sound region. This fact means that it is both more likely to experience large scale social disruptions and to be more severely impacted by them. Most of these events are planned and target community vulnerabilities, places, or systems where pressure will be most easily 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 and 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. During WTO, law enforcement personnel were understaffed. This was one reason the situation escalated.

Transportation routes are vulnerable to disruption. Seattle lacks significant reserve capacity in its road network. I-5 is by far the most heavily used corridor in Seattle. Because of its significance, demonstrations have targeted it. The only mitigating factor is that traffic is so frequently bad that 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. 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 the authorities, a community's reputation and confidence in itself are sensitive to conflict.

Consequences

Because the pace of social change is orders of magnitude greater that the 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.” Still, the framework of examining a most likely scenario and a maximum credible scenario remain.

Every several decades, Seattle seems to go through spasms 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 a lot of things, Vietnam, intergenerational conflict, and race; in the 1990s, race again and globalization. The Mardi Gras incident was similar to the 1969 University District troubles but had more conflict between people in the crowd with alcohol, crowding, and racial tensions as contributing factors.

Seattle will surely face incidents similar to past disorders and protests that have either stemmed mostly from local causes (Mardi Gras) or featured Seattle as a secondary site to events spread across the country (Vietnam Protests). These incidents have been smaller, but as the Mardi Gras incident shows, they can be violent.

Most of these incidents 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.

While Injuries have been more common lately, we do not know how many have occurred. Many injuries resulted from the WTO protests, but the total is not known. The examples given in the press include bruises, sprains and some broken bones. Several police officers were injured as well.

It is probable that future disorders will again be directed mostly against property. Furthermore, the destruction of property has been selective and will probably 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.

Indirect effects can have a large effect. Cities often worry about being stigmatized and losing investment and tourism as a result. This concern appears justified when the violence has been highly visible. 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 as scrutinized 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 some kind of conflict between groups. It could be a large, more violent WTO-type protest or large-scale violence directed at a minority group. Such situations are very unlikely but not implausible.

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.

Most Likely Scenario

A riot occurs after a well-attended, evening football game at Husky Stadium. Fueled by alcohol, the crowd of mostly college students, turns over cars, sets fires, and engages in a pitched battle with the outnumbered law enforcement officers. The crowd, estimated at 25,000, moves onto campus where dormitory and Greek Row residents join the rioters. Several people are injured and two are killed.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Seattle has experienced civil disorder in every decade since the 1960's. Seattle has not experienced major sports violence, but many cities, including Vancouver have.
Geographic Scope	3	This riot affects the University District.
Duration	1	The worst rioting happens on one night. Some participants return the following night, but the second night does not have the same intensity.
Health Effects, Deaths and Injuries	2	Two people are killed. One is murdered in a fight and another falls off a roof. 45 people suffer injuries requiring medical attention.
Displaced Households and Suffering	4	Apartment and university dorm residents leave the area and seek shelter during the riot. 1 apartment building burns. Its 124 residents need longer term shelter.
Economy	1	Stores on the Ave have broken windows and five stores are looted.
Environment	1	The riot does not affect the environment.
Structures	2	Rioters loot five stores and set dumpster fires. One of them spreads to an older commercial building on the Ave. Fire crews are unable to reach it before it becomes fully involved.
Transportation	2	The incident closes streets in the U-District. Small groups are caught dropping objects onto I-5.
Critical Services and Utilities	1	Critical services and utilities are maintained throughout the city except in areas directly affected by the riot.
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.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	2	The rioters cause major fire that burns commercial buildings and an apartment complex.

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 attack the smaller groups in a deliberate manner to terrorize them and drive them out of the area. 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. The most serious rioting happens 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 cannot be delivered in affected areas. Power outages occur due to fires and deliberate sabotage.
Confidence in Government	5	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 civil disorder is an ugly event. Many people are upset it occurred and think that the government should have been able

Category	Impacts 1 = low 5 = high	Narrative
		to prevent it. Victims blame the government for allowing them to be attacked. Perpetrators and their sympathizers resent law enforcement for stopping them from doing more damage.

Conclusion

With the very notable exception of the WTO disturbances, Seattle has only seen civil disorder that echoed events focused in other locations. Because we have been a secondary site, the disorders have not been as big. Probably that trend will continue. The exception, WTO, was sparked by an international conference and not social conditions that are endemic to our community. Most of the violence has been looting, vandalism and street fires. The most dangerous kind of disorder happens spontaneously in multiple locations hampering law enforcement's efforts to contain it.

Terrorism

Key Points

- Terrorism is a bit different that the other hazards presented because it is a method that uses hazards. The actual damage is caused by explosions, shootings, fires, crashes, infrastructure collapses, computer failures and the release of harmful agents, be they chemical, biological or radiological. This chapter will concentrate on the unique aspects of terrorism while impacts will be covered in related chapters: biological hazards, infrastructure failure and hazardous materials incidents.
- Since 9/11 terrorism has been recognized one of the top risks facing the United States. Modern technology allows small groups to inflect high casualties. Large amounts of resources have been appropriated to reduce the threat of terrorism.
- Defining terrorism is somewhat subjective with multiple definitions. Most agree that it involves acts that endanger human life through mass destruction, assassination and kidnapping. These acts are intended to intimidate a population and influence government policy. Most agree that acts by individuals can be called terrorism. One of the major differences of opinion is whether terrorist acts are restricted to non-governmental actors.
- Seattle has not experienced a large-scale 9/11 or Oklahoma Bombing-type of terrorist act, but it has had several smaller incidents and has been connected to larger incidents.
- The terrorist threat in Seattle comes from multiple sources. Al Qaeda and related jihadism, the extreme right and radical environmentalism have been the most frequent causes.
- The targets of terrorism depend who is doing the targeting. Target selection depends on ideology, strategy, resources and target protection. Many groups aim to kill as many people as possible, but eco-terrorists have focused more on property destruction. Most groups aim to destroy sites related to their ideology, but some sites seem chosen more for other reasons. Because of this dependence, it is necessary to understand the ideologies, beliefs and motivations of the groups involved.

Context

The U.S Code of Federal Regulations defines terrorism as "…the unlawful use of force and violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objectives."[173]. While there are many different legal and scholarly definitions of terrorism, this is the one that is the most important domestically in the United States.

Terrorism is a strategy. This section focuses on this aspect of terrorism. The violence can be perpetrated using a wide variety of means, e.g., bombs, chemicals, firearms, computer attacks, biological agents, and as 9/11 demonstrated, vehicles. Because terrorist acts use such as wide variety of means, the means are covered in accompanying chapters. For example, bombs are covered under hazardous materials, aircraft under transportation incidents.

In the past, in comparison to other countries, the United States has had few terrorist acts committed within its borders. Between 1990 and 1997, there had never been more than four incidents in a year[174]. This situation 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 2001, several incidents involving anthrax spores placed in 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.

While Al-Qaeda is the main focus of counter-terrorism today, it is important to remember that other groups that employ terror tactics have been active in the United States. These 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 Hamas.

Hate groups are now espousing the "leaderless resistance" model for fighting the people they view as their enemies. This doctrine advocates independent actions by individuals or small leaderless cells. The 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.

Another type of terrorism experienced in Seattle is eco-terrorism. During the November 1999 World Trade Organization disruptions and again in 2001, suspected Earth Liberation Front eco-terrorist attacks occurred at the University of Washington's Center for Urban Horticulture.

Finally, with the emergence of the Internet and the increasing dependence of the economy on information technology, the possibility of cyber-terrorism has materialized. Criminal and terrorist organizations are rapidly building their capability to attack the electronic and communications systems upon which the economy depends. It can be difficult to discern the difference between a criminal act and a terrorist act, but vulnerability to either is frequently demonstrated by worms, viruses and other cyber-threats.

Diseases can be intentionally spread as part of a bio-terrorism attack. 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 were confirmed[175]. Bioterrorist agents are likely to be highly virulent and cause severe illness.

History

Seattle has had activity related to terrorism, but it has never had a full-scale terrorist incident. There have been many smaller scale incidents that fit into terrorist mold and could represent the first step in a pattern of escalation. The incidents below include incidents occurring in the region. They relate to both domestic and international terrorist groups. Activity comes in cycles. In the 1960s and 70s, left wing radical groups were most active. In the 1990s, it was the extreme right wing and in the 2000s, it is al Qaeda and allied groups. Eco-terrorism has also been a periodic presence in the Pacific Northwest.

Besides committing acts of terrorism in the United States, many foreign terrorist groups use this country 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 20th century with heavy IRA fundraising in the United States.

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. 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. Spokane. Members of the white separatist group Phineas Priesthood committed two bank robberies in Spokane. Both were preceded by bombings. The first occurred on April 1, 1996 and targeted the Spokesman-Review newspaper; the second occurred on July 12, 1996, targeting an abortion clinic. There were no injuries, but property damage was extensive[176].

1996. Bellingham. Eight individuals were arrested near Bellingham. They had plotted attacks against a bridge, railroad tunnel and a radio tower[177].

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. An Algerian man with links to Osama bin Laden was caught smuggling bomb-making materials into the U.S. at Port Angeles. 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.

1999. Seattle. Suspected eco-terrorist attacks at University of Washington’s Center for Urban Horticulture.

2001. The Earth Liberation Front claimed responsibility for an arson attack against a University of Washington building. The fire caused $6,000,000 in damage(http://www.fbi.gov/seattle/press-releases/2011/fugitive-who-built-firebombs-linked-to-2001-arson-of-uw-center-for-urban-horticulture-arrested-following-expulsion-from-china) .

2001. Nation-wide. September 11th attack on the World Trade Center in New York City and the Pentagon. Fourth terrorist-hijacked airliner crashes in Pennsylvania.

2002. Seattle. James Ujama pleads guilty to providing assistance to the Taliban government of Afghanistan.

2002. Seattle. Individuals opposed to a Seattle company’s involvement with animal research entities released smoke bombs in major downtown buildings, causing substantial economic disruption and evacuations.

2003. Monroe. The Animal Liberations Front released 10,000 mink in Monroe, Washington, causing a loss of animal life and over $40,000 in damages.

2003. Pullman. Two incendiary devices were left at the Washington State University College of Veterinary Medicine.

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 political.

2011. Seattle. Two men were arrested for a plot to attack a Seattle armed forces recruiting center.

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 15 active hate groups active in Washington State in 2010[178].

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.

Likelihood of Future Occurrence

The pattern in the Seattle area has been a series of smaller scale attacks punctuated by the large arson attack against the University of Washington. At the same time, the international threat from jihadist extremists has been growing nationally. While Seattle has seen some of this activity, the focus seems to be elsewhere.

It seems very likely that Seattle will experience smaller scale incidents targeting property. There have not been as many incidents linked with right-wing or radical environmental extremists groups in recent years, but these groups are still in existence.

A large-scale attack seems like 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 on potential target lists. As long as the capability and motives exist, the threat of an attack is real.

Terrorist groups frequently target sites and groups that are both symbolic and easy to attack. Being a large, diverse and open city, Seattle has many such potential targets.

Vulnerability

Most of the same vulnerabilities that cities in general and Seattle in particular have for other hazards also apply to terrorism. One significant difference is that attackers are deliberately selecting targets. Some groups have focused more on property while others are targeting people. All aim to commit acts that are shocking and have a high media profile.

Many attacks occur in downtown areas. The high population in these areas is an inherent vulnerability, as is their high economic, political and cultural significance. Many of our transport linkages connect through downtown and would be impacted by a large attack. Many attacks target transportation systems. Seattle, with limited reserve capacity in surface transportation, has a vulnerability.

Terrorist attacks use a wide variety of weapons, each of which has its own specific vulnerability. The vulnerability to these specific means of attack is covered in other chapters. For example, bioterrorism is covered in the chapter on disease. The proliferation of the number of means of attack stretches the ability to mitigate the effects of an attack.

Dependence on networked computer systems is a growing vulnerability. Like other governments and businesses across the nation, Seattle relies heavily on computers and networks to conduct its normal business. Future terrorist attacks could target the computer systems and networks that control the electric power grid or water supply or those that are used to dispatch and manage police officers, firefighters, emergency medical technicians and utility workers.

Preparation reduces 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. The attempted 2009 Christmas Day bombing of a Northwest Airlines flight was stopped by alert citizens.

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 organizations. These groups have a presence in the Seattle community and 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 probably made it harder to act. Citizens are more alert and more likely to act. Institutions have tightened security.

Terrorism has a lasting psychological component. The community at-large can become traumatized both because they identify with the victims and because terrorists often target well-known public places. The sense of public trauma is further heightened by the overwhelming media coverage at terrorist 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.

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 Shooting suggests that future actions may target people. It is very difficult to detect individual actors; the expectation that all attacks can be prevented is unrealistic.

Another likely threat is an attack on city computer systems. Several Internet worms have already caused temporary outages. Cyber-attacks against computer systems could potentially shut down radio, telephone and computer-aided dispatch systems. In the most likely cases, the outages would be short and could be mitigated by workarounds.

It is possible that a large scale attack could occur in Seattle. Such an attack could come from either a domestic or international group. Given the number of potential weapons, it is impossible to predict what form such an attack is most likely. Terrorist groups are always seeking new means of attack. In the past, weapons have included bombs, aircraft as missiles, chemicals and firearms. Bombs have been most common. Most troubling is the potential for using weapons of mass destruction: nuclear, radiological, chemical and biological weapons.

Bioterrorism is the maximum credible threat out of several possible scenarios due to the devastating impact a successful attack would have. An attack could causes hundreds or even thousands of deaths. Quick detection and surge medical capacity would be critically important. In the case of plague, treatment should start within 24 hours of first symptoms. Both anthrax and plague can be treated if caught soon enough. While the federal government maintains a large stockpile of antibiotics that can be shipped anywhere in the U.S. in 12 hours, distributing the medication would be a challenge. After the initial attack, the affected area may have to be decontaminated. It depends on the type of agent used. In the case of anthrax, clean up could take years, render the affected area uninhabitable during clean up, and cost millions or billions of dollars.

Most Likely Scenario

Home-grown independent actors target 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	4	Seattle has experienced major extremist violence on two occasions in the past twenty years. Even more violence has been prevented. 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 attack destroys 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.

Maximum Credible Scenario

One kilogram of aerosolized anthrax is dispersed throughout the Seattle downtown area. The media describes in detail the potential for mass death. This, combined with a general lack of faith in government’s ability to provide the needed antibiotics in time, contributes to a general panic. Disturbances occur at many locations where antibiotics are dispensed. Police are unable to respond to every incident and several large scale riots break out in several locations. Although authorities are quick to dispense antibiotics 1300 people die.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	An attack of this magnitude has never occurred in our region and a bioterrorism attack of this magnitude has never occurred in the world.
Geographic Scope	4	Downtown Seattle is attacked, but because downtown is the hub of the community, the whole city is affected directly and indirectly.
Duration	3	The attack is over in less than 24 hours, but it takes a week for public safety and health officials to stabilize the situation. Short term recovery will take months and long term recovery will take years.

Category	Impacts 1 = low 5 = high	Narrative
Health Effects, Deaths and Injuries	5	Based on CDC estimates, 1300 people would die if 1kg of aerosolized anthrax were spread in a dense urban environment. 12,000 people become severely ill and require medical attention.
Displaced Households and Suffering	5	20,000 people are displaced from their homes due to possible contamination of their buildings. The attack centered mostly on the financial center, but also targeted Belltown on a weekend summer night.
Economy	5	Many buildings remain closed pending inspection and / or cleaning. Businesses cannot retrieve vital records. Those without adequate business continuity plans suffer severe hardship. In all 167 businesses are forced to declare bankruptcy. Many more relocate their operations. 50% of downtown ceases operating for eight months while recovery occurs.
Environment	5	The attack itself constitutes catastrophic environmental damage from the standpoint of human health. The anthrax also affects animals living in the area. It is washed into the wastewater system. Some spores survive spreading damage to other parts of the Seattle area ecosystem.
Structures	5	Although no buildings are physically destroyed, 1251 are rendered inoperable. 5423 probably clean inside but are not accessible due to contamination in the surrounding area.
Transportation	5	The entire downtown area is shut down. Initially I-5, I-90 and SR 99 are closed. Mass transit systems have to adjust routes. They open to limited traffic a week later. Some people remain afraid to travel near the affected area.
Critical Services and Utilities	5	he incident overwhelms public safety. The headquarters of the Fire and Police departments are contaminated as is City Hall and the Seattle Municipal Tower. Waste water systems are contaminated. Maintenance cannot be performed on power, water and communications infrastructure increasing failures. As a precaution, service is stopped in affected areas.
Confidence in Government	5	The public is angry that government did not prevent this attack. They are suspicious of government claims that buildings areas are clean and safe for re-occupancy.
Cascading Effects	3	Although the attack does not physically damage infrastructure the depopulating of the downtown area makes infrastructure harder to maintain increasing the likelihood of failures.

Conclusion

While we cannot predict the next target of terrorists, it is clear that the pace and severity of attacks are increasing. The quest by terrorists to obtain weapons of mass destruction is relentless, and they have already acquired crude capabilities in this arena. Seattle has become a major economic and cultural center, increasing is symbolic value and therefore likelihood of being targeted. Seattle’s downtown areas in particular are densely populated and thick with attractive targets. Much of Seattle’s economic and social life is concentrated in these areas and vulnerable to disruption. Also, Seattle is a transport hub and transportation systems remain vulnerable.

Active Shooter Incidents

Key Points

- Overall violent crime has decreased in the past decade.
- Active shooter incidents are a newly defined category of hazard, but similar incidents have occurred for many years.
- Media reporting on active shooter incidents has increased, resulting in the perception that active shooter events have increased.
- Active shooter incidents are distinguished from multiple homicide incidents by the need for an immediate response by law enforcement supported many other sectors such as emergency medical services, transportation and utilities.
- Three significant active shooter incidents have occurred in the Puget Sound region in the past ten years.
- Active shooter incidents have occurred in every part of the country.

Context

The Columbine High School Shooting in 1999 was a watershed event that defined "Active Shooter" incidents as a hazard in the public's imagination, but even before this event, incidents that would now be called active shooter incidents have not been uncommon in the United States. Similar incidents date back at least to 1966 when a gunman at the University of Texas killed 14 people and probably go much further back.

The term "Active Shooter" describes:

- In-progress, deadly-force attacks in which,
- The attacker has unrestricted access to multiple victims, and
- Direct, immediate law enforcement action is necessary and likely to save lives.

Key to this definition is the understanding that the situation is exigent, dynamic and rapidly evolving. Attacks in which multiple victims have been killed or seriously injured but where the suspect has been apprehended or killed are not "active shooter" events.

While most attacks are committed with firearms, a deadly-force assault with any weapon meets the first element. In Europe, where firearms are less readily obtainable than in the United States, several active "shooters" have used edged weapons and even a flame-thrower. Unless an assailant is armed with multiple devices, persons armed with explosives are not considered active shooters.

Some definitions of an active shooter incident describe the suspect's access to "mass potential casualties" and further define "mass casualties" as a number of casualties for which the potential need exceeds the medical response capability. Many law enforcement agencies now use the phrase "multiple victims," which allows for situational discretion. For example, a botched bank robbery in which two suspects have fired multiple shots at four victims, all of whom appear to be dead, would probably not meet the second element and should be treated as a murder scene with a barricaded suspect. On the other hand, a work-place shooting with one victim shot on the first floor and a second person calling 9-

1-1 from a second floor office would probably meet the second element of the definition and necessitate a rapid intervention response to an active shooter.

Exigency guides first responders' actions. Where immediate and direct intervention, as in moving toward and using deadly force to stop the suspect, is not necessary or likely to save lives, responders are trained to treat the incident as a barricaded person or hostage incident.

Further complicating predictive analyses are the varying motives for the attack. Media accounts may drive people to think first of psychopathology as the motive defining an active shooter, as in the student, fired employee or jilted lover who "snaps." Clearly, psychopathology can be described as an element of any murder, but a cautious definition is needed, lest motives be too narrowly defined. Active shooters have demonstrated extensive planning, deliberation and cognitive functioning in the commission of the attacks. Not all active shooters suddenly, impulsively and randomly open fire in a public place. Like context and environment, an active shooter incident is defined when the three criteria are met, not by the attacker's motive.

History

Although there have been multiple homicides in Seattle's history, with the Wah Mee Massacre of 14 people in 1983 being the most prominent, the number of active shooter events have been smaller. Significant recent regional active shooter incidents:

November 21, 2005. Tacoma Mall, Tacoma. Man opens fire in mall, wounds seven.

March 25, 2006. Capitol Hill, Seattle. Kyle Huff kills seven at house party.

July 28, 2006. Seattle Jewish Federation, Seattle. Navid Haq kills one, injures five.

May 30, 2012. Café Racer shootings. A man shoots and kills four people at Café Racer and kills a fifth person near downtown Seattle while attempting to escape.

A survey of school shooting incidents from 2008-2009 indicates (Washington Ceasefire):

- There were **34** shooting incidents in schools of all levels.
- Of these, **4 resulted in multiple deaths and 7 resulted in multiple injured victims.**
- A total of **25 persons were killed and 49 persons were injured** in all incidents.
- School level: **10 colleges and universities; 20 high schools, 2 middle schools and 1 elementary school.**
- Primary motives were: **11 escalated disputes, 3 domestic violence, 3 hate crimes, 9 psychopathologic and 7 unknown.**

Likelihood of Future Occurrences

Active shooter incidents are often prominently reported in the national media, especially following the landmark Columbine High School Shooting on April 20, 1999 in Jefferson County, Colorado. Data supporting trend and frequency analyses are obscure and unreliable. Credible studies exist for school violence but include many incidents that fail to meet the criteria for *active shooter* events, and filtering is difficult. Active shooter events have occurred in elementary, middle and secondary schools; in colleges and universities; at offices, plants and other workplace environments; at shopping malls, public sporting events, parties, bars and family gatherings. Irrespective of the environment or context, where the three criteria are met, the incident is defined as an *active shooter* event.

Vulnerability

It is very difficult to construct a vulnerability profile for active shooter incidents because they can happen in any community and in many different locations. Recent incidents have occurred in schools, workplaces, restaurants, centers of worship, parties and community centers. The only similarity between these locations is that they are enclosed facilities where the shooter has an easy choice of victims. People are crowded together and escape is difficult. Unlike typical criminals who tend to murder victims in private spaces, active shooters most often choose public spaces.

Because of highly publicized incidents, some organizations have developed stricter security policies. School districts, including the Seattle School District, have been especially active. Still, it is impossible to completely secure a facility with a large population.

Because some perpetrators were known to authorities as potentially dangerous, there is a hope that such people can be identified before they commit crimes. While individual shooters may perhaps be identified ahead of time, it is impossible to screen all potential perpetrators.

Some active shooter incidents are acts of terrorism. The individuals undertaking these acts have very different motives than other active shooters. The vulnerability profile for these incidents fits with terrorism.

Consequences

Active Shooter incidents are especially traumatic for communities. The intentional murder of innocent members of the community by another community member is disturbing. As mentioned above, what distinguishes active shooter incidents from other crimes is that the threat is ongoing, making a response more complex and involving multiple government functions besides law enforcement. Most incidents are single site, but as the 2008 Mumbai, India attack proved, multi-site incidents are possible, especially if the incident is terrorist.

Most Likely Scenario

The United States has had number attacks by individuals or pairs. It is very possible that Seattle could witness an attack of this type with even more casualties than past incidents.

Two individuals attack a gathering at Town Hall. The attack is still in-progress when police arrive. The attackers do not have formal military training but have done some planning. They set off a bomb in another part of the City as a diversion.		
Frequency	4	Mass shootings have unfortunately become common in the US. Several have occurred in Seattle within the past decade. As tragic as they are, most do not require activation of the City's emergency plan. This scenario envisions a more complex event that requires more multi-agency coordination.
Geographic Scope	2	The attack occurs in a mall. It is a large, but contained area. Police are not sure where the attackers are when they arrive. The diversionary bomb goes off in Sodo near CenturyLink stadium.
Duration	2	The attackers take hostages. It takes law enforcement 2 days to end the standoff.

Health Effects, Deaths and Injuries	2	9 people are killed in the shooting attack and 1 person is killed in the bombing. 34 people require hospitalization and 107 are treated by medical personal and released.
Displaced Households and Suffering	1	The attacks occur in commercial areas so no residents are displaced, but the surrounding office buildings need to be cleared. The incident does not affect the public's access to essential commodities.
Economy	1	The attack has an immediate impact on downtown businesses that are forced to close for two days, but the effects are short-lived.
Environment	1	The attack does not damage the environment.
Structures	1	The bomb and bullets damage buildings but no buildings are destroyed.
Transportation	1	Law enforcement creates a one block cordon around Westlake Mall. This action ties up traffic through downtown, but the closure of many businesses reduces the traffic impacts.
Critical Services and Utilities	1	The response requires large amounts of law enforcement officers. Seattle must use mutual aid to backfill and adopt 12 hour shifts, but it avoids decreasing service levels. No utilities are compromised and no responders are killed. 2 responders are injured.
Confidence in Government	1	The public sees local government's response as swift and decisive.
Cascading Effects	1	The attacks cause no significant secondary incidents.

Maximum Credible Scenario

While single/paired shooter scenarios are bad, the prospect of a multiple group/multiple site event is even worse and cannot be ruled out, especially after the attack in Mumbai, India in 2008. In that attack, heavily armed terrorists launched ten coordinated attacks. The attacks lasted almost 72 hours, resulted in 173 deaths and locked down much of downtown Mumbai. While the attacks were made easier by the close proximity of the terrorists' base in Pakistan, it would not be impossible to launch similar attacks in the U.S.

A well-armed, well organized and motived group launches a planned attack using a mix of automatic weapons and improvised explosive devices 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 improvised explosive devices (IED). 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 leave 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.

Frequency	2	This active shooter scenario is also an act of terrorism similar to attacks in Mumbai, India and Nairobi, Kenya. Such an attack has not occurred in the United States. Significantly, in both the Mumbai and Nairobi attacks, the attackers were able to move over borders relatively easily. 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.
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 a 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.

Conclusions

Active shooter events are an old threat in the United States. Newspaper accounts can be found for public attacks dating back at least to the late 1800s. Recently, several highly public and shocking attacks on children focused public attention on this problem. Most attacks are carried out by a single attacker in a single location. Terrorist group have used assaults with firearms, most recently in Mumbai, India. They represent the extreme end of firearms-based attacks.

Transportation and Infrastructure

This section covers all the hazards related to our transportation system and infrastructure. It includes one of Seattle's most deadly disasters, a World War II airplane crash. Transportation incident mean accidents involving vehicles. Infrastructure failure refers to structures, many of which are used by vehicles.

Transportation Incidents

Key Points

- 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 all 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, these accidents remind us that transportation incidents can be very dangerous. The 1998 shooting of a Metro driver that caused his bus to plunge off the Aurora Bridge was another reminder. Only the driver and the shooter died. It could have been much worse. In 2008 a similar accident was narrowly avoided when a tour bus slid down a snowy Capitol Hill street, crashed through a barrier over I-5 and came to rest with its front third overhanging the freeway.

- 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. Since 2001, 74 commercial aircraft have crashed during flight in the U.S. despite more than 10 million flights annually[179]. 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 directly impact Seattle directly are the greatest hazard. There have been no disastrous 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 until recently mostly transported freight but now included growing commuter rail and light service. The main hazards are derailments, collisions and tunnel incidents. Seattle has several miles of tracks that are exposed to landslides. A freight train was knocked into Puget Sound in 1997.

- **Motor vehicles**: Several recent bus accidents nationally have resulted in tragic loss of life and focused attention on highway accidents. Seattle has experienced two bus incidents and several tanker truck fires.

- **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 infrastructure 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.

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 this infrastructure see the Community Profile.

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 involved.

Air Transport

75% of all accidents involve general aviation (private aircraft) and 25% involve commuter, charter and scheduled airlines. The majority of accidents occur immediately after take-off and before landing. 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. In some areas, bad driving conditions have caused car crashes involving hundreds of vehicles.

History

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 making the circumstances under which these accidents occurred different from today, they illustrate the potential for high loss of life.

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. The focus here is on accidents involving passenger vehicles.

Aviation Overview
Since the beginning of 2003, the National Transportation Safety Board has recorded 13 accidents or incidents in the Seattle area, none of them fatal. Of these, six involved commercial aircraft. 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 is 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 vast majority of passengers ride the Washington State Ferry, which has a very strong passenger safety record. The 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 the Bering Sea. Fishing is a dangerous business and there have been a number of sinkings, most recently of the Alaska Ranger when five people died.

Rail Overview
Seattle is a rail terminus for Burlington Northern Santa Fe (BNSF) and Union Pacific. Historically, use of the rail network for passenger service has been limited, but it is increasing. Seattle has an Amtrak station that is seeing increased ridership. Sounder Commuter rail began in 2003. Neither service has 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 major incidents. 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[180].

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[181]. 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[182]. 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[183].

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.

Since 1951 there have been no major crashes within Seattle, but there have been a few significant incidents.

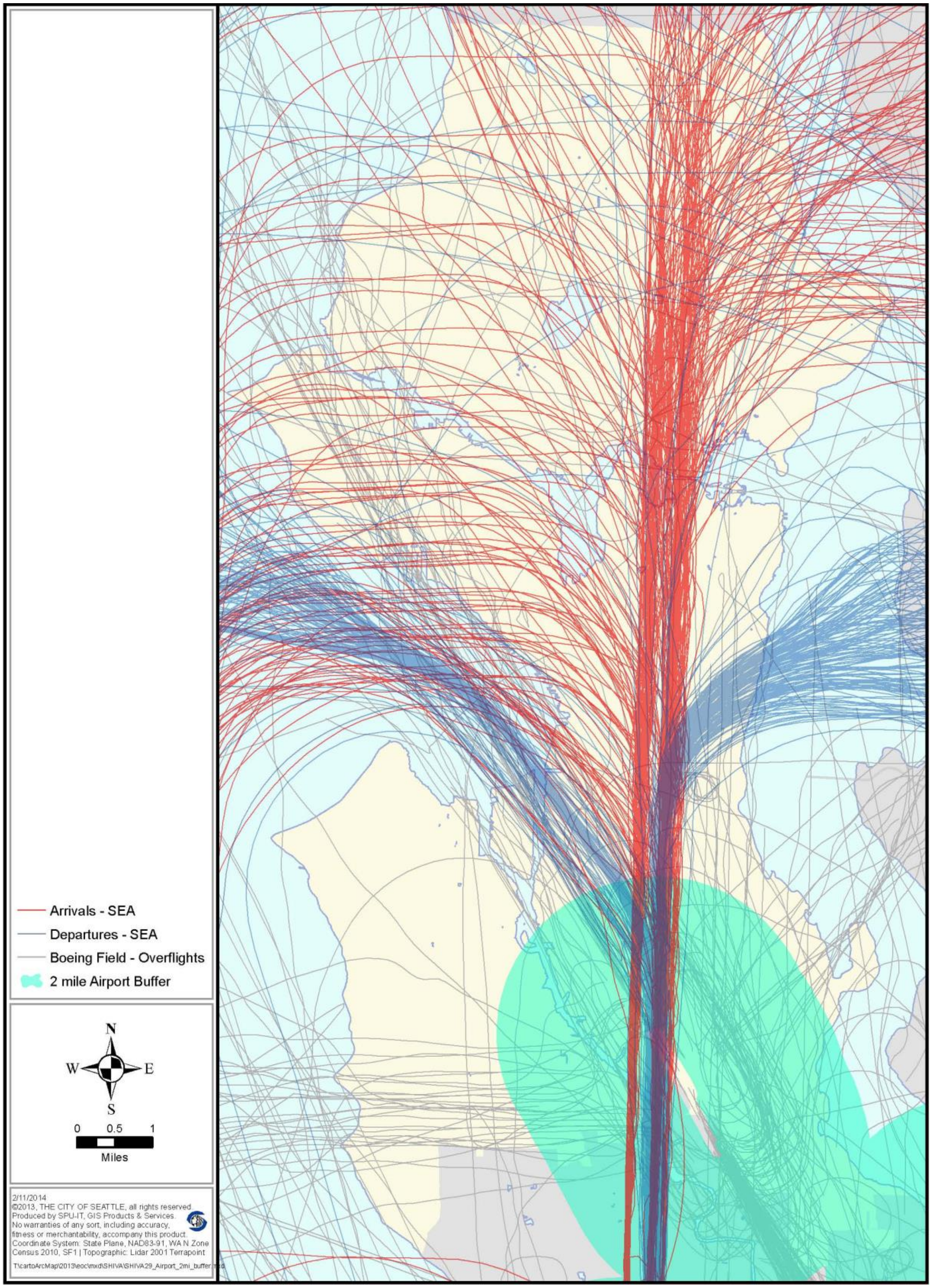
- October 18, 1984, Air Force Two and a private aircraft nearly collided eight miles from Boeing Field. The pilot of Air Force Two had to take evasive action to avoid a collision.
- December 19, 1984, only two months after the Air Force Two incident, a DeHavilland DHC-3 helicopter crash-landed on an 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. A chartered bus slipped down a steep and snowy 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 to SeaTac and aircraft production to other locations.

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 rate of accidents 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.

Figure 36. Areas Within Five Miles of Airports.



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 often an environment in which they could not long survive without help. Naturally, when things go wrong many passengers 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.

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 36 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 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.

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

Consequences

Transportation accidents are a classic case of a hazard with a huge number of low-impact events and a tiny number of high-impact events. Every year more than 40,000 people die in transportation accidents in the United States. The vast majority of these are the result of traffic accidents. Of the traffic deaths, most occur on highways and rural roads. 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.

In a hazard like transportation incidents where there are so many 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 incidents have a higher probably of being 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.

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 fairly quick and complete.

Most Likely Scenario

A bus crashes off of Aurora Bridge into a Fremont apartment building causing 15 fatalities and 34 serious injuries. The bus knocks over telephone landlines and blocks an arterial.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Major transportation accidents are one of the most common large scale emergencies faced in Seattle. The type of accident envisioned here is estimated to occur about once every ten years. Past accidents have not resulted in high casualties but a number of past accidents could have easily been much worse.
Geographic Scope	1	The bus heavily damages a mixed use apartment / retail building in Fremont. The bus comes to rest on an arterial.
Duration	1	The accident occurs mid-day. It takes emergency crews the rest of the day and into the night to stabilize the scene, look for survivors in the apartment and conclude an investigation
Health Effects, Deaths and Injuries	3	15 people are killed including passengers, pedestrians and building residents. Many more are injured.
Displaced Households and Suffering	2	The crash damages an apartment building. Its residents need to be sheltered.
Economy	1	Businesses in the immediate area are affected, but the larger economy does not suffer.
Environment	1	The crash spills gasoline but does not do major damage to the environment.
Structures	2	1 apartment building is severely damaged and is red tagged.
Transportation	2	The accident investigation blocks SR 99 and surface streets in Fremont for a day.

Category	Impacts 1 = low 5 = high	Narrative
Critical Services and Utilities	1	No critical services are impacted by the incident. The crash damages power lines causing a local outage. Telephone landlines also go down in the area.
Confidence in Government	1	Local government is able to conclude its investigation quickly. The public perceives its response as measured and competent.
Cascading Effects	2	The accident causes a minor secondary incident, a local and short term power outage.

Maximum Credible Scenario

A large passenger aircraft crashes into Beacon Hill around 7:00 AM. Debris is strewn over multiple blocks. Electrical and gas lines are severed. Fires have started. Debris is blocking I-5. It is not known if the cause is terrorism related.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	Seattle has experienced three significant aircraft crashes into residential areas with resulting casualties on the ground. All three occurred before 1951. Since then aviation's safety has dramatically improved, but crashes like American Airlines Flight 587 that went down in Queens on November 12, 2001 still occur.
Geographic Scope	3	The aircraft impacted two blocks on Beacon Hill but an additional four blocks are damaged from aircraft debris. Smaller debris is found up to 1/2 mile away. An engine and part of the wing fell onto I-5.
Duration	2	Stabilizing the incident, rescuing survivors and putting out fires takes 24 hours.
Health Effects, Deaths and Injuries	4	All 160 passengers and crew onboard perish along with 25 people on the ground (in houses and on I-5).
Displaced Households and Suffering	3	220 people are displaced from their homes and require shelter. Of these 180 are able to return home after three days when the investigation is concluded and their homes are inspected. Outside the impacted area services are maintained.
Economy	2	Several businesses in the immediate neighborhood have to shut their doors while the structures are evaluated and investigators search for debris. They are able to resume operations once the investigation is concluded.
Environment	2	The aircraft crashed shortly after takeoff. It was loaded with fuel. Most of the fuel burns. Some enters the waste water system. Toxic dust enters the immediate area.
Structures	2	6 houses are destroyed in the crash or burn in the ensuing fire. Another 15 are yellow tagged due to debris impacts.
Transportation	3	(WAS a 4). The crash temporarily halts traffic into and out of Sea-Tac and King County International Airports. It also completely blocks I-5 where a multiple vehicle accident has occurred due to debris. Transportation impacts are wide ranging but limited in

Category	Impacts 1 = low 5 = high	Narrative
		duration.
Critical Services and Utilities	2	The response occupies a large amount of public safety resources, but mutual aid is available because this is a single site disaster. Utilities in the affected area are shut off as a precaution, but those outside the area are not affected.
Confidence in Government	3	Some members of the public are unhappy that planes have been allowed to overfly the City and believe that Sea-Tac's expansion lead to the accident.
Cascading Effects	5	The crash releases hazardous materials, causes a major fire and a large transportation accident.

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.

Fires

Key Points

- Fires are among the deadliest of hazards nationally. They 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 and vehicle-related fires.
- Seattle has lost six firefighters since 1989 and 65 civilians since 1994. The trend in the number of casualties seems be dropping, but it is still statistically impossible to verify the drop. 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 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 are 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.
- Wildfires a significant hazard for some cities in the West and Florida, but they are unlikely here because Seattle does not have urban – wildland interface.
- Large structural fires remain a substantial risk and are most likely to occur in areas with older buildings, i.e., 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 undergrounded. The effects of these power outages are covered in the chapter on power outages.

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.

This section covers all major types of fires: multi-structure fires, large single structure fires, ship fires and fuel tanker fires. Seattle can even be affected by rural fires in its Cascade watersheds. Electrical fires are a special category that is covered under the power outage section. Nationally, some of the worst urban fires have been in cities with a large urban-wildland interface. Seattle doesn't 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.

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 Oakland wildfires, when automated suppression systems do not work properly or when they occur in places that are difficult to reach.

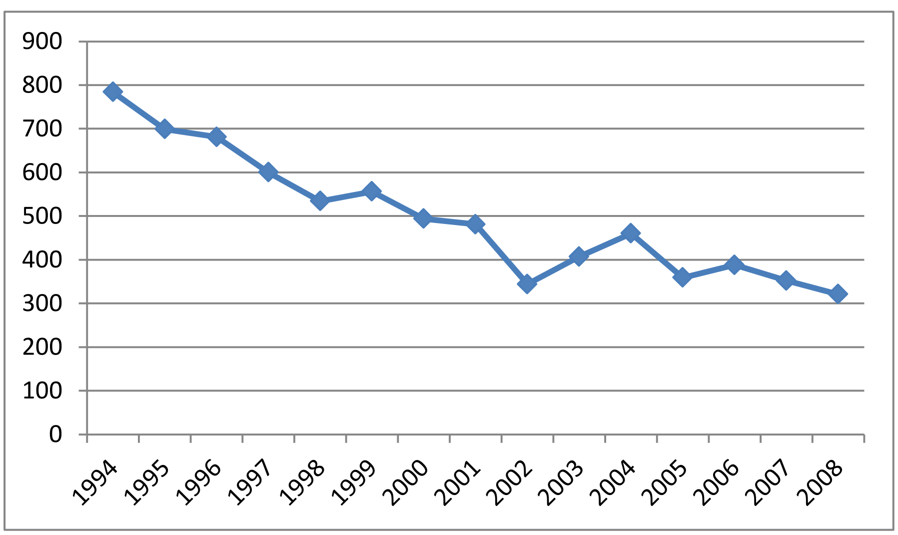
Fires are secondary impacts of other hazards. Fires after earthquakes and during riots are especially threatening. Due to damage to transportation infrastructure or security problems, fire fighters may be unable to reach fires quickly or in adequate strength. An earthquake may damage the water distribution system, lowering water pressure at hydrants. In these circumstances, unattended fires could grow and threaten large areas. From 1900 to 1995 there have been nine large fires following quakes, including Kobe[184]. 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

History

Seattle is a city shaped by fire. The catastrophic fire of 1889 consumed 60 acres of downtown Seattle just as the city was poised to become Washington State's leading urban center[185]. 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 vulnerability to a hazard can be mitigated during the recovery process.

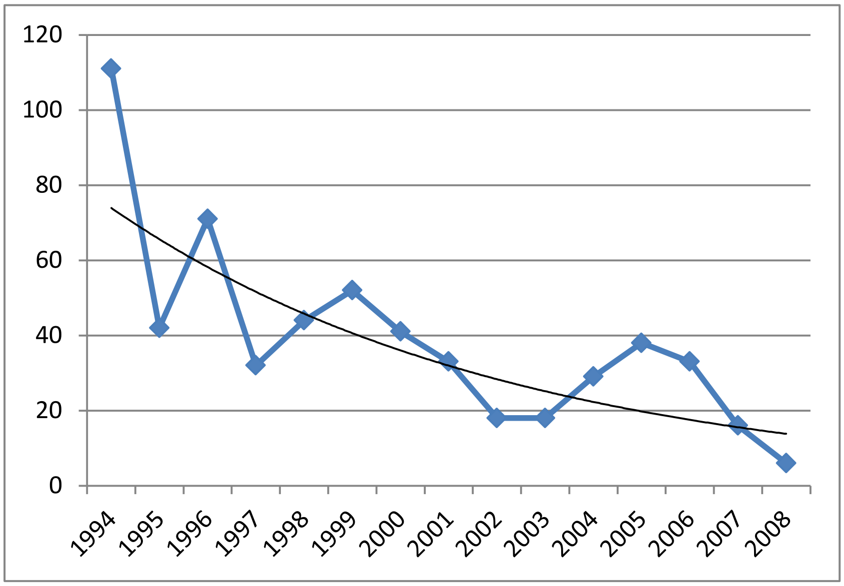
In the past 16 years, the number of structural fires has decreased, following national trends. This has occurred despite recent building booms that have added a considerable number of new structures. As with the rest of the country a combination of better education, decrease in smoking and increased use of smoke detectors is responsible.

Figure 37. Structural Fire Trend



Besides the decrease in incidents there has been a decrease in casualties. The number of deaths is dropping, but it is still too soon to know is this is a part of a trend or a temporary dip.

Figure 38. Casualty Trend.



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.

Non-structural fires (i.e., brush, dumpster, vehicle fires, etc.) are another class tracked by the Seattle Fire Department. Like structural fires, highway vehicle fires show a decline. The other categories do not, they have held steady or slightly increased in recent years. It is not clear why.

Significant Fires After the Great Seattle Fire

The Seattle Fire Department 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 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, included 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 unhappy 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 Ave. and a meat market connected to Pike Place Market.

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 then common that served homeless and seasonal workers. It was a known fire risk. The fire department had inspected in often, but 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. One of the key provisions was the introduction of new, active fire suppression technology like smoke detectors and sprinklers as well as passive systems, such as improved fire engineering in building design. One major unintended consequence of the code revision was the abandonment of the upper floors of older buildings. Owners were required to retrofit these floors if they wanted to continue to occupy them. Most owners found it was not financially viable to do the retrofits and simply abandoned the floors.

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. The Seattle Fire Department 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.

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 it 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 chances of another fire like it are remote. The most likely scenario for a multi-block fire like is a post-earthquake fire. Large sections of Kobe, Japan were destroyed is a huge blaze following the earthquake. Damage to the water system crippled the response.

Vulnerability

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

1. 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.
2. Apartments and hotels. These structures are vulnerable because of their high occupancy.
3. Nightclubs, stadiums, and theaters. Also vulnerable due to high occupancy.
4. Substandard buildings.
5. Arson Targets.
6. Ships.
7. Bridges.

In general, there are two types of fire vulnerability: the first are factors that are more likely to turn an ignition into a major fire and the second is 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. If fires grow quickly before fire apparatus can arrive, single structure fires can spread to other structures. A response time under five minutes is considered good. Seattle's average is under four minutes.

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 requires smoke detectors in all new and existing residential buildings and most other types as well. This law improves the chance the Fire Department will detect fires early, decreasing the probability a fire will get out of control. Due to these factors, the older neighborhoods, where the houses are closer 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. Some would add environmental resources as well. 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 big structures. If a fire were to occur, more people would be at risk. Density has many positives aspects like reducing sprawl, but its risks must along be acknowledged. Dense residential areas include Downtown, Pioneer Square, Belltown, the International District, Capitol Hill and the University District. Seattle's deadliest fire, the Ozark Hotel fire, occurred on the edge of downtown in the Denny Triangle area at 7th Ave 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 skyscrapers 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 there 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.

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. At least once, brush along I-5 has burned, threatening homes adjacent to it. The Seattle Fire Department was able to put this fire 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 tracts of wildlands. Additionally, the Fire Department has good access to most areas where they could occur. Wildland fires are a threat to Seattle's watersheds, which are heavily forested, remote location. Their greatest impact is on water supply, which is covered in a separate chapter. Seattle Public Utilities maintains its own wildland firefighting capability to combat fires in the City's watersheds.

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 be a few big incidents.

Large fires are likely to happen again. There are just too many potential targets. 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 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.

Due to the factors outlined above, the scenario that Seattle is most likely to face 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, e.g., for example a bridge that had to be closed force transportation detours.

Most Likely Scenario

A fire onboard a cruise ship erupts shortly after guests have arrived. The vessel is underway in Elliott Bay. The crew cannot contain the fire and requests help from SFD and Coast Guard resources. 7 people are killed. Thousands evacuate. The fire is deep in the ship and difficult to reach. Bunker fuel is leaking from the ship.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Large fires have occurred with regularity in Seattle. Overall trends show a decrease in the annual number of structural fires, but property losses show no decrease. A handful of big fires seem to be dominating fire losses. Casualty trends are decreasing, but there is large variability in the data.
Geographic Scope	2	The large ship fire is centered on a single site but the incident's complexity affects a part of the waterfront.
Duration	2	Ship fires are difficult to fight because it is hard to get at the fire itself. It takes 2 days to put out the fire and 1 more day to stabilize the ship. During this time, shelter must be found for guests and crew.
Health Effects, Deaths and Injuries	2	7 people are killed and 23 are critically injured.
Displaced Households and Suffering	5	The fire leaves thousands of guests and crew members (many are not Seattle residents) stranded and in need of shelter. The cruise line can help but there is a shortage of hotel space in the area.
Economy	1	The cruise line takes a big loss, but is able to keep its operation in Seattle running. Local businesses cater to stranded guests see an uptick in sales
Environment	2	The burning ship leaks bunker fuel into Elliott Bay. Crews are able to contain and skim more of it, but a significant amount escapes.
Structures	1	The fire does not damage buildings on shore.

Category	Impacts 1 = low 5 = high	Narrative
Transportation	2	Most of the city is not impacted, but the area around the Bell St. pier is used as a staging area for on shore fire response and reception of guests. Traffic in this area is heavily impacted. Later a marine terminal is necessary to salvage the ship.
Critical Services and Utilities	2	Seattle Fire 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 Fire must reduce its level of service.
Confidence in Government	1	The Seattle Fire Department is able to effectively fight the fire. The City of Seattle is able to work with the cruise line to find shelter for cruise guests and out of area crew. The public views the response as a success.
Cascading Effects	2	The fires cause a hazardous material incident in Eilliott Bay. It is a serious problem, but does not constitute a second disaster.

Maximum Credible Scenario

An Amtrak train and a freight train carrying crude oil collide in the BNSF tunnel near the southern entrance. The oil train is only partially inside the tunnel. The tunnel lacks modern fire suppression technologies. The smoke collects in the tunnel overwhelming many passengers. 116 people die and 230 are injured. 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	116 people 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.

Category	Impacts 1 = low 5 = high	Narrative
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 cannot access parts of downtown due to toxic smoke, including routes to Harborview hospital. Surface transportation is affected by the evacuation of downtown. I-5 is closed while the plume covers it (12 hours). After the fire is out the tunnel remains closed for repairs. Surface transportation returns to normal but rail remains severely impacted.
Critical Services and Utilities	2	Toxic smoke drifts into Harborview. Health officials must decide whether to shelter in place or evacuate. Seattle Fire must backfill with mutual aid.
Confidence in Government	3	The accident begins a 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.

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.

The most credible worst case risk is the outbreak of multiple large structural fires 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

HazMat Incidents (Chemical / Radiological Releases and Explosions)

Key Points

- 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. Most are received from shippers, e.g., UPS or Federal Express. Since 1998, U.S. DOT record 545 incidents in Seattle resulting in total of $1,316,452 in damage, but no fatalities or injuries requiring hospitalization. Nine incidents were classified as serious.
- The Seattle Fire Department (SFD) records hazardous materials-related dispatches. It lists 1,086 incidents since 1995, with a sharp spike in 2001-2003 following 9/11 and the 2001 anthrax attack. A rough measure of severity is the recorded alarm level, which ranges from 1 to 3. Only three incidents were over level 1. Two were fires with hazmat components.
- Fixed sites are the most frequent locations for accidents, but transportation accidents are often riskier because they happen in uncontained spaces 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 Dept. of Transportation. An incident could affect thousands of people in densely populated sections of Seattle.
- Other disasters such as earthquakes and landslides could produce hazardous materials incidents.

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 Sprint (1962) and tragedies like the Bhopal chemical disaster (1984) that hazardous materials have become recognized one of the most significant hazards facing society. The problems hazardous materials pose vary widely in intensity and duration. While many materials pose long term problems (like 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 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). The reporting requirements mandated by these acts have produced a rich set of data of chemicals in the community.

Around 80% - 90% of accidents involving hazardous materials accidents 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 Seattle Fire Department because personnel at the sites where they occur can handle them.

Transport incidents are usually more difficult to fight since 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.

The Fire Prevention Division of the Seattle Fire Department, 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.

The Fire Department 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 an organization, CHEMTREC, which runs a 24-hour hotline for emergency that happen in transit. Additionally, several 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, Burlington Northern Santa Fe Railway, Bank of America and a member of the public.

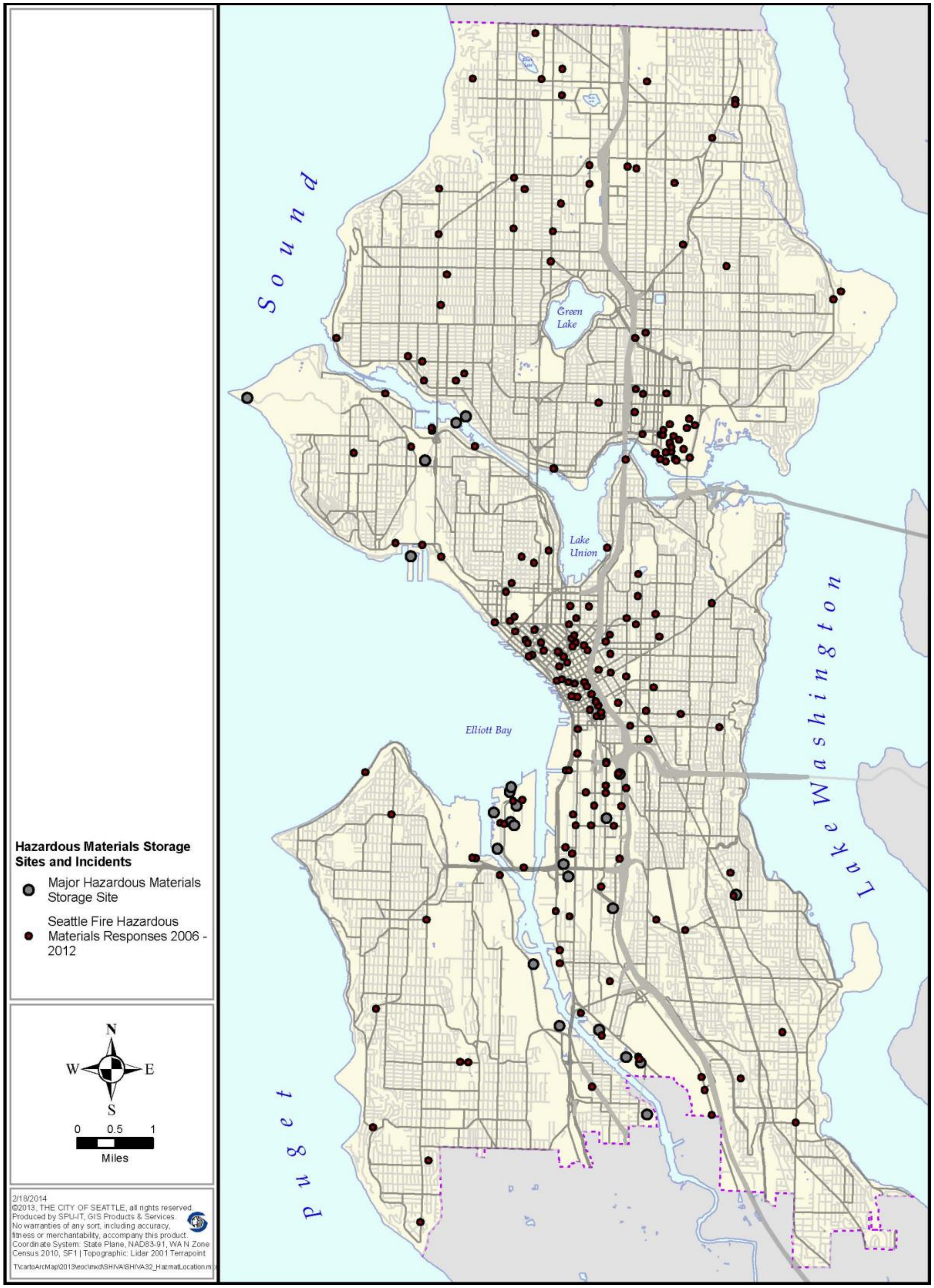
The number of chemicals in use today makes it critical to know which ones are at a particular site. OSHA lists 28,000 toxic chemicals and each of them has a unique way of interacting with their environment and with other chemicals, including the ones used to clean up spills. Responders can make matters 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 killed 12 and injured thousands in 1995. The use of radiological devices is also rare. Radiological attacks are not nuclear bombs; 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.

History

Hazardous materials emergencies have emerged as a public concern only within the past 30 years, so the historical record does not extend far. Older records mix hazardous materials emergencies with fire

Figure 39. HazMat Incident Locations 1997 -2006[186].



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 Hazardous Materials). 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.

The Seattle Fire Department (SFD) responses have been recorded since 1995. These data show SFD has 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:

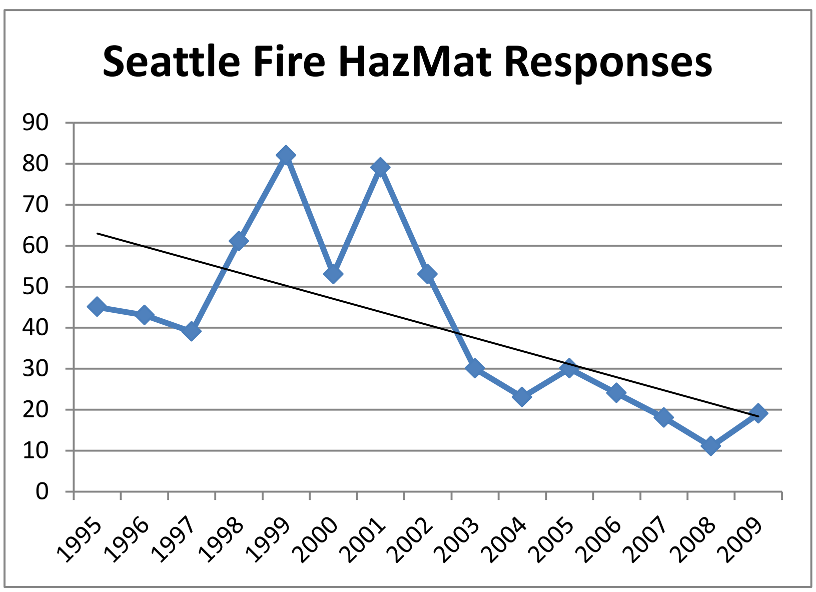
March 24, 1997. Fire with Hazardous Materials. Kincaid Hall, University of Washington. The zoology lab burned.

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.

Besides being mostly single alarm incidents, the total number of incidents is declining. (Note: After the 2001 Anthrax attack there was huge spike in 911 calls related to white powder. These calls have been removed).



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 Seattle Fire Department.

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.

A 1994 King County study shows that the most common material transported along I-5 is gasoline[187]. The most commonly released chemicals in transportation accidents were volatile organic compounds, acids, herbicides and insecticides.

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 1999 it was 33rd with 141 and in 2009 in was 22nd with 230. None were listed as major incidents. Nationally, the number of incidents is declining, however, so Washington's growing number of incidents is running counter to the trend. The most common transport mode is highway by far.

Likelihood of Future Occurrences

The length of the record 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.

While there may be very significant long-term problems involving the build-up of toxic chemical 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.

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.

One exception is that if the emergency is an induced incident caused by some other type of event like an earthquake, accidents could occur in non-typical locations. This possibility and recognition that no tracking system can be complete highlights the need to maintain a watchful eye over all parts of the city.

The Washington State and Seattle Fire Department 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 and SR 520. 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.

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.

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, although the 1975 tanker fire showed that transportation cannot be ruled out. In that incident, a crowded tavern was near the incident site. If it had been affected, there could easily have been multiple fatalities.

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 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 another primary incident 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 such as transit systems, entertainment venues and other locations where people are crowded together. In a scenario where numerous hazardous materials releases occur as a secondary impact to another incident, response resources would be diminished. In past events bystanders have been injured because people were not removed quickly enough or allowed to return in a prolonged evacuation[188].

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 the 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. 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 disaster.

Most Likely Scenario

A fire and explosion releases large amounts of anhydrous ammonia from rail cars parked on Harbor Island. A southeasterly wind blows the material toward Sodo and downtown. The Mariners are playing at Safeco Field which is just on the edge of the modeled plume. The release necessitates the evacuation of the surrounding residential area and closure of major transportation corridors. Many people are severely ill at the site. Schools, nursing homes and day care centers affected.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	Hazardous materials incidents are common occurrences in Seattle but most are small and easily handled in the field by the Seattle Fire department. The most dangerous and complex hazardous materials incident in modern Seattle history was a fire at a lab storing pathogenic bacteria. Even this did not require activating the City's emergency response plan. Balancing the lack of disastrous incidents historically is the presence of facilities housing large amounts of hazardous materials and transportation of those materials. Combining the history and exposure, we estimate the most likely scenario is a 1 in 100 per year event.
Geographic Scope	3	The plume from the release and fire blows toxic smoke into a residential area. People within the area must shelter in place and then evacuate.
Duration	1	The fire is put out in 24 hours, but 2 more days of clean-up are required to stabilize the site.
Health Effects, Deaths and Injuries	2	1 person is killed on the site. 39 people require hospitalization. 325 people are treated by medical personnel.
Displaced Households and Suffering	4	900 people are forced to leave their homes and businesses but are allowed to return in less than 48 hours. 300 of them need short term shelter. The release does not cause any commodity shortages.
Economy	2	The incident has a large impact on the business that released the material. Businesses in the plume are forced to close for 2 days. Most are able to reopen. Some must clean their buildings and merchandise.
Environment	2	The release degrades air quality. Most of the material diffuses into the atmosphere but some is left as toxic residue on buildings, sidewalks and streets.
Structures	2	The building where the fire occurred is destroyed. 12 more buildings are temporarily damaged when their exteriors are coated in dangerous chemicals. Additionally, the HVAC systems for these buildings pulled chemicals inside the buildings damaging the interiors.
Transportation	2	Major transportation corridors (SR 99, West Seattle bridge, 1st Ave S and 4th Ave S) are closed for 24 hours. Traffic must be detoured.
Critical Services and Utilities	2	Due to the closure of the West Seattle bridge, West Seattle residents face longer emergency response times. Some local utility damage happens on Harbor Island due to the incident. No emergency responders are killed or injured.
Confidence in Government	1	The incident's danger is readily apparent to the public. Swift response to the incident makes the public appreciate Seattle's emergency response capabilities.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	2	The hazardous material release occurred when dynamite in the same train exploded. Some minor power and water outages occur near the explosion.

Maximum Credible Scenario

BP is fixing the pipeline normally used to supply fuel to tank farms on Harbor Island. An oil tanker is brought in to supply the farm. As it enters Elliott Bay it collides with the Bainbridge Ferry. Both ships are crippled but not in danger of sinking. Thousands of gallons of oil spill into the Bay.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	This is a very low probability event. Oil tankers do not regularly come into Elliott Bay and a large ship collision has not happened in the waters off Seattle in over 100 years.
Geographic Scope	3	The oil spill would affect all of Elliot Bay and its shoreline.
Duration	3	It takes crews working from multiple agencies five days to remove most of the oil, but the oil has reached the shore at Alki Beach and Myrtle Edwards Park. Cleaning these areas will take months.
Health Effects, Deaths and Injuries	2	2 people are killed in the ship collision and 24 require hospitalization.
Displaced Households and Suffering	2	No households are displaced but many residences near the shore are indirectly affected by the oil on the short, especially along Alki. 452 people must be evacuated off the stricken ferry and sheltered temporarily.
Economy	3	The spill response interrupts port activity for five days. An emergency shipment of fuel must be brought into the region. The public is sensitive about bringing in another oil tanker while the pipeline is down for repairs.
Environment	4	The oil spill is a major disaster for the Elliott Bay marine environment. The ecosystem will take years to repair.
Structures	2	No buildings are destroyed by the oil spill, but infrastructure on the shore is coated with oil and must be cleaned or replaced.
Transportation	3	Spill response affects maritime traffic on Elliott Bay and indirectly on roads surrounding the Bay.
Critical Services and Utilities	2	Because most of the incident is in the water and shoreline, critical services and utilities remain intact. Fuel supplies are a problem. Some gas stations run low.
Confidence in Government	5	The public is upset and blames a lack of government oversight for the accident and spill.
Cascading Effects	3	The oil began with a significant accident. The oil emerges as the primary hazard in the incident.

Conclusions

Minor incidents are fairly common, making them high probability events. 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

Infrastructure Failures

Key Points

- Infrastructure is the network of utilities that supplies our basic needs for mobility, power, water, sewer and communications.
- This chapter covers major structural failures that are not triggered by some other hazard (e.g., an earthquake).
- Computer failure whether accidental or deliberate (e.g., cyberattack) is a form of infrastructure failure.
- The American Society of Civil Engineers (ASCE) gives the infrastructure of the United States an overall D grade and estimates it will cost $2.2 trillion to fix. The main concerns for Washington State are roads, bridges and mass transit.
- Many problems due to poor infrastructure are individually small but quickly add up, e.g., a vast number of small leaks causing some municipal water systems to lose up to 20% of their water during transmission.
- Infrastructure can be damaged during construction e.g., a contractor breaking a water main, or fail when new due to a design flaw, e.g., the collapse of the Tacoma Narrows Bridge in 1940. Not all infrastructure failures are caused by aging systems and structures.
- Occasionally, what is known about 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 the earthquake risk here.

Context

On August 1, 2007, the I-35W Mississippi Bridge in Minneapolis collapsed highlighting aging and vulnerable infrastructure across the United States. Many citizens began to wonder about the state of not just the bridges in their communities but also other critical infrastructure and buildings. This section addresses infrastructure failures of all types. Because power failures are especially complex, they are covered in their own section.

Most complex infrastructure is now controlled with computer systems (called supervisory control and data acquisition or *SCADA* systems). SCADA system failure is a type of infrastructure failure. There has been a lot of attention given to the threat of a cyber-attack on infrastructure system, especially the power system. The chance of a successful attack is very small, but the consequences would be very large if a successful attack did occur.

Examples of infrastructure failures include building collapses, water main breaks, gas pipe ruptures, dam failures, steam pipe explosions and related types of events. Recently failures in communications infrastructure have been added to this list.

Many 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 this age. The shear amount of investment it would take to upgrade all of it would be $2.2 trillion according to the American Society of Civil Engineers, which also assigned an overall D grade to the nation’s infrastructure[189].

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

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.

While many problems of failing infrastructure are small scale and cumulative, this section concentrates on the upper end of the problem, large scale emergencies. Nevertheless, it is important to note that these large scale emergencies represent only part of a larger issue.

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, e.g., the $365 million the Bridging the Gap levy.

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. In some cases, like the vault fires, the same events are dealt with in greater detail in another chapter.

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 collapses, causing a massive sinkhole under Ravenna Boulevard. 10 families had to be evacuated. The system took two years to repair and cost $16,000,000 to repair (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. Hours before a baseball game, four large waterlogged tiles peeled from the ceiling and plunged into the seats. Two construction workers died in a crane accident during the repair. The cause 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.

July 3, 2009. Fisher Plaza Data Center Communications/ Internet Outage. 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.

Likelihood

Infrastructure failures are unavoidable. 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 failures occur every year, but these can be handled through daily business procedures. The question is how likely are major failures that precipitate large-scale emergencies? There seems to be an increase within the past 30 years, but this could be random variation or the result of earlier events being lost to history. Major infrastructure failures *seem* to happen very roughly once a decade on average but several can happen within a few years or decades can past without one.

The chance of a catastrophic infrastructure failure is much smaller than the failures described above. Most infrastructure failures are single-site incidents. Unless a single failure such as a dam failure or nuclear accident can affect 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.

SCADA systems make it theoretically possible to affect a whole infrastructure system at once. Despite the theoretical vulnerability, the world has never experienced a major computer-caused infrastructure failure. An attack is the most likely cause of cyber-induced infrastructure failure. Most analysts consider it a remote possibility because agents with the means (like states) lack the motivation to attack and those with the motivation (terrorist organizations) lack the means[190].

Vulnerability

Seattle is 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 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 could be affected by one type of failure or another because of the ubiquity and dependence of every social and economic function on infrastructure. Some places are more sensitive than others, e.g., 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 most dramatic 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.

Consequences

Infrastructure failures cause outages in whatever utility or service the broken structure provides. Most are single-site incidents. Infrastructure failures have caused fatalities, injuries and economic losses in Seattle and are expected to do so again. They are one of the most common secondary hazards where multiple sites could be affected. The scenarios below outline cases where the failure itself is the primary hazard.

The mostly likely infrastructure failure scenario would resemble past events. 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 1) in a heavily used or populated area and 2) the failed component is co-located with other key infrastructure. Finally, Seattle has a lot of infrastructure and therefore many potential failure scenarios.

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’.

There is no guarantee that the future will be a continuation of the past. The rise of networked SCADA systems fundamentally changes the nature of the infrastructure failure hazard because it is now theoretically possible to disable or even destroy a whole infrastructure network instead of mostly single-site failures. The chance of a catastrophic failure is currently considered very remote, but the consequences would be severe. The exact consequence profile depends on the infrastructure affected.

Most analysis highlights the power system as the greatest vulnerability in a modern urban environment. Following this work, a cyber-attack on the power system was chosen as the Maximum Credible Scenario even though there have been no such successful attacks to date and the chances of one are very small.

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 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. 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.

Maximum Credible Scenario

The world has never had a major cyber-attack, but in a first, an unknown group finds the motivation and overcomes major obstacles to mount a cyber -attack on the US power generation and transmission system. 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 on line.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	There has been only one confirmed case of a cyberattack destroying equipment, the STUXNET attack on Iranian centrifuges. Additionally some analysts doubt the motivation and/or capability of states or terrorist organizations to execute a paralyzing cyber-attack. Therefore, the frequency is given the lowest rating.
Geographic Scope	5	Vulnerable utilities are affected throughout the US.
Duration	4	Generators in the City Light and Bonneville Power Administration system are destroyed. Operators lose the able to control power management systems for three weeks causing blackouts and brownouts.
Health Effects, Deaths and Injuries	2	5 people die due to the effects of power outages. They are involved in traffic accidents. 230 people become ill from eating spoiled food.
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. 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 or relocate operations outside Seattle. There is a surge in sales after the attack ceases partially offsetting lost business.
Environment	3	The attacks disable King County's sewage treatment plants. Untreated sewage has to be discharged into Puget Sound.

Category	Impacts 1 = low 5 = high	Narrative
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. Air traffic control systems continue to operate as do marine navigation systems.
Critical Services and Utilities	4	Multiple utilities are inoperable due to extended power loss and a lack of generators: communications, water, and power. Public safety is operating on manual systems which reduce capacity.
Confidence in Government	3	The public is initially sympathetic to the government but grows impatient as the outages continue.
Cascading Effects	4	Many control systems that prevent hazardous materials releases are offline.

Conclusions

Seattle has had infrastructure failures in the past and will probably continue to have them. As this community's infrastructure ages, it will require major investment to fix. Even if the maintenance backlogs are fixed, it is impossible to eliminate all design flaws, construction errors and operator errors. The big question is whether future incidents will be small or large.

Failures of single structures or sites can cause high numbers of casualties but have a limited geographic scope. Single failures can usually be contained relatively easily and recovery is fairly quick and complete.

Multiple failures or collapses could occur as a secondary hazard but are often so tied to the primary hazard than there is often no functional distinction. The major effect of an earthquake on the human community is structural collapse.

In the long run, the cumulative effects of all the small incidents related to aging infrastructure probably outweigh the effects of big, spectacular incidents. Much as chronic disease imposes a health burden on a community, chronically poor infrastructure imposes a socio-economic burden.

Power Outages

Key Points

- The 2003 Northeast Blackout highlighted the fragility and interdependence of the country's electrical system.
- About half of Seattle City Light's unplanned power outages are caused by falling trees or branches.
- Over 86% of Seattle's power comes from hydroelectric power; 51% of the power Seattle consumes is purchased.
- A regional cascading blackout is a distinct possibility in this region. It seems likely that a problem would originate outside the Seattle City Light system because the Bonneville Power Administration (BPA) transmission system is in need of a major upgrade.
- 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 and demand, lowering demand during the winter and increasing demand during the summer.
- By 2021, demand may not be met in late summer, early fall and winter.

Nature of the Hazard

On August 14, 2003, a large part of the upper Midwest, East Coast, and Ontario, Canada lost power. The 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.

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 may be referred to as a "blackout" if power is lost completely, as a "brownout" if the voltage level is below the normal minimum level specified for the system or a "dropout" when the loss of power is only momentary, from milliseconds to seconds. Some brownouts, called voltage reductions, are made 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 area blackouts.

In power supply networks, the power generation and the electrical load (demand) must be very close to equal every second to avoid overloading network components. In order to prevent this, parts of the system will automatically disconnect themselves from the rest of the system or shut themselves down to avoid damage. Under certain conditions, a network component shutting down can cause current fluctuations in neighboring segments of the network, though this is unlikely, leading to a cascading failure of a larger section of the network. This may range from a building, to a block, to an entire city or to the entire electrical grid.

The City of Seattle owns its own generating capacity, transmission lines and distribution system. It is operated by Seattle City Light and connected to the BPA network, which is part of the western electric transmission system made up of 11 western states, two Canadian provinces and northern Baja California, Mexico.

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. Seattle City Light's existing portfolio includes a seasonal exchange with utilities in Northern California. The interconnection brings danger of cascading failure and relief of load shedding under differing circumstances.

The City of Seattle gets most of its power from Seattle City Light, a City department. As a publicly owned power utility, it operates as a public service. It serves more than 330,000 customers and is the seventh largest public power system in the country. Seattle City Light owns seven dams, mostly on the Skagit and Pend Oreille Rivers. Over 86% of Seattle's power comes from hydroelectric power, both from its own dams and those of the BPA. Seattle City Light purchases 51% of the power that Seattle consumes. 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. More information on Seattle's power supply can be found in the Community Profile section.

History

All power systems experience unplanned outages. Most are small, resolved within a few hours and do no lasting damage. Larger outages occasionally occur. These outages are usually secondary events caused by other hazards, e.g., winter storms. 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 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.

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.

2006. Seattle. 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 were 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 this event demonstrated that Seattle is also vulnerable to demand spikes during the summer.

Likelihood of Future Occurrences

No system is 100% reliable. The costs of such a system would be prohibitive even if possible. Seattle will have major unplanned outages in the future. The more important questions are how frequent will these outages be, how many customers will they affect and how long will they last?

Wind will continue to be a hazard to power transmission. Although it has fewer trees that the rest of the county, Seattle is attempting to re-grow its tree canopy. Seattle City Light has increased its tree trimming program, but it is still possible that the number of tree-related outage could increase.

Improvements have been made to underground electrical vaults, including automatic fire suppression. These improvements should reduce the likelihood and duration of downtown outages.

A regional cascading blackout is a distinct possibility in this region. It seems likely that a problem would originate outside the Seattle City Light system because the BPA transmission system is in need of a major upgrade. Seattle has the ability to isolate itself but, because the city can only generate a portion of its power, an "islanding" could cause short-term, supply-related brownout problems.

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. In the rest of the city the situation is reversed. Wind damage is linked to the number of trees close to wires. 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.

Communities with older high-rise and commercial buildings are generally more vulnerable to a blackout because they often lack backup generators. During the 2006 storms and power outages, it was discovered that many nursing homes lacked back-up power. With many residents dependent on electrical equipment, these facilities proved highly vulnerable to outages.

Hospitals are even more sensitive than nursing homes . For this reason, 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. The City of Seattle is current upgrading all its fire stations to 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 2003, there was none. The social climate is an important external variable in any widespread outage.

Many businesses depend on reliable power, especially with growing technology dependence. Other 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.

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.

Despite the seriousness of the 2006 outage, 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. It is therefore plausible that another as large or even larger could occur. The most likely sources are another underground vault fire or a regional windstorm. The effects would be similar or worse than past incidents, with major parts of Seattle losing power.

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, 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.

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 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.

Maximum Credible Scenario
The western power grid fails during December when City Light needs power from it. Cold temperatures are creating a high demand for power for heating. City Light must attempt to meet demand using only its own resources (which can supply 30% of demand). 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. City Light would have to implement rolling black outs to spread the pain among customers, including high-priority customers like hospitals.

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. City Light has its own generating and transmission capability which mitigates vulnerability to problems with the Western Interconnection, but 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.
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.

Long term impacts

In October 2005, local experts in climate change evaluation, the University of Washington Climate Impacts Group, issued a report stating that “projected climate and hydrologic changes will likely alter the annual patterns of electricity demand and stream flow. Projected warming due to climate change will likely lower electricity demand during the winter and increase demand during the summer in Washington.” This will alter power transfers with other parts of the region. More impacts are discussed in the climate change chapter.

Conclusions

In order to plan for the acquisition of new resources, which can take many years, Seattle City Light forecasts future power consumption or load in its service area 20 years into the future. Over the 20-year planning period, load is expected to continue to grow. Additionally, some of the power purchase contracts will expire.

By 2021, loads may be unserved in late summer, early fall and winter. In order to reduce the risk of unserved energy, additional energy must be available. 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.

Currently, Seattle City Light sells much more electricity into the market on an annual basis than it purchases, primarily because it requires more resources to meet the three-month winter peaking load requirement than are needed during the remaining nine months of the year. If BPA were to go out, Seattle City Light could isolate the city and protect the city’s network. This strategy is more feasible in the summer when Seattle supplies power to other areas than in the winter when Seattle needs to draw it from BPA to meet increased demand.

About half of Seattle City Light’s unplanned power outages are caused by falling trees or branches. Starting in January 2007, Seattle City Light revitalized the schedule for power-line clearance, focusing on feeders and the main lateral lines.

Weather and Climate

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.

Excessive Heat Events (EHE)

Key Points

- Heat is an extremely deadly but 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, a heat disaster's extent is often not visible to the public.
- Since the mid-1970s, an average of three or four 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 typical cool 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 seasonal normals 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. As a community, Seattle presents a mixed picture in terms of vulnerable population. We have fewer elders and infants than many other cities, but many more single-person households.
- 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 frequent and severe in the Pacific Northwest in recent decades, and climate models project that this trend will continue in the future.
- Heat can be costly. The costs of one extreme heat wave in California in 2006 were estimated at over $200 million.

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 extreme heat even more dangerous when it occurs.

An 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 and can cause dehydration, heat cramps, heat exhaustion, heat stroke and even death.

Of all the natural hazards in the United States, heat is the number one, non-severe weather-related killer. In an average year, about 658 Americans succumb to the effects of summer heat[191]. During the summer of 2006, more than 150 people in the United States died as a direct result of heat. 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 degrees Fahrenheit. The heart begins to pump more blood, blood vessels dilate to accommodate the increased flow and the bundles of tiny capillaries threading through the upper layers of skin are put into operation. The body's blood is circulated closer to the skin's surface and excess heat drains off into the cooler atmosphere. At the same time, water diffuses through the skin as perspiration. 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 retards evaporation. The evaporation process itself works this way: the heat energy required to evaporate the sweat is extracted from the body, thereby cooling it. Under conditions above 90 degrees Fahrenheit and high relative humidity, the body is doing everything it can to maintain 98.6 degrees Fahrenheit inside. The heart is pumping a torrent of blood through dilated circulatory vessels; the sweat glands are pouring liquid, including essential dissolved chemicals like sodium and chloride, onto the surface of the skin.

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 heat-related illness may develop.

Once the ambient temperature exceeds skin temperature, convective cooling from the skin is no longer possible and 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.

History

Looking at Seattle area weather and mortality statistics back to the mid-1970s, an average of three or four fatalities have occurred each summer[192]. During excessively warm summers, such as the summer of 1992, up to 50 to 60 deaths have occurred. 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 heat as a source of disaster only recently, records are marginal.

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. This research studies day to day baseline conditions and not extreme events. It suggests that mortality and morbidity can spike sharply in extreme heat events.[193]

The Washington Climate Change Impacts Assessment studied heat events from 1980 to 2006. It found that the Greater Seattle Area had an average of 1.7 heat events per year with an average duration of 2.2

days and a maximum of six days. It correlated the heat increases and found that "risk of death from non-traumatic and circulatory causes was significantly elevated for all ages on most days of heat events."

Some of the major heat events from this time period are:

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[194].

1994. A city-wide heat extreme is set, recorded at 100 degrees.

2009. A new all-time record set, and two deaths in Western Washington are directly attributable to the heat.

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. 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.

Vulnerability

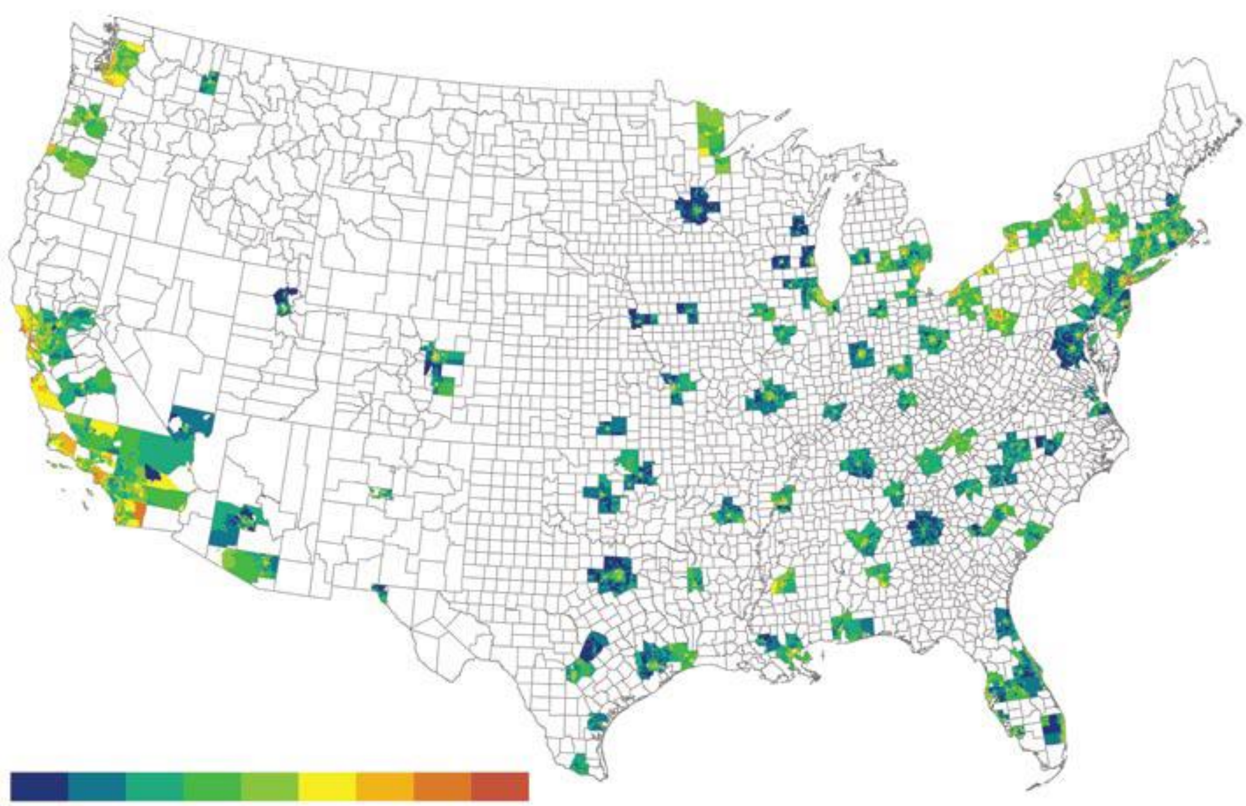
Demographic vulnerability to extreme heat events is similar to other hazards. Factors that increase vulnerability include: age (65+), ethnicity (especially Pacific Islander), lower levels of educational attainment, lower incomes and minority status.

Many residents lack efficient cooling systems in their homes or businesses and remain unaware how to protect themselves. 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 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, e.g., hypertension and diabetes. The most vulnerable people in Seattle tend to be the elderly.

A 2009 study of vulnerability on a national scale found that Seattle is on par with Chicago, site of a 1995 event that killed over 700 people. The study found that four factors drove heat vulnerability. These four are social isolation, lack of air conditioning, the proportion the population with chronic medical conditions and social vulnerability factors such as 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.[195]

Figure 40. Heat Vulnerability



Source: Reid et al, 2009

Consequences

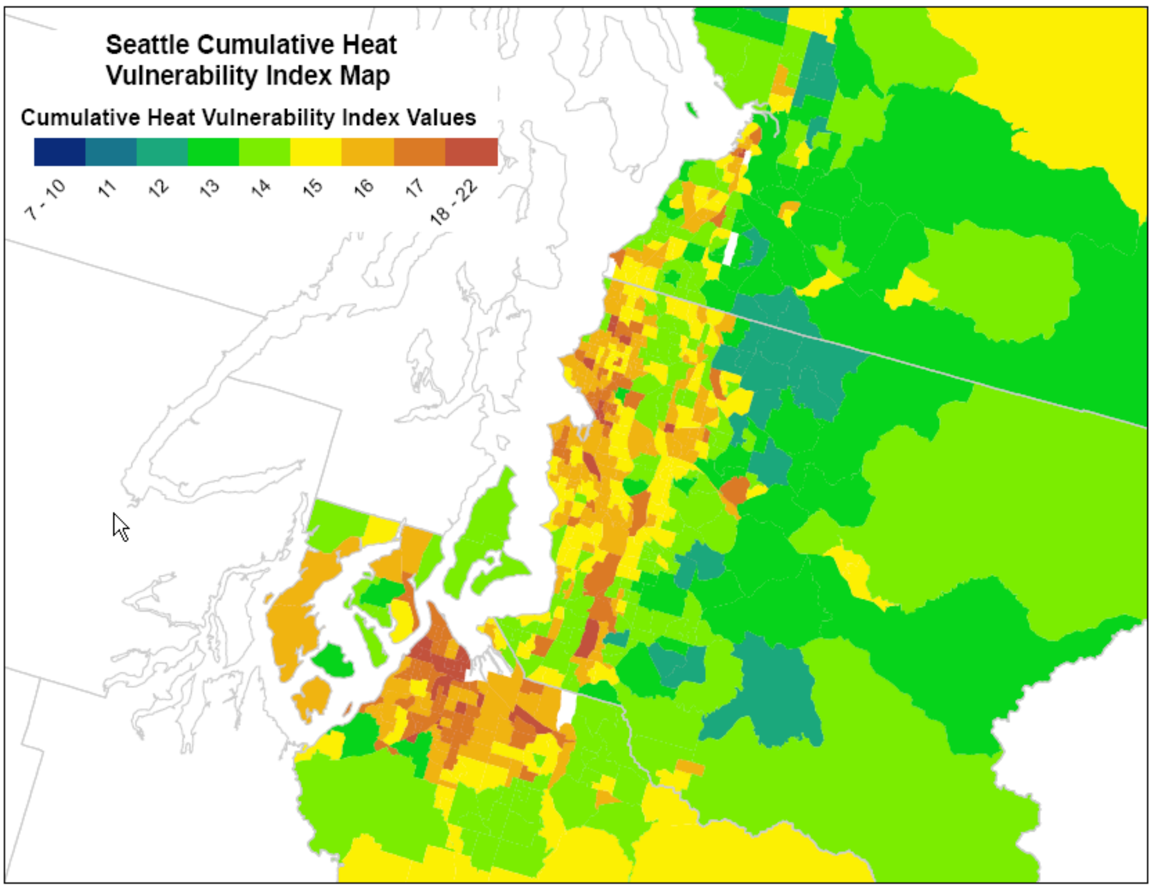
Two studies based on Seattle's 1990 population found that the city had widely varying averages of five and 96 estimated heat-attributable deaths and a heat-attributable mortality rate of 0.17 and 3.27

deaths per 100,000 people, respectively[196]. In Seattle, most fatalities are indirectly caused by heat, e.g., heart attacks, strokes and respiratory illness.

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.

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.

Figure 41. Seattle Heat Vulnerability Index



Source: Colleen Reid, personal communication. 2009.

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.

Climate research suggests an increase in EHE frequency and severity, discussed further in the chapter on climate change.

Most Likely Scenario

Seattle experiences an event slightly more extreme than the previous milestone, the 2009 heat wave. Temperatures are over 90° for seven straight days with two over 100°. Lows are over 70°. 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	Seattle is experiencing more extreme heat events recently. It seems likely that the previous record of 103° will be broken in the near future. 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 in the next 10 to 50 years 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 suffered 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 are killed by 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.

Maximum Credible Scenario

Seattle experiences an unprecedented heat event. Temperatures are over 90° for 14 consecutive days with three over 100°. Temperatures do not sink below 75° 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° mark this scenario is not viewed as unrealistic. 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 80° which makes the event more dangerous.
Health Effects, Deaths and Injuries	3	42 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 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.

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 on the rise. This may help acclimate people to relatively hotter conditions but may also increase the exposure of vulnerable populations.

Flooding

Key Points

- Nationally, floods are the most costly and destructive disasters. Most damage caused by Hurricane Katrina was caused by flooding. Western Washington is very prone to flooding. Seattle's flood profile is very different from rural areas of the state.

- Seattle has three distinct flooding hazards:

    - **Riverine flooding** – Heavy precipitation causes a river or stream to overflow its banks into the adjoining floodplain. Seattle's creeks, especially Thornton and Longfellow, have flooded more often than the managed Duwamish River. Failure of the Howard Hanson dam or the release of large volumes of water from the dam could affect the Duwamish River. (See Infrastructure Failures for more on dam failures). These areas are small for a large urban area comprising 388 acres.
    - **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 suddenly 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 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.

- Seattle has fewer than ten buildings that have had more than one flood loss.

Context

Nationally, flooding is the costliest type of hazard this country faces. The rivers of Western Washington flood almost every year. While the Snohomish, Skagit and other rivers flood, Seattle has largely been spared. However, an incident in December 2006 raised awareness of "urban flooding" in Seattle. Heavy rains overwhelmed the City's drainage systems and water backed up at the top of an embankment. When it finally overtopped the embankment, it rushed downhill, slamming a home, and causing one fatality.

With over 200 miles of waterfront, flooding is a natural concern in Seattle. It is surrounded by Puget Sound and Lake Washington and contains the Duwamish River, a ship canal and several streams. Flooding outside Seattle can have an indirect effect. 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.

There are three types of floods that can occur in Seattle - riverine, coastal, and urban:

- **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 managed Duwamish River. Failure of the Howard Hanson dam or the release of large volumes of water from the dam could affect the Duwamish River. (See Infrastructure Failures for more on dam failures).

- **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 suddenly 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. They map area that floods on average once every 100 years and once every 500 years. A 100-year flood is simply one that has a 1% chance of happening in any given year. 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 Sometimes casualties occur when floods develop rapidly, as in a dam burst or a flash flood. 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. 1993 flooding in Texas cut several large oil pipelines, releasing oil that later caught fire.

Coastal flooding is usually more violent along open coastlines. Storms push water ahead of them 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.

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. Recent catastrophic flooding like that on the Mississippi in 1993 has lead federal authorities to emphasize a suite of non-structural mitigation strategies, such as flood insurance, government buyouts and more restrictive land use planning.

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, i.e., 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 caused only localized structural damage and bank erosion[197]. The record of flooding in these areas is limited, but FEMA indicated there were 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 that lies at a low elevation along the Duwamish 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 and due to higher stream flow during a storm. Occasionally, the water level in the Duwamish rises above the level of the outfalls that drain the neighborhood and the drainage system backs up until the tide recedes.

December 14-15, 2006. Six landslides of various sizes as well as flooding to 300 homes were reported throughout the city due to intense rainfall (about 2.17 inches in 24 hours) and stormwater facilities strained beyond capacity. Usually, rainfall in Seattle is a few hundredths of an inch per hour. The peak of this storm was a swath through the middle of Seattle that produced an inch of rain in one hour.

Both Seattle City Light and Seattle Public Utilities 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.

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 have been on the Cedar River. The river flooded many times with major incidents occurring in 1975, 1990, 1995 and 1996. This flooding led to turbidity that impacted the city's ability to divert water due to the lack of filtration. These floods occurred in the winter when demand for water is low, minimizing impact. 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.

Likelihood of Future Occurrence

Seattle will experience flooding in the future. The principal unknown is the severity of future events. Seattle Public Utilities has examined the amount of rainfall collected in its gages between 1978 and 2007. It discovered a small but statistically significant trend towards short-duration, high-intensity events. 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 supported by the Washington Climate Change Impacts Assessment whose simulations "generally predict increases in extreme high precipitation over the next half-century, particularly around Puget Sound." (p2). Seattle Public Utilities is already upgrading the city's drainage system in critical areas.

Vulnerability

The National Flood Insurance Rate Maps and 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. The Flood Insurance maps are being updated as of late 2009. These maps show that the locations prone to flooding are quite limited. These areas are most vulnerable during the winter 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 stormwater detention basin on Longfellow

Figure 42. Flood Prone Areas

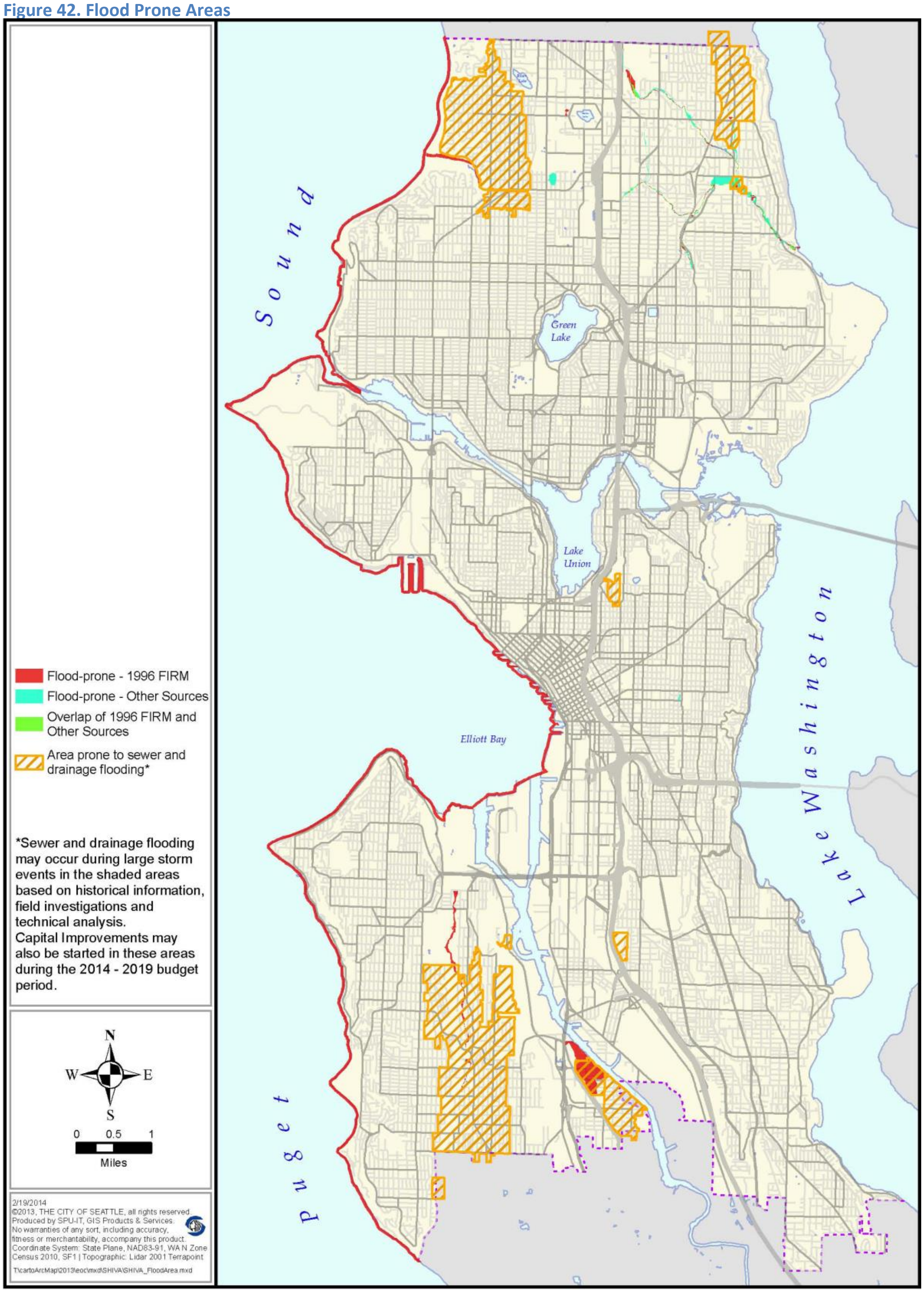


Table 48. Land Use in Flood Prone Areas

	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 43. Summary of Land Use in Flood Prone Areas

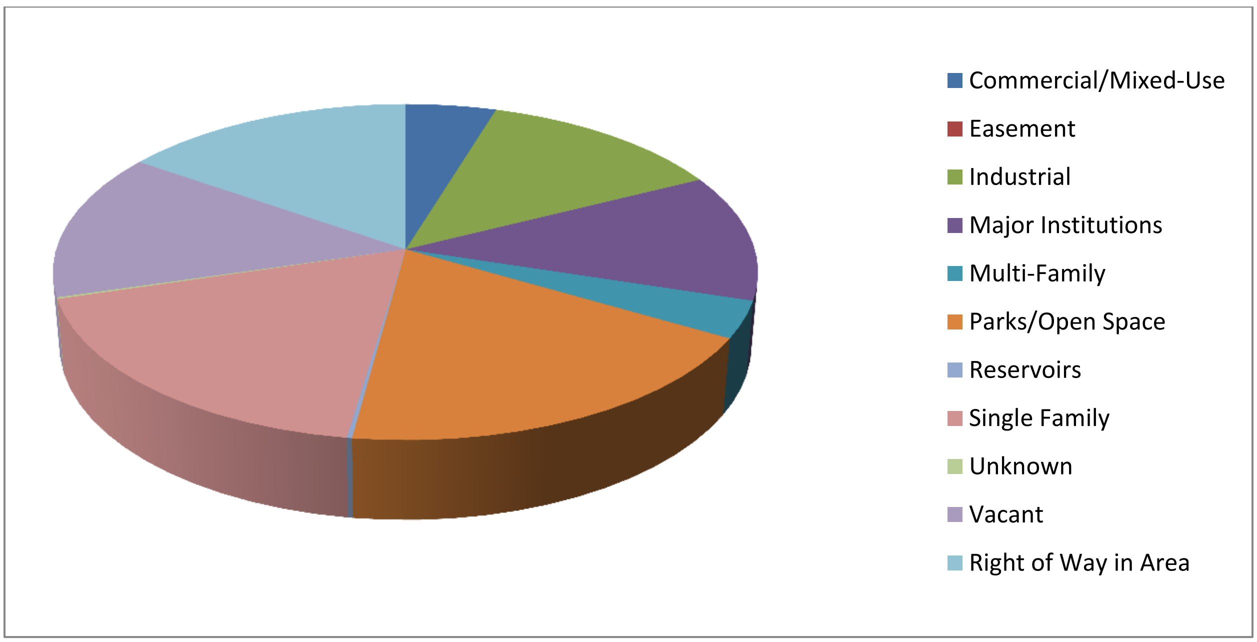


Table 49. Estimated Population, Buildings and Assessed Value in Property Touching on Flood Prone Areas.

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

* 1,722 represents the number of buildings on property that overlaps flood prone area even if the building itself is not in the flood prone area. The number of actual building that touch on the flood prone areas is 924.

Table 50. 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 51. Facilities with 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 52. Zoning in Flood Prone Area.

	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 53. 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 54. Wildlife Area in Flood Prone Area.

	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%

Creek. However, each has its limits. The Thornton Creek diversion is effective up to the 100-year flood; the Longfellow basin was only partially effective during the January 1986 flood[198].

The Howard Hanson Dam regulates the only large river in the city, the Duwamish. The dam's reservoir can usually contain the runoff and melt from winter storms, but it could fill if a huge snow pack melted rapidly during a very rainy spring. If the dam reaches its design capacity, it will have to release water. Seattle's South Park neighborhood could have flooding in this scenario, especially during high tides and heavy rain. The rest of Seattle would probably not suffer.

In 2009, a void was discovered in the Howard Hanson Dam. Concerns about its strength have 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 Corps of Engineers, the dam's operator, estimated a 1 in 33 chance of flooding due to releases. The dam was subsequently repaired successfully.

The failure of levees just outside the city limits could produce localized flooding at Boeing field and City Light facilities, but The Corps of Engineers reports that these levees are in good repair.

Another potential risk facing the city is the Hanson Dam's failure. A break would produce a massive, sudden flood. It would have a huge impact upstream, where most of the water would spill over into the Kent Valley. This upstream flooding would relieve pressure on downstream areas like Seattle. The Corps of Engineers estimates a catastrophic failure of the Hanson Dam would still produce crests five feet below flood stage within the Seattle city limits, including South Park.

The Cedar 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 lowest, water from Lake Youngs and the Tolt system can meet the full needs for water supply.

Table 55. Land Use in Urban Flood Area

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 44. Summary of Land Use in Urban Flood Prone Areas.

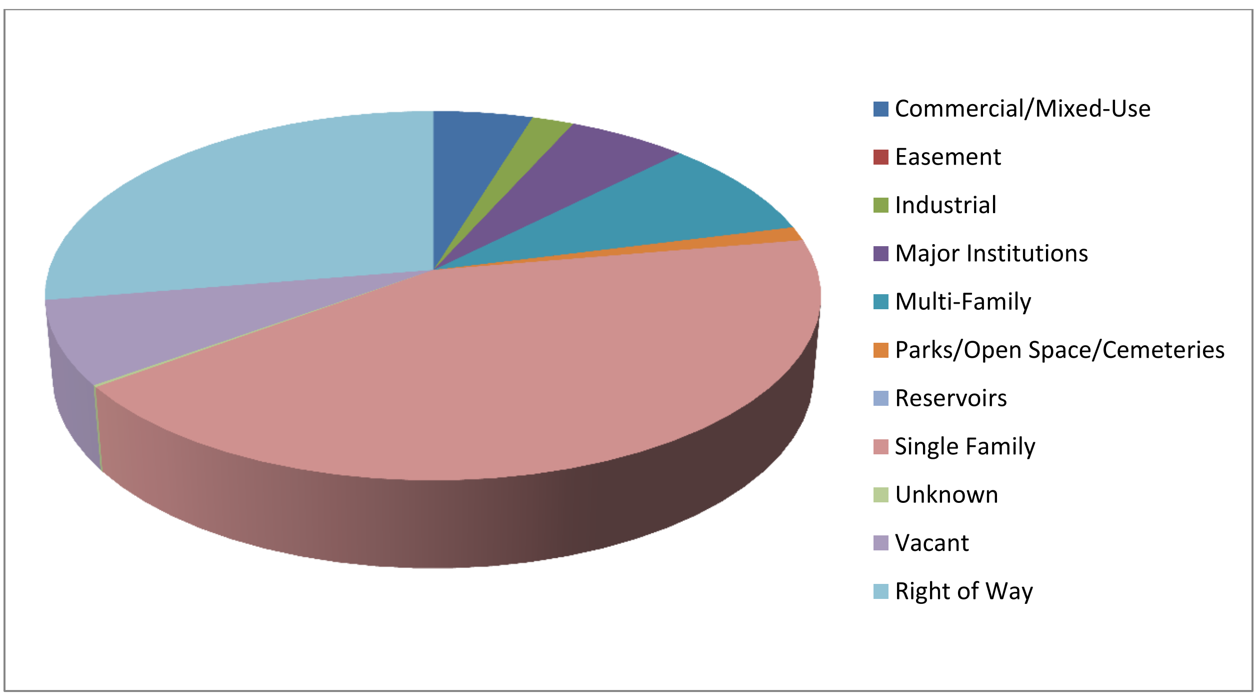


Table 56. Estimated Population, Buildings and Assessed Value in Urban Flood Area.

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 57. Critical Facilities in Urban Flood 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 58. 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***

Table 59. Zoning in Urban Flood Prone Areas.

	Acres	% of Seattle	% Area
Seattle	53178.37	100%	
Urban Flood Prone Areas	3312.57	6%	100%
Parcel area in zone	**2398.31**	**5%**	72%
Unzoned	0.03	0.00%	0.00%
Commercial - C1	122.87	0.23%	3.71%
Commercial - C2	6.24	0.01%	0.19%
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	14.29	0.03%	0.43%
Industrial Commercial - IC	0.00	0.00%	0.00%
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	11.93	0.02%	0.36%
General Industrial - IG2	55.19	0.10%	1.67%
Lowrise - LR1	102.94	0.19%	3.11%
Lowrise - LR2	97.21	0.18%	2.93%
Lowrise - LR3	167.23	0.31%	5.05%
Major Institution - MIO	82.89	0.16%	2.50%
Multi-Family, Midrise - MR	12.37	0.02%	0.37%
Neighborhood Commercial - NC1	2.96	0.01%	0.09%
Neighborhood Commercial - NC2	16.35	0.03%	0.49%
Neighborhood Commercial - NC3	25.08	0.05%	0.76%
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	762.17	1.43%	23.01%
Single Family - SF 7200	744.13	1.40%	22.46%
Single Family - SF 9600	174.43	0.33%	5.27%
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	**914.26**	**1.72%**	27.60%

Table 60. Growth Centers in Urban 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%*		
Urban Flood Prone Areas	3312.57	6%	100.00%	
Hub and Residential Urban Villages in Zone	476.88	0.90%	14.40%	8.35%
Urban Centers in Zone	16.32	0.03%	0.49%	0.44%
Manufacturing / Industrial Center in Zone	117.72	0.22%	3.55%	2.00%

Table 61. Wildlife Areas in Urban Flood Prone Areas.

	Acres	% Seattle
Seattle	53178	100%
Urban Flood Prone Areas	3312.57	6.23%
Wildlife Habitat Areas	3749.89	7.05%
Wildlife Habitat in Urban Flood Areas	188.67	0.35%

Coastal problems are the final item on this list of possible flood hazards. The National Flood Insurance Rate Maps show a coastal flooding hazard directly along the coast but not extending inland. Coast flooding has occurred along the west side of West Seattle when winter storms coincide with extra high tides known as 'King Tides'. The South Park neighborhood is also at risk from these King Tide events.

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, Magnolia and along Lake Washington, homes are built along the shore. These properties are exposed to coastal storm damage.

Many of the low-lying coastline areas, especially the more heavily used parts of the waterfront, are protected by seawalls. Some of these structures are aging and prone to failure during earthquakes.

Sea-level rise will make coast flooding worse. The estimate for the amount of rise in Puget Sound by 2050 range from 3" to 22," increasing by 2100to between 6" and 50"[199]. In the worst case scenario, seawalls could be overtopped, if not 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 City Light 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 coast flooding.
- The BNSF rail corridor runs along Puget Sound north of the Ship Canal are is exposed to flooding although landslides are a more common threat.
- Lake City Way and 35th Ave NE 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.

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 urban flooding becoming a larger threat. Flooding is frequently part of a larger storm event.

The sort of large events that Seattle is most likely to experience would be an extension of the sorts of events we have experienced in the past, not orders of magnitude worse. There is a very good chance that Seattle will experience more extreme weather events, although scientists are not certain. Seattle's drainage system is being retrofitted to add surge capacity. The challenge will be anticipating the amount necessary.

With the exception of the South Park community, 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 area. 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 Lake Washington or 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 Burlington Northern Railway might also be affected because of their proximity to the water.

The Duwamish Valley is not likely to flood, but if it did occur the results 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, adding another dimension to the city's vulnerability.

Other severe scenarios include coast erosion caused by coastal flooding supported by sea-level rise. Such events could endanger people living along the shore or near coast bluffs. The main danger is landslides, which in extreme cases can even generate tsunami.

Although the circumstances that led to the recent Madison Valley fatality are unusual in that the extra high curb structure functioned like a small dam, the fact that it occurred once means that it is possible for a similar set of circumstances to arise again. Lives as well as property are at risk due to flooding.

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'
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, Southpark 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.
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 Londfellow 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.

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 occurs during this period. In Seattle creeks flood. South Park is flooded due to the King Tide and drainage problems. Urban flooding in 12 locations. 36 major landslides 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 is has roots in a powerful storm that struck California in 1961-2. Furthermore climate data suggests that extreme precipitation *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 to expect.
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 of more 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 Southpark from their homes. Areas in the interior of the city flood when the drainage system becomes overwhelmed. Altogether 850 people need to be sheltered. 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 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.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	3	The storms have caused landslides and hazardous materials releases.

Conclusions

Flood control is an old activity in King County, including Seattle. Changes in the landscape, like the dredging and filling along the Duwamish, have reduced most of the immediate threat. 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, recent urban flooding incident point to a hazard that is shifting and exposing new vulnerabilities.

Snow, Ice and Extreme Cold

Key Points

- Most of the time Seattle's winter weather is controlled by the Pacific Ocean which remains relatively even in temperature throughout the year. Occasionally, however, 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 very 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[200].

- The main effect of snow is the impairment of transportation. Because nearly all social and economic activity is dependent on transportation, snow can have a serious impact. Most of the effects are cumulative, so the longer transportation is impaired, the greater the impacts.

- Some of the most 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 as some people attempt 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 close.

- Seattle does not have dedicated snow plows, trucks have to outfitted with snow removal equipment when snow threatens.

- Even with all trucks have been outfitted with snow removal equipment, there is not enough of them 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.

- The Seattle Department of Transportation and King County Metro developed new snow and ice plans following the challenges of the 2008 snow and ice storm. The new plans stress increased use of salt, more pre-staging of snowplows, better gathering of information about conditions of streets and buses and better communication with the public.

- 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.

Context

A 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 area 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 Cascades 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[201].

During major snows storms the transportation system shuts down, trapping people at home or work. Accidents rise among those who try to drive. Access to emergency services is 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, spikes in energy demand have reached crisis levels. During the 1993/94 winter, some parts of Pennsylvania had to ration power. Some poorer people and those on fixed incomes cannot afford the extra expense and must suffer through the cold.

Snow storms slow the local economy, but there is a debate about whether these slowdowns cause permanent revenue losses. Productivity and sales may decline but often accelerate after a storm. Some permanent effects may occur if some areas are accessible and some are not. For example, holiday shoppers may go to Bellevue to buy Christmas presents if they cannot get to Seattle stores. For workers, snow can be a hardship, especially for those who lack benefits and vacation time. For local government, responding to snowstorms can be a major unbudgeted expense. Some have even had to issue emergency bonds to cover recovery costs.

There is some evidence that widespread and lingering snow can act as a brake on economic activity. The Liscio Report, a private financial newsletter, found that during the cold and snowy winter of 1977/78 economy growth nationally slowed from 6-7% to 1% in the last quart of 1977 and 3% in the first quarter of 1978.

Snow, ice and cold also present health risks. Unfortunately, previous studies tending to downplay their consequences because few fatalities are directly attributable to the weather. As the analysis grew more sophisticated, researchers learned that indirect effects of the storms resulted in many fatalities, e.g., traffic accidents, sledding, exposure to cold, falls and carbon monoxide poisoning. Research by the National Weather Service has found that:

- Ice is more deadly 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 if the cold is accompanied by power outages. The primary danger is hypothermia. This danger is mainly to the homeless population and those without heat. The elderly and socially isolated are the most vulnerable.

Excessive cold especially when accompanied by wind can cause frostbite and hypothermia. Wind chill is the temperature it "feels like" outside and is based on the rate of heat loss from exposed skin caused by the effects of wind and cold. As the wind increases, the body is cooled at a faster rate, causing the skin temperature to drop. Frostbite is an injury to the body caused by freezing body tissue. The most susceptible parts of the body are the extremities, especially fingers, toes, ear lobes or the tip of the nose. Hypothermia is an abnormally low body temperature, below 95 degrees Fahrenheit. Warning signs include uncontrollable shivering, memory loss, disorientation, incoherence, slurred speech, drowsiness and apparent exhaustion.

History

The unofficial record for the most snow in one winter is 64 inches in 1880. The single-day record is 21.5 inches in 1916[202]. Other historical records that extend back beyond modern record keeping indicate that Seattle was colder and snowier in the past. Several authors mention extended periods of below freezing temperatures.

December 1861. Very cold, with an unofficial -4 degree temperature. Newspapers mentioned ice-skating on Lake Union covered in six inches of ice.

Winter 1880. Usually regarded as the snowiest winter in Seattle. An unofficial 64 inches 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 snowfall.

January 1943. Total of 18.4 inches in a 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. There is no indication if this was a record, but it does point out that Seattle snows can persist for weeks.

December 1964. Eight inches of snow fall.

December 1968 Ten inches fell on New Year's Eve. Despite the chances for increases in alcohol-related accidents, there was not a reported increase.

January 1969. 19 inches 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 fell on Thanksgiving Day.

December 1991. Snow closed SeaTac and brought traffic to a halt.

December 1996 Near record snow falls the day after Christmas. Metro halts service completely for the first time in its history. Freeze and snowmelt contribute to flooding and landslides during the following week.

December 2008. Seattle experiences a rare extended period of lingering snow.

The city's Snow and Ice Response Plan gives more detailed information for recent years. Data from the National Oceanic and Atmospheric Administration for the Seattle-Tacoma area shows that from 1990 to 2003 there were 146 days of snowfall. This includes 70 days when there was only a trace amount of snow. Of these 146 days, 131 had light snowfall of less than 1 inch and 22 had heavy snowfall of more than 1 inch[203]. Figure 4 indicates the snowfall from October through March between 1948 and 2009.

Likelihood of Future Occurrences

Seattle will continue to get snow storms, but the trend is uncertain. Detailed records in the Puget Sound region date back only 120 years. While climate change will increase the average annual temperature, the effects on snow events is less predictable. Mountain snowpack is predicted to drop dramatically as more precipitation falls as rain rather than snow.

Other global weather patterns will continue to overlay global climate change to complicate matters even more. 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 which works in a similar way to ENSO, but on a decade long scale[204].

It is possible that Seattle could get generally warmer winters but still have periodic large storms. It is also possible that Seattle could see a period of extended cold as occurred in the latter half of the 19th century and early 20th century.

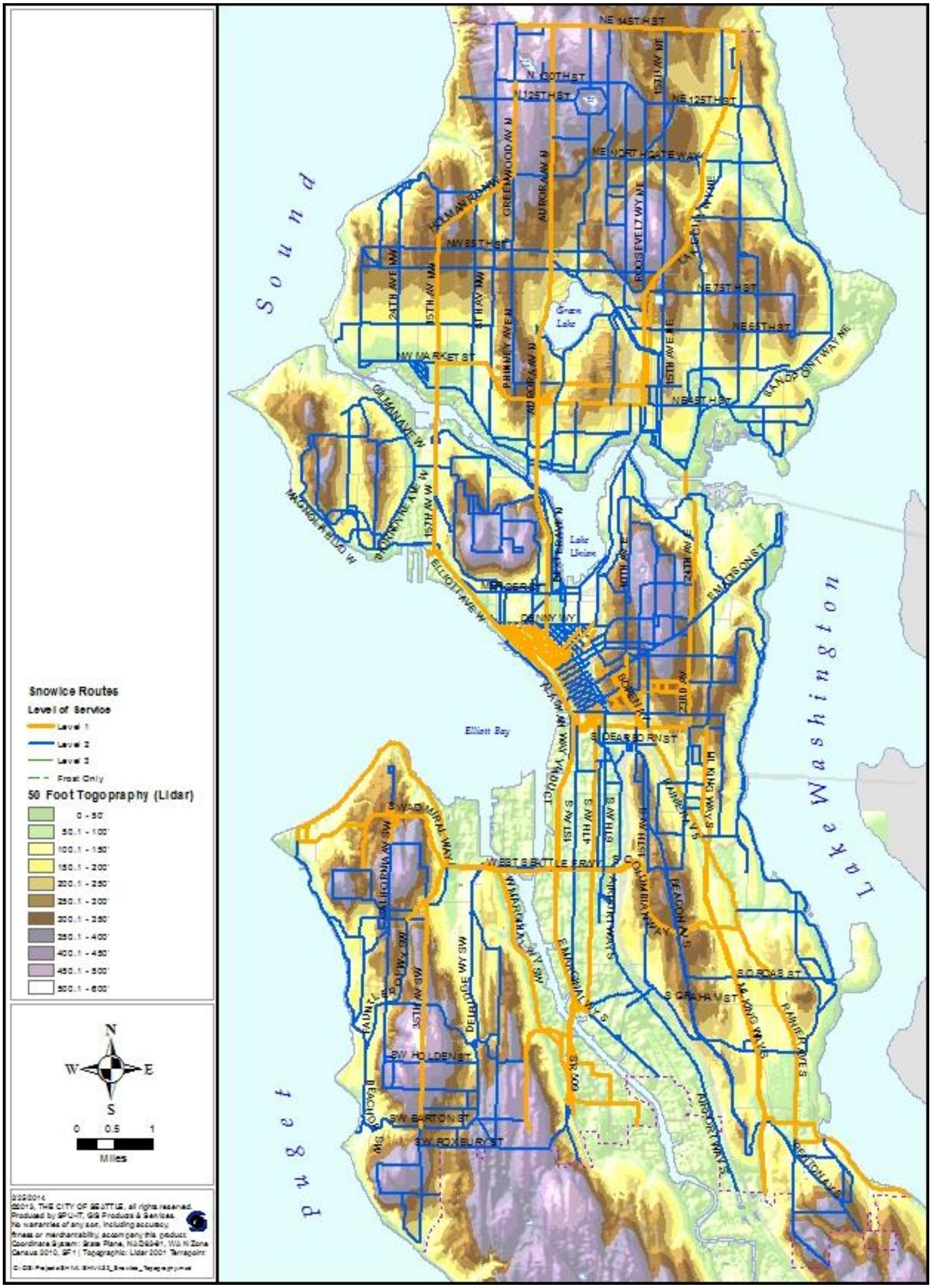
Vulnerability

Seattle's geology and climate work against it during 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. Finally, the lack of dedicated equipment adds to the city's vulnerability.

The city's poorer and older residents are the hardest hit. The homeless are the most vulnerable. Although attempts are made to find extra space for them in shelters, many are still on the streets even in harsh weather. People without back-up sources of heat will also 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. Older people 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, emergency department care and

Figure 45. Snow and Ice Routes by Service Level[205].



admission. This places an additional burden on the healthcare system in King County. Children are another risk group because they play along dangerous streets. Several have been killed in sledding accidents.

Several socio-economic groups have high exposure to winter storms. Seattle retailers are vulnerable because a major part of the snow season overlaps the holiday season. The loss of sales at this time can be critical. Seasonal, temporary, contract and other workers who lack paid time off lose income during snow storms.

Consequences

Snowstorms are a recurring hazard in Seattle. Their indirect, secondary effects outweigh their direct effects. The two biggest direct impacts are cold 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 will face 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.

Residents must be prepared for several days of restricted access to many services and shutdowns of schools and other institutions. Workers and business need to develop contingency plans to get people into work and open businesses.

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.

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 snowpack is reduced, City Light may have to purchase additional power from external sources to meet demand.

Secondary effects of snow 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

Because Seattle once had a colder, snowier period during the late 19th and early 20th century, Seattle must remain open to the possibility that such a period could return again. The more extreme winter storms of this period would present challenges to our more complex and time-dependent society. The types of impacts would be the same as the more likely scenarios, just worse.

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. 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).
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	1	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.
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 forecast. 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.

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. This scenario envisions a set of storms marginally worse than these 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.
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 short of food and medicine.
Economy	3	The storm hits during the December shopping season. Businesses cannot remain open. Major employers have to close.
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.
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.

Conclusions

Seattle does not sit in the Snowbelt and Seattleites do not have the experience of many Midwesterners and New Englanders. Seattle is a northern city, though, and 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.

Water Shortages

Key Points

- 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.
- It is extremely unlikely that Seattle would run out of water. To avoid failure of the water supply, a series of increasingly severe usage curtailments would be enacted to ensure that Seattle would have enough water for essential functions. While the curtailments would mitigate a greater disaster, they would have increasingly severe impacts on residents and businesses.
- The City of Seattle 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.
- Peak demand for water for people and businesses occurs in the summer. Replenishment of the city's reservoirs does not occur until the spring, however, when snow accumulated during the winter melts and runoff from rains is stored. Low winter precipitation followed by hot summer weather or later-than-normal return of fall rains can cause a shortage.
- A drop in 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.
- During shortages, the City of Seattle undertakes "Phased Curtailments" in four stages: Advisory, Voluntary, Mandatory and Emergency. Restrictions may begin to impose hardships on the community during the Mandatory and Emergency Phases.
- 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.

Context

Water shortages develop when the supply of water is too low to meet demand. The cause can be either a drop in supply or 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.

The city manages its reservoirs in the Cascades to provide water supply for consumption and fisheries, as well as to provide flood management and hydropower generation. During the spring, the city captures runoff from melting water from the winter snowpack and rainfall and stores the runoff in city-owned reservoirs. Water is stored there until the demand increases and releases from storage are required. During times of 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.

The city draws most of its water for direct consumption from two watersheds in the Cascades—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 Highline wells provide water in emergencies and peak water use periods[206]. This water is delivered to Seattle's retail customers and SPU's wholesale customers through large diameter pipes.

As for power, City Light gets most of the power it generates from dams on the Skagit and Pend Oreille River. When the amount of water in the reservoirs drops, City Light cannot generate as much power. When peak demand exceeds supply, City Light 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. There is always doubt 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 the drought is well underway. SPU and City Light, with real-time information about snowpack known, can forecast supply for the summer. 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 more stringent restrictions.

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 due to 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 and 2005, annual water consumption decreased about 24% (40 million gallons per day), even while population increased by 13%.

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 million gallons per day (mgd), compared with only 270 mgd during an extremely hot summer 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.

Droughts do not necessarily cause water shortages, so the existence of one should not be taken as proof of a shortage. Droughts do often contribute to shortages, though. 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), although numbers beyond these bounds can occur. 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, which is important for Seattle's water supplies[207].

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.

Public inconvenience is the most visible and widespread effect of a shortage. If the public is not aware of the severity of the shortage, it will not be inclined to support restrictions. Most residents define a shortage differently than city officials. While the city defines shortages by the amount of supply, the public defines them in terms of the severity of restrictions.

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. Here are the most important events:

1919. A hot, dry summer.

1928/29. This was a long drought that lasted nearly one year. 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. At the time, it was a record dry growing season in Western Washington. 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. The war years were dry ones. 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 lack of winter precipitation was a possible reason that the state ordered power cuts for hydroelectric dams.

1965/66. The entire state was dry. 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% and 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[208].

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 Seattle Water Department (now SPU) 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%. However, November was an off-peak month 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 in1992.

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 in early March. 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%.

2005. The worst snowpack in 60 years of record keeping occurred 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.

Shortages seem to occur once every five to ten years. In most cases, water shortage response actions were implemented during the summer. Unfortunately, the extent of the damages is difficult to determine due to lack of information. The most severe shortages were the result of either low snowpack or dry fall conditions. Often SPU's water utility was the only City-system impacted; in at least two cases, during 1952 and 1977, City Light was also affected. This data suggest some patterns of vulnerability that the next section will explore.

Likelihood of Future Occurrences

The Washington Climate Change Impacts Assessment (WACCIA) conducted an analysis of the effects of climate change on Seattle's water supply. The authors defined system reliability as the percentage of years within their model in which there were no municipal and industrial delivery shortfalls. They found that, given current demand, reliability remains at 99-100% even through 2080. These estimates deal with long-term reliability.

Summer and fall reservoir draw-downs are likely to become more extreme. The same analysis found that Seattle's system currently has a 34% chance of being half full and a 1% of being a quarter full. By 2020, less reserve is likely and these numbers increase to 49% and 4%, respectively[209].

Demand is the critical variable. Total consumption or demand is falling, despite population growth, but consumption can still spike, especially during the 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.

If demand rises instead of continuing to fall, Seattle could face long-term challenges in meeting demand. In the worst case, the WACCIA estimates that a 50% increase in demand, a high carbon dioxide emissions scenario and no increase in supply would combine to degrade the reliability of the water supply to 38% by 2080.

The challenges are different for City Light. Historically, its peak demand is in the winter when stream flows are also at their peak. Demand peaks in summer are checked by the limited, 8% - 10% market penetration of air conditioning systems locally. The WACCIA forecast 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. The authors caution that, in the near term, annual production will be more influenced by other factors, like the El Niño/La Niña phenomenon, than climate change.

On the demand side, population increases will lead to an increased demand for heating even as per capita demand goes down due to warming winter temperatures. Energy demand for cooling is projected to increase rapidly as more people acquire air conditioning. Taken together, these projections suggest that adaption to climate change will be easier in the winter than the summer.

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. The reason is that 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[210]. 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; City Light'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 the most recent challenge for the utilities. To create these flows, Seattle Public Utilities and City Light 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.

Water shortages also harm Seattle's utilities and their rate payers. Both Seattle Public Utilities and City Light are publicly owned utilities, so their financial difficulties can be transferred to their customers.

Chance of a water shortage endangering public health and safety is remote. A shortage could indirectly expose Seattleites to harm if it contributes to power failures, if low stream flows suppress power production at a time of peak demand, or to fires due to low water pressure or dry vegetation.

Consequences

Seattle has a water shortage risk that is likely to increase with climate change; however, an even bigger driver will be demand increases. With good planning, it will be possible to boost supply or enact conservation measures to address demand increases. Seattle has two distinct water shortage hazards: water for direct consumption and water for power production.

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. More likely is 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 be indirect increases in 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.

Most Likely Scenario

Low snowpack followed by hot, dry summer and cold fall. Water levels in the Cedar fall below 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. 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 region 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.

Category	Impacts 1 = low 5 = high	Narrative
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 curtained 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 shortages doesn't have any significant impacts on the transportation system
Critical Services and Utilities	3	The primary impact is on water service. City Light must curtail power generation to preserve stream flows for endangered salmon. 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.
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.

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. 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.
Geographic Scope	5	The drought and water shortage are region wide.

Category	Impacts 1 = low 5 = high	Narrative
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. 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. City Light is able to maintain power without curtailments, but implements surcharges. Due to prioritization water pressure remains adequate for firefighting and public health.
Confidence in Government	3	The public understands the severity of the drought and water shortage, but the increasing bite of curtailments and the implementation of surcharges is not popular. Many are convinced that government could do a better job shielding the public from the costs of the shortage.
Cascading Effects	2	The extreme dry weather contributed to a serious brush fire. The fire was not a disaster by itself.

Conclusions

Experience suggests that Seattle Public Utilities and City Light can manage most 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.

Windstorms

Key Points

- 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.
- 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 an event that includes flooding, landslides and power outages.
- Tornadoes are very rare in the Puget Sound region but have occurred. Washington ranks 43rd in tornado frequency. Between 1950 and 2005 there were 94 tornados in Washington, compared to 3,204 in Kansas. Most were weak. Those in the Puget Lowland were mostly associated with the Puget Sound Convergence Zone[211].
- Puget Sound is sheltered compared to the Washington Coast, but it can still received sustained winds of 60-70 mph and gusts up to 90mph[212]. Local terrain has a strong effect on wind speeds. Winds speed up as they move over hills and ridges.
- Power outages are the most significant problem causes by windstorms. The 2006 storm overwhelmed City Light when 49% of customers lost power. While 95% of customers were restored within two days, full restoration took a week.
- 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.
- Structural 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.
- Much of the damage in windstorms comes from falling trees. Areas with heavy tree cover and limited street connections to the rest of the city are vulnerable to power outages and transportation problems.
- Large windstorms are regional events. The more heavily forested areas in the suburban areas are often hit even 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. The SR520 Bridge is closed when wind speed reaches 50 mph for 15 minutes. This most recently occurred during the 12/14/2006 storm.
- Scientists project that large windstorms will become less frequent but more intense.

Context

The Pacific Northwest can sometimes receive violent windstorms that reach hurricane strength, but it is not subject to hurricanes like the East Coast. These regional storms are known as 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. Areas of low pressure lie at the center of the storms. Theses lows can exceed those of weak to moderate hurricanes.

Tropical cyclones can become mid-latitude cyclones when they push into the mid-latitudes (30˚ - 40˚) through a process called *extra-tropical transition* (ET). The Western 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.

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 is known formally as the El Niño Southern Oscillation or ENSO. It has an effect on the development of major windstorms. The cycle is typically three to seven years. Most major storms occur in the "neutral" years between the two extremes. 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.

These powerful storms are different from this area's typical winter storms, although both approach Washington from the southwest. Typical "Pineapple Express" storms here have much weaker although still considerable winds and often much more water. They occur when the Jet Stream funnels clouds up from the moist tropics to Pacific Northwest. Typically, these common storms cause much more flooding and landslides than mid-latitude cyclones.

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.

Juan de Fuca Strait Wind Surges

The Strait of Juan de Fuca can act as a wind funnel in the right conditions. In winter a strong surge can push sustained wind speeds to 50 – 70 miles per hour and gusts to 70 – 80 miles per hour. 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, routines 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 miles per hour 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.

History

The Pacific Northwest is periodically hit by mid-latitude cyclones and other more localized wind events. The coast usually records more violent winds, but the Puget Sound has also has its share of powerful storms.

Most storms happen in late fall and winter. Of the nine major storms to hit Seattle since 1962, seven have occurred in winter. The other two occurred in early fall and early spring. Nearly half happened in November, while two struck in February.

1943. Official records at the Federal Building show one occurrence of 65-69 mph winds[213]. 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[214].

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. "Columbus Day Storm". It had 85 miles per hour 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. Main trunks carrying power to Portland were destroyed.

12/12/1969. Tornado strikes the Kent valley. The storm causes 1 injury and no deaths. 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 breaks apart in a violent storm.

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.

11/14/1981. This storm caused power outages, closed the bridges, and damaged buildings.

11/24/1983. "Thanksgiving Day Storm." This storm surprised even the National Weather Service, revealing that long warning periods cannot always be counted upon. 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.

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. (See Infrastructure Failure).

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 Inaugural Day Storm." Massive outages occurred 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 in the Puget Sound gusted to 60-70 miles per hour.

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 1.5 million customers were without power throughout western Washington and Oregon, 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 tempest.

Likelihood of Future Occurrence

While there has been a projection that violent storms will increase in frequency and intensity globally, trends for mid-latitude cyclones in the Eastern Pacific have shown a *decrease* in frequency but an *increase* in intensity. (Dello, 2010)

Vulnerability

Trees and wet soils make windstorms worse in the Pacific Northwest. The northwest's tall conifers are often shallow rooted and prone to being uprooted, especially when the ground is saturated with water. Unfortunately, the ground is often saturated in the late fall and winter when the majority of these powerful storms arrive. Seattle has fewer trees than suburban and rural areas, but it still has substantial numbers of them.

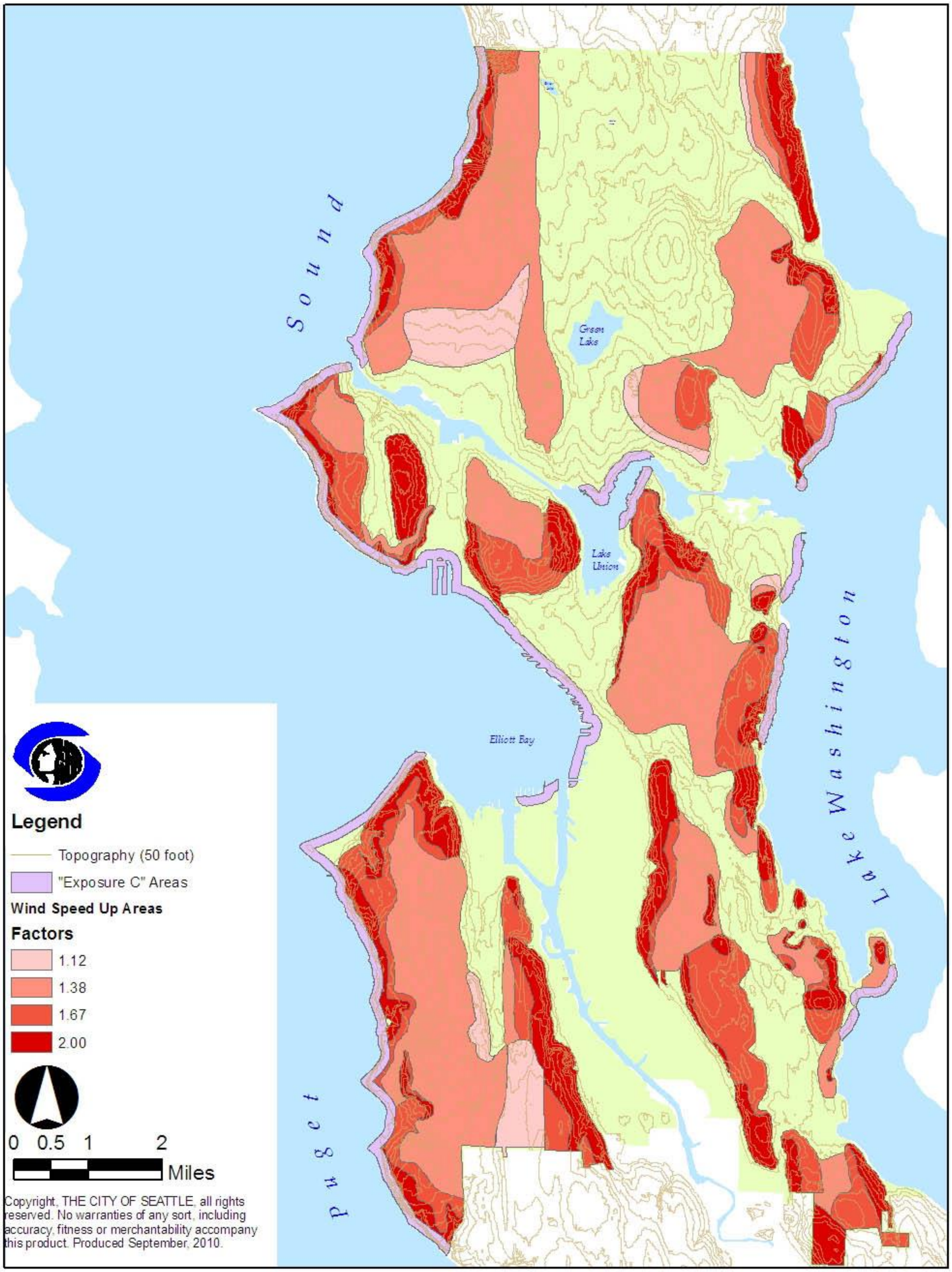
Falling trees and branches are the major hazard in windstorms. They snag power, cable television and telephone lines and bring them down, causing outages. When they fall across roads, they interrupt transportation. A downed tree can usually be cleared quickly; when accompanied by downed power lines, the job takes much longer. Finally, trees pose a direct hazard to homes.

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 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 Figure 46 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 miles per hour.

Areas with limited access, such as Magnolia, can become isolated if trees fall on the few roads that lead into them. This information suggests that North and West Seattle have a higher vulnerability than the rest of the city since they are the most heavily forested.

Wind driven waves are another hazard for the city. Large waves can endanger the floating bridges. On average, more than 260,000 vehicles move over these bridges daily[215]. This traffic gives them enormous socioeconomic importance. Their susceptibility to damage and their value to the local economy make them vulnerabilities for Seattle.

Figure 46. Wind Speed Up Areas[216]



During the 1993 Inaugural 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 more than superficial damage, e.g., both of the floating bridges across Lake Washington, I-90 and SR 520, had damage to pontoons that keep the bridges afloat[217]. 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, the rain can lead to urban flooding and landslides while extreme cold will increase the hardship caused by power outages.

Consequences

Windstorms are a regular part of Pacific Northwest weather as are rain driven flooding and snow. There is research to suggest that mid-latitude cyclones, the cause of our most damaging storms, may be increasing in intensity[218].

Windstorms cause direct physical damage to structures, infrastructure for power and telecommunications and coast bluffs. They 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 expense 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 miles per hour can drive objects through walls[219]. Other research shows that wood-frame and unreinforced masonry structures can be damaged or even destroyed at speeds less than 100 miles per hour 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 miles per hour[220]. In Seattle, winds have exceeded this threshold 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.

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, sections of dozens of major arterials and hundreds of neighborhood streets were blocked, mostly by fallen trees. An estimated 700 trees fell on public property.

Power outages are another widespread problem. Parts of the Eastside lost electricity for days after the 1993 Inaugural Day Storm. These outages also affect traffic lights, making driving a long and difficult process. Finally, 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 damage is more likely to be higher damage from windstorms. While windstorms are always dangerous, their main effect has been economic.

If it is true that mid-latitude cyclones are increasing in intensity and number, Seattle could face a storm even stronger than the Columbus Day Storm. When combined with Seattle's density and aging infrastructure, especially SR 520 and seawall, the consequences of such an intense storm could be large. If Seattle experienced a "super storm," it could cause major building damage, widespread power outages, infrastructure damage, landslides, coastal flooding and transportation gridlock. With increased structural damage, it is likely that the number of injuries and fatalities would also increase.

Most Likely Scenario

Seattle faces another storm similar to the 1993 or 2006 storms: numerous downed trees, scattered outages, limited structural damage. City Lights aggressive tree trimming mitigates power outages and its power outage management system speeds restoration.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	The Seattle had experienced major windstorms nearly every decade. The impact of climate change is not clear, but some evidence suggests that it could increase the frequency and intensity of mid-latitude cyclones which are the Pacific Northwest's source of major wind storms.
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. 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.
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. City Light tree trimming operations 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	1	Aside from the power outages which are the major impact of the storm, it does not cause any secondary effects.

Maximum Credible Scenario

Climate change fuels a mid-latitude cyclone even stronger than the 1962 Columbus Day storm. Winds are recorded at 90 mph at West Point. The ground is saturated from previous heavy rain. Many trees down and power lines down. The whole region is affected. Waves damage a floating bridge heavily. The storm hits during a king tide causing heavy coastal flooding. Several piers on waterfront affected.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	This storm is record setting. One this powerful has never occurred but there is evidence to suggest that mid-latitude cyclones will increase in intensity.
Geographic Scope	5	This storm is massive. It affects the entire Pacific Northwest coast from Oregon to British Columbia. Coastal areas receive the strongest winds of 120 mph. The storm maintains strength far inland and affects areas east of the Cascades as well.
Duration	2	The storm itself lasts for 10 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 65 people. In Seattle itself, there are 9 fatalities.
Displaced Households and Suffering	3	Building damage, power outages and urban flooding drive 95 people from their homes. 25% of the city loses power. 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 more business have serious physical damage. Many lack adequate business continuity plans. 25% of the businesses without plans that are damaged fail.
Environment	3	The storm produces massive amounts of debris. Most is natural but non-compostable debris must be transferred to landfills. Secondary hazards (landslides, transportation accidents) have caused hazardous material spills. Heavy rain preceding the wind has caused urban flooding. Flood waters contain sewage from broken waste water lines.
Structures	3	Thousands of buildings have roof damage. Most damage is minor but 128 buildings have to be yellow tagged and 32 are red tagged. 50% of the city is without power. Urban flooding impacts another 45 structures. Coastal flooding damages two piers downtown.

Category	Impacts 1 = low 5 = high	Narrative
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. Landslides have damaged several major roads and bridges. The airports and marine ports are able to resume operations quickly after the storm.
Critical Services and Utilities	4	Power outages are major problem throughout the city. 50% of the city loses power. Public safety responders have a difficult time reaching many 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	4	The storm causes many secondary effects: landslides, urban flooding, coastal flooding and hazardous materials incidents.

Conclusions

The Pacific Northwest is prone to violent windstorms. Although it is difficult to predict trends, the data suggest an increase in intensity of windstorms. As Seattle grows, so will the damage caused by them.

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Endnotes

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[4] (Emergency Management Accreditation Program) p2. 'Disaster' is used here as a term of convenience that includes 'incident' and 'catastrophe' unless otherwise stated.
[5] (Emergency Management Accreditation Program)
[6] It also depends on who works in and visits it, but the data to analyze this vulnerability is harder to obtain.
[7] (Jones and Mars)
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[9] (Baum, Godt and Highland)
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[12] (Baum, Godt and Highland)
[13] (Western Regional Climate Center)
[14] (Western Regional Climate Center)
[15] (Western Regional Climate Center)
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[19] (Seattle Urban Nature)
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[149] Because the nature of the tsunami depends on the initial deformation of the earthquake, which is poorly understood, the largest source of uncertainty is the input earthquake. The earthquake scenario used in this modeling was selected to honor the paleoseismic constraints, but the next Seattle fault earthquake may be substantially different from these. Sherrod and others (2000) show that an uplift event at Restoration Point predating the A.D.900–930 event was smaller. Trenching of subsidiary structures to the Seattle fault that are thought to be coseimic with the main fault trace (Nelson and others, 2002) indicate that there were at least two earthquakes in the 1500 years before the A.D. 900–930 event. These, however, did not produce prominent uplifted wavecut platforms similar to the one made by the A.D. 900–930 event, suggesting that significant earthquakes have occurred on the fault that had different and smaller uplifts in central Puget Sound.
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[161] Barberopoulou, 2009
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[163] Titov et al, 2003
[164] CDC, 2013

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[165] Estimates are based on extrapolation from past pandemics in the US, and do not include the potential impacts of interventions not available during the 20th Century pandemics. The calculations used to determine the figures in this table are based on the following assumptions:
·King County accounts for 0.6% of the total US population.
·Susceptibility to the pandemic influenza subtype will be universal.
·The clinical disease attack rate will be 30% in the overall population. Illness rates will be highest among school-aged children (about 40%) and decline with age. Among working adults, an average of 20% will become ill during a community outbreak. Of those who become ill with influenza, 50% will seek outpatient medical care.
[166] Janowitz, 1969
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[186] Some incident locations are plotted on top of each other. As a result an area may seem to have a higher density than the number of incident locations seems to indicate.
[187] King County, 1994.
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[196] Kalkstein and Greene, 1997. and Davis et al., 2003a. Although differences in the time series, definitions of urban populations, and other analytical methods prevent an exact comparison of results from Kalkstein and Greene *(1997)* and Davis et al. *(2003a)*, their other findings correspond closely.
[197] FEMA, 1994
[198] FEMA, 1994
[199] University of Washington Climate Impacts Group and the Washington Department of Ecology, 2008
[200] Mass, 2009.
[201] Mass, 2009.

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[202] Mass, 2009
[203] Seattle Transportation, 2003
[204] Mass, 2009.
[205] Definition of Service Levels:

1. Bare pavement within eight hours over all land on the most critical arterials as soon as there is a significant lull in the in storm.
2. Bare pavement within eight hours for one lane in each direction on selected major arterials and remaining King County/Metro Transit (Metro) winter storm bus routes, as soon as there is a significant lull in the storm.
3. De-ice hills, curves, bridges, and controlled intersections as soon as there is a significant lull in the storm.

[206] Seattle Public Utilities Department, 1993
[207] Wilhite, 1993.
[208] Forbes and Pond, 1977.
[209] Washington Climate Change Impact Assessment, 2009. P122.
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[211] Mass, 2009.
[212] Mass, 2009.
[213] US Weather Bureau, 1959.
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[216] The map shown is a resource for engineers designing structures for wind loads in Seattle. It shows wind exposure and terrain adjustment factors, was derived from the wind load provisions in ASCE 7-02, and is appropriate for those using ASCE 7 or SEAW's Rapid Solutions Manual in their designs.

The color-coded areas identify wind speed-up areas in Seattle, with acceptable Kzt values and areas defined as being Exposure Category C. The Kzt values will be accepted by DPD as default values for Kzt in lieu of the calculated values required by Section 6.5.7.2 of ASCE 7-02. Similarly the areas identified as Exposure Category C will be accepted by DPD in lieu of a determination required by Section 6.5.6.3 of ASCE 7-02. NOTE: There are no areas in Seattle that DPD requires to be considered as Exposure Category D.

[217] (Dello)
[218] Graham and Diaz, 2001.
[219] Marshall, 1993.
[220] Liu, 1993.

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