Hazard Identification & Vulnerability Analysis

City of Seattle

Seattle Police Department

Emergency Preparedness Bureau
Emergency Management Section

Seattle Emergency Management

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February 2004

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Emergency Management Section
(206) 233-5076
seattle.gov/emergency_mgt

Cover photo: Erik Stuhaug

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Executive Summary

Seattleites enjoy great access to economic opportunities, to medical services, to communication facilities, shopping, culture, and education. Unfortunately, the very factors that provide this abundance create vulnerabilities by concentrating population, infrastructure, and service centers. In the past the federal government has come to the aid of urban areas, but reimbursement of disaster costs has become a political issue in the Congress as more emphasis is placed on mitigating disaster effects rather than rebuilding vulnerable structures with generous federal aid. Consequently, it is now unwise to expect large amounts of assistance.

Emergency Management in Seattle

Seattle's emergency management system is designed to pro-actively devise and implement policies to cope with large-scale hazards. However, despite many improvements, much of Seattle's system remains fragmented. Mitigation is still decentralized with many government and non-profit organizations designing their own policies without systematic coordination. One of the chief roles of emergency management should be to collect and organize broad mitigation strategies.

Recovery is much the same, although the Winter Storms of 1996/7 prompted new interest in recovery planning. Resources and strategies need to be identified before the emergency.

Chapter Summary

This document provides a narrative assessment of the history of hazards in Seattle and the city's exposure to them. It is a tool that can be used to build an emergency plan around the most dangerous disasters the city faces. The following is a summary of the chapters in this analysis.

Conditions Affecting Vulnerability in Seattle.

This section summarizes the conditions that produce vulnerability within the city. The city is broken into three components: the natural, built, and social environments. Analysis of each component shows how characteristics of Seattle itself can increase or decrease the impacts of hazards.

Aircraft Accidents

There have been three major aircraft accidents within the city involving ground casualties. The city's deadliest disaster was a plane crash that occurred in 1943, killing 32 people in the air and on the ground. Areas in the Southern Duwamish Valley are the most vulnerable. A crash could cause fatalities, fires, power outages and other disruptions.

Civil Disorder

Like many other American cities, Seattle has suffered from civil unrest. The most recent episodes were related to the World Trade Organization held in 1999 and the 2001 Mardi Gras celebration in Pioneer Square. Previous Seattle disorders centered on Downtown and Capitol Hill. Violence targeted against people has been rare and looting light, but fires were a significant threat. Response to large disorders could require an enormous expenditure of money and time to control.

Conflagration

Conflagrations are rare in modern, developed cities, but could happen after an earthquake or during civil unrest. Ignitions could occur throughout the city simultaneously. A 1994 study (EQE) estimated that 80-100 fires could occur in Seattle following a large earthquake. Such a large number of fires could overwhelm the capabilities of the Fire Department. Fires in the city's power distribution network can create large power outages.

Earthquakes

Earthquakes are the most destructive hazard Seattle faces. Three major quakes have struck Seattle since the beginning of the century (in 1949, 1965 and 2001). Recently, geologists have found evidence of massive earthquakes off the Washington coast and along a fault (the Seattle fault) that runs through the center of the city. These findings are discussed in greater detail in the section devoted to earthquakes. The bulk of potential damage from a major earthquake would come from building collapse, landslides, fires, land subsidence, and even a tsunami or seiche (a large oscillation in an enclosed body of water). Casualties could exceed 1,000 people, and economic damage could easily run into billions of dollars.

Floods

Seattle does not have a large flood problem within its city limits. The Duwamish has been dredged and is regulated by the Hanson Dam. Thornton and Longfellow Creeks have flooded in the past. However, Seattle Public Utilities has built control structures on both creeks. Past flooding in these areas was usually not severe and was limited to local areas.

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.

Hazardous Material Incidents

A hazardous materials incident is generally described as the intentional or accidental release of toxic, combustible, illegal or dangerous nuclear, biological or chemical agents into the environment. Most incidents happen at fixed sites, but incidents involving transported hazardous materials are often more dangerous, since they occur in less controlled environments.

Landslides

Landslides are a common problem in Seattle – and are secondary to other hazards, such as earthquakes and storms. Most slides are small enough that they do not create city-scale emergencies, but occasionally weather and soil conditions cause slides throughout the city within a short period of time. Slides can destroy buildings, block roads and sever lifelines. The main impacts are economic.

The city recognizes that landslides are a complex problem. Following the major slides of 1996/97, it convened an Interdepartmental Landslide Team to address this problem. In addition, USGS monitoring of rainfall and soil conditions, along with new landslide susceptibility maps, add new accuracy to the city's predictive ability.

Snowstorms

Once every four or five years a major storm paralyzes the city. The immobility causes economic damage and inconveniences for many. The snow can also cut power and phone lines, topple trees, and even collapse roofs. Seattle has snow removal equipment, but it must be placed on vehicles that are normally used for other purposes.

Terrorism

In recent years, Seattle has experienced a number of terrorist incidents perpetrated by right-wing hate groups, eco-terrorist groups and others. During the November 1999 World Trade Organization (WTO) and again in 2001, suspected Earth Liberation Front eco-terrorist attacks occurred at the University of Washington's Center for Urban Horticulture. In December 1999, Ahmed Ressam was caught smuggling bomb-making material into the country through Washington State. His arrest raised fears that Seattle had become a terrorist target, although it was later determined that the actual target was Los Angeles.

The 2001 attacks on the World Trade Center and the Pentagon brought heightened awareness of the possibility that any large city like Seattle could become a target. In the aftermath of 9-1-1, Seattle has also taken the threat of bio-terrorism seriously. In addition, cyber-terrorism is an increasing threat.

Tornadoes

One tornado touched down in Seattle in 1962 and another struck nearby in 1969. A tornado killed six people in Vancouver, Washington. While tornadoes rarely occur in our area, the National Weather Service notes an increase in tornado sightings – speculating that the increase may be due to a growth of the region (hence more reporting) rather than weather patterns. If this is true, tornadoes were under-reported in the past and may be more common than previously thought.

Tsunami and Seiches

Tsunami, or 'tidal waves,' are the product of earthquakes or large landslides. They contain a massive amount of wave energy and travel at high speeds. When they strike land, they push water with tremendous force far inland. The generation of a tsunami is complex, but usually an earthquake must be large (magnitude 7.0 or over) and shallow to cause a dangerous tsunami. Some scientists think that an earthquake along the Seattle Fault has produced a tsunami and could do so again.

Seiches develop when an enclosed body of water is shaken. They are rare occurrences in our area. An 1891 earthquake produced an eight-foot seiche on Lake

Washington, and the 1964 Alaskan quake generated seiche-caused damage around Lake Union.

Volcanic Eruptions

There are five active volcanoes in Washington State. All of them are too far away from the city to cause any blast effects. The most probable impact is ash. Mt. Rainier and Glacier Peak are the most likely sources. Ashfalls from Rainier's most recent eruptions have been light, but Glacier Peak's have been some of the heaviest in the Pacific Northwest. Heavy ashfall could paralyze the city, damage infrastructure, and cost millions of dollars to clean up.

Water Shortages

Urban water shortages result when water demand exceeds supply over an extended period. Unlike the other hazards covered in this report, droughts are slow-onset emergencies. Seattle has a history of water shortages. The main impacts are the inconveniences of usage restrictions and economic hardship for some businesses that use large amounts of water. In 1993, the Seattle Public Utilities adopted a plan to mitigate water supply problems. Water shortages are also associated with earthquake damage to water supply and distribution systems.

Windstorms

Sustained winds of 85 mph have been recorded in the Seattle area. Normally, the hilly terrain breaks up strong winds, but there are occasional strong storms that halt normal activity throughout the city. They cause widespread line damage and power outages due to toppled trees and broken tree limbs. The City of Seattle has programs for vegetation management that serve to mitigate damage to electrical systems during windstorms.

Future Directions

All of the hazards addressed in this analysis are long-recognized risks to safety, but future work may want to consider other types of crises, such as a governmental financial emergency or a severe economic recession. Changes to conditions in Seattle that affect vulnerability should continue to be monitored as the city grows in population and economic importance. The emergency management system must continue to be well supported to ensure it can adapt to the new challenges the city will face.

Hazard Summary Tables

Table 1. Hazard Relationships

	Aircraft Accidents	Civil Disorders	Conflagrations (Fires)	Droughts	Earthquakes	Floods	Haz-Mat Incidents	Landslides	Snowstorms	Terrorism	Tornados	Tsumanis and Seiches	Volcanoes	Windstorms
Aircraft Accidents	■		■				■							
Civil Disorders		■	■											
Conflagrations (Fires)			■				■							
Droughts				■										
Earthquakes			■		■		■	■				■		
Floods						■	■	■						
Haz-Mat Incidents							■							
Landslides						■	■	■						
Snowstorms						■		■	■					
Terrorism	■	■					■			■				
Tornados							■				■			
Tsumanis and Seiches							■	■				■		
Volcanoes						■	■	■					■	
Windstorms						■			■					■

Table 1 summarizes the relationships between hazards Seattle has historically experienced. Often the primary hazard event triggers other problems, called "induced" hazards. For example, earthquakes may trigger fires, hazardous materials incidents, landslides, tsunamis and seiches. Winter storms can trigger landslides and power outages.

Table 2. Hazard Impacts

	Expected Impacts											Potential Impacts										
	Area Affected	Safety	Economy	Utilities	Transportation	Structures	Social Services	Medical Services	Psycological	Secondary Imapacts	**Average Score**	Area Affected	Safety	Economy	Utilities	Transportation	Structures	Social Services	Medical Services	Psycological	Secondary Imapacts	**Average Score**
Aircraft Accidents	1	3	1	3	2	3	1	1	2	2	**1.9**	1	4	2	3	3	3	2	2	4	3	**2.7**
Civil Disorders	3	3	3	2	2	4	3	1	3	3	**2.7**	4	4	4	3	3	5	4	2	4	4	**3.7**
Conflagrations (Fires)	2	3	2	3	2	4	2	2	2	2	**2.4**	4	4	4	3	3	5	3	3	3	3	**3.5**
Droughts/Water Shortages	5	1	3	1	1	1	1	1	1	1	**1.6**	5	2	4	2	2	2	1	2	2	1	**2.3**
Earthquakes	5	4	5	5	4	5	4	4	3	5	**4.4**	5	5	5	5	5	5	5	5	5	5	**5.0**
Floods	2	2	2	2	2	2	1	1	1	2	**1.7**	3	3	3	3	3	3	2	2	2	2	**2.6**
Hazardous Materials	1	2	2	1	2	1	1	2	2	3	**1.7**	3	4	2	2	3	2	3	3	3	3	**2.8**
Landslides	3	2	2	3	3	3	2	1	2	2	**2.3**	4	4	3	4	3	3	2	2	3	3	**3.1**
Snowstorms	5	1	3	4	4	2	2	2	1	2	**2.6**	5	2	3	4	4	2	3	3	2	2	**3.0**
Terrorism	4	3	4	3	2	4	3	2	5	4	**3.4**	4	5	5	4	4	5	4	3	5	5	**4.4**
Tornados	1	2	1	2	1	2	1	1	1	1	**1.3**	1	3	2	3	3	3	2	2	3	2	**2.4**
Tsumanis and Seiches	3	3	4	3	4	4	3	2	2	3	**3.1**	3	4	4	4	4	4	3	2	4	3	**3.5**
Volcanic Eruptions	5	2	3	5	4	3	3	3	2	2	**3.2**	5	4	4	5	4	3	4	4	4	3	**4.0**
Windstorms	5	2	4	4	4	3	3	2	2	2	**3.1**	5	3	4	4	4	3	3	3	3	2	**3.4**

Table 2 summarizes the most likely (expected) and maximum credible (potential) impacts for each hazard. These numbers are based on an assessment of the qualitative research presented in the SHIVA. By their nature, they are subjective. Individual readers may draw different conclusions from the same body of evidence.

Each impact is rated on a scale of one (low) to five (high) relative to one another. The scores reflect only the damage stemming directly from the primary event itself (i.e., no induced hazards are included). To compensate, one category is set aside to express the likelihood for induced hazards. The two scores are averaged to obtain the most likely impact and the maximum credible impact.

Table 3. Summary of Hazard Risk in Seattle

Hazard	Frequency	Expected Effects	Potential Effects	Risk
Earthquakes	3	4.4	5.0	66.0
Windstorms	4	3.1	3.4	42.2
Snowstorms	5	2.6	3.0	39.0
Landslides	5	2.3	3.1	35.7
Civil Disorders	3	2.7	3.7	30.0
Terrorism	2	3.4	4.4	29.9
Volcanic Eruptions	2	3.2	4.0	25.6
Conflagrations	3	2.4	3.5	25.2
Hazardous Material Incidents	5	1.7	2.8	23.8
Tsunamis/Seiches	2	3.1	3.5	21.7
Floods	4	1.7	2.6	17.7
Droughts/Water Shortages	4	1.6	2.3	14.7
Air Crashes	2	1.9	2.7	10.3
Tornadoes	1	1.3	2.4	3.1

Table 3 summarizes Seattle's hazard risks. The "risk score" is a final assessment of the danger Seattle faces from each hazard. It was obtained by multiplying the event frequency by the scores for expected and potential impacts. The latter two numbers were taken from the preceding table. The same caveat from that table applies to this one: the numbers in this table are a subjective assessment of qualitative data.

Conditions Affecting Seattle's Vulnerability

Vulnerable conditions are hard to spot under normal conditions in Downtown Seattle.
Credit: Ian Edelstein / City of Seattle

Conditions Affecting Seattle's Vulnerability

The physical and social character of a region determines whether a harmful event is a brief unpleasant incident or becomes a disaster. The most striking characteristic of the Puget Sound region in this regard has been its rapid growth in the past decade. With it comes a greater exposure of people and property in areas prone to dangerous hazards.

Seattle's population is growing, having reached 563,374 (2000 Census) after dropping to a post-war low of 497,000 in 1980 (City of Seattle, July 1994). As the general population grows, so does the number of people who are members of vulnerable groups: the poor, the elderly, and the linguistically isolated. Table 4 contains general information about Seattle's population and economy.

Table 4. Seattle Data

	Geographic Area	53,760 Acres, 84 Sq Miles
	Founded	1851
	Local Government Type	Strong Mayor System
Population		
	Population (1980)	496,846
	Population (1990)	516,259
	Estimated Population (2000)	563,374
	Population Density (2000)	6,736 person/sq mi
	Foreign Born (2000)	94,952
	Under 15 (2000)	74,099
	Over 65 (2000)	67,807
	Median Age (2000)	35.4
Economy		
	Median Household Income (2000)	$45,736
	Largest Regional Businesses (by 2000 revenue)	Boeing - $51.32 Billion
		Cost Co - $32.16 Billion
		Microsoft Corp - $23.00 Billion
		Weyerhouser - $15.98 Billion
		Washington Mutual Bank - $15.76 Billion
		Paccar - $7.92 Billion
	Total Jobs in Seattle	527,393
	Employment Distribution by Sector (2000)*	Services - 30.4%
	*For greater Seattle area including King, Kitsap,	Wholesale/Retail - 23.7%
	Pierce and Snohomish Counties	Government - 15.2%
		Manufacturing - 13.1%
		Construction - 6.0%
		Transportation/Public Utilities - 5.8%
		Finance, Insurance and Real Estate - 5.7%

Source: City of Seattle Website - Seattle Data Sheet

The population increase was the result of a booming local economy headed by the Boeing Company and Microsoft. As the county seat, Seattle is also home to the largest concentration of government offices and producer services in the region.

The growth has strained infrastructure. In 1992, the State passed the Growth Management Act in an attempt to check urban sprawl. Seattle's response to the Act has been to promote greater density in clustered "urban villages" with its new comprehensive plan, Towards a Sustainable Seattle. The plan should help the emergency management system by improving the City's infrastructure and promoting development that could reduce vulnerability to hazards.

Cities, Hazards, and Vulnerability

Urban theorists have variously defined the city as a "relatively large, dense, and permanent settlement of socially heterogeneous individuals" or a "point of maximum concentration for the power and culture of a community" (both quoted in Kostof, 1991). Urban economists see the city as a place that concentrates a region's wealth and technology to allow residents to efficiently utilize economies of scale and scope (Mills and Hamilton, 1994). This concentration has huge economic and cultural benefits, but makes social systems highly vulnerable to disruption.

Cities are intricate systems that combine people, infrastructure, and organizations. They include physical infrastructure like the street network and parks; organizations like Metro and the city government; and social networks such as the local economy. The population that lives and works in the city depends on this structure for its safety, livelihood, and welfare.

Small disruptions are absorbed into the evolutionary process, but beyond a threshold change becomes too rapid and severe for a system to incorporate in its gradual evolution. Disasters embody that kind of change.

Disaster Impacts and the Urban Environment

Physical and social systems within urban areas are highly interdependent. Disasters start with physical destruction, but their indirect effects cause impacts to spread throughout the urban system to parts unaffected by the physical damage. The biggest economic effect of the collapse of the Old I-90 bridge was the added transportation costs to commuters and businesses and not the loss of the bridge itself.

Changes in Vulnerability Over Time

Cities are constantly changing. Their economies 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.

The trends in a city's growth or decline are exaggerated by disasters. 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 (Jones, 1974).

Dangers of Concentrating Resources

Concentrated populations are more vulnerable than dispersed populations because one event can affect more people. Urban centers are even more vulnerable because their population density makes them dependent on a sophisticated infrastructure. The increase in disease in cities following the destruction of their sanitation systems is just one notable example of this dependence.

This concentration is not solely a liability. Dense population centers have more resources than rural or suburban areas. If not rendered totally inoperable, these resources become valuable assets during a response and recovery. Hospitals are clear examples of this type of resource.

Isolation

Many parts of Seattle are in danger of being cut off from emergency services due to geologic barriers and the centralization of services and businesses (see figure 1 for map of Seattle neighborhoods). Many government services and employers are located in or near the downtown. Most of the hospitals are on First Hill. 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. The Bay Area 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.

The Natural Environment

Seattle is well known for its temperate, soggy climate, steep hills, and greenery. These traits influence its vulnerability to hazards.

Geology

Geophysical events are directly responsible for many of the risks associated with natural disasters. Geological features and individual types of hazards often have a direct, one-to-one relationship and are examined in detail in later chapters. The indirect effect of the city's geology is no less important, but is subtler. Seattle's natural physical structure has had an influence on its economic growth, the patterns of land use, and the placement of transportation routes, utility networks, and other important facilities. Often this influence produces development in areas that are vulnerable to hazards.

Seattle is located on a strip of land in between Lake Washington and Puget Sound. Elliott Bay pushes into the middle section of the city from the West, giving it a rough hourglass shape. The narrowness of this middle area, as well as its importance as the central business district, creates a vulnerable concentration of economic activity and infrastructure.

The city's topography (figure 2) was heavily modified during the last ice age when glaciers moved south, scooping out long valleys and leaving a series of long north-south running hills with steep eastern and western sides, especially in the middle and southern parts of the city. Two waterways, the Lake Washington Ship Canal and the Duwamish Waterway, divide it internally. The Ship Canal runs east-west, separating the northern third of the city from the South. The Duwamish runs from the southern edge of the city north into Elliott Bay, dividing the southern third of the city in half: with West Seattle, South Park, and White Center on the west bank and Beacon Hill, Rainier Valley, Rainier Beach, and Mt. Baker on the east bank.

Several landfills, regrades, and cuts have modified this natural landscape and influenced Seattle's vulnerability to earthquakes, landslides, and floods. Many areas of the city rest on reclaimed land, including the Duwamish Valley, Interbay, the University Village area, and parts of Downtown. Supplying the fill for some of these projects was Denny Hill, flattened to create the Denny Regrade. Other fill came from a cut was made between Yesler Terrace and Beacon Hill.

Seattle's geology makes it vulnerable to landslides. The many steep hills composed of glacial till and sand underlain with clay have caused many slides over the years, especially during heavy winter rains and earthquakes (Tubbs, 1975). Another danger is on reclaimed land. Much of this soil is loosely consolidated with large amounts of water suspended in it. This soil can compact and turn into mud with the consistency of quicksand during an earthquake, causing the ground under buildings to fail. Areas where this can occur are called liquefaction zones and many exist within Seattle, especially on reclaimed land.

Indirectly, geology impacts vulnerability through its effects on land use and infrastructure. Industrial and large wholesale operations usually require flat land close to major transportation routes. Much of Seattle's supply of flat land is in the Duwamish Valley and Interbay. Both of which are low elevation landfills. Transportation and utility networks are channeled through the steep topography, following the long hillsides, rather than going over them. They run much more smoothly north-south than east-west because there are fewer slopes to cross. This layout could affect emergency access by making east-west movement more difficult that north-south movement. This problem occurred during the winter of 1996/7 when snow on these slopes made it difficult for police and fire vehicles to travel on them.

The geology produces a dependence on bridges. Within the city limits, there are only six bridges connecting north Seattle with the rest of the city, three bridges leading in and out of West Seattle, and only two crossing Lake Washington to join the middle section of the city with the Eastside. Each of these bridges is a bottleneck during normal peak hours. During a disaster they pose a risk and after one could cause new levels of transportation delays.

The same is true for any other networked infrastructure, like the electric, water, sewer, and natural gas systems where trunk lines must cross landslide prone hillsides and liquefaction zones. These indirect geologic effects will be discussed in later chapters covering individual hazards.

Climate

Seattle's climate is regulated by the Pacific. Prevailing wind patterns bring the city's weather in from the ocean. Since air temperature over water does not vary as much as it does over land, these patterns give Seattle mild summers and winters. While the amount of rain here is not unusual, it does fall more frequently than in many parts of the country, especially between mid-October and March. The location of the city, in the lowlands between the Olympic and Cascade mountain ranges, traps moisture, and causes the city to have many overcast periods. Often the summers can be very dry with vegetation withering and water running short. Snow is not as frequent as in other northern U.S. cities, but does occur regularly. Between 1990 and 2003, there were 22 days having snowfall totaling one inch or more (City of Seattle, Seattle Transportation, 2003).

Ironically, the climate's usual mildness makes the city residents unprepared for many of the weather-related hazards that do strike, e.g., water shortages, windstorms, snow, and even heavy rain. Many people (especially newer residents) who think of Seattle as waterlogged are caught by surprise during water shortages. Windstorms create power failures and debris clearance problems in a city with many trees. Finally, snow often paralyzes the city, because of its steep hills and the lack of available snow removal equipment.

Weather often hampers emergency response. One of the biggest dangers is a major disaster striking when snow is on the ground. 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 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. Weather will always play a large part in any disaster response and emergency planning must account for all its different variations.

Vegetation

Seattle still has thick tree cover in some places. Vegetation's presence or absence can influence landslides, windstorms, snowstorms and floods. Landslides are generally more common on bare slopes. The areas prone to slides are mapped, but the extent of vegetation on these slopes is not known. The correlation (if any) between vegetation and past landslides in the city is also an unknown. Trees are a hazard during major storms, since they can fall onto houses, power and telephone lines and their roots can pull up underground pipelines. North Seattle has the densest tree cover in the city, followed by areas in West Seattle. It is likely that the greatest amount of debris, fallen trees and the associated service disruptions could be expected in these areas. Vegetation also exacerbates floods by blocking drainage.

Built Environment and Organizational Infrastructure

Seattle's built environment encompasses all of its buildings, roads, bridges and other human-made structures. Its organizational infrastructure consists of all the governmental and private sector services that keep the city running.

Table 5. Land Use

Residential	40%
Single Family	35%
Multi-family	5%
Rights-of-Way	26%
Commercial and Industrial	9%
Parks	9%
Public facilities/Utilities	8%
Other (e.g. cemetaries, reservoirs)	8%

Source: Dept. of Planning and Development, 2003

Land Use

Table 5 describes Seattle's major types of land use: residential, commercial, industrial, open space, public facilities/utilities and transportation. Figure 3 shows how the land use is zoned in the city. Each use generates a different pattern of vulnerability. According to 2000 Census Bureau data, the city's official population is 563,374. These numbers expand to more than 1.5 million during the weekdays since many people who work in Seattle live in surrounding areas. Both the higher day population and its greater concentration of workers in the Downtown area suggest that Seattle is more vulnerable to the impact of a major disaster occurring during the workday than it would be at any other time.

Figure 4 shows the city's residential population density. 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. Damage in any of these areas would probably produce higher numbers of casualties than in other parts of the city.

Infrastructure

Infrastructure is the city's physical and organizational skeleton. It provides the support systems for residents in their daily life and that the local economy needs to sustain growth.

Emergency Services

During any major emergency, the city will rely on fire, police, and medical services as the first line of defense. Figure 5 shows where the major emergency facilities are located. There is important information beyond these statistics. First, many of their personnel live outside

Table 6. Critical Facilities

Emergency Response	General Service	High Population
Emergency Operations Center	Boeing	Hotels
Emergency Shelters	Community Centers	Large Apartment Complexes
Fire Stations	Government Offices	Large Office Buildings
Hospitals	King County Airport	Malls and Department Stores
Police Stations	Port of Seattle	Schools
Transportation Facilities	Street Maintenance Facilities	Stadiums
Communications Facilities	University of Washington	The Convention Center

Seattle (75% of the firefighters for example). It is doubtful all essential staff would be able to report for duty in the first few hours after a major disaster strikes (Seattle Planning Department, 1990). Second, the mayor can call on the state government for assistance. However, bringing in outside help takes time that the city may not be able to afford. Finally, transportation disruptions can paralyze a service by limiting their access to customer and job sites.

Emergency planning and programs at all levels of government and in the private sector address some of these problems. The local control of land use issues is especially noteworthy. While many programs such as hazardous materials regulations and disaster relief funding come from the federal level, land use issues are largely left to local governments. They represent an opportunity for the city to make a strong impact on hazard mitigation.

Critical Facilities

Table 6 shows the types of critical facilities in the city. They fall into three categories: those containing emergency services, those that house large numbers of people, and those that are key parts of the local economy or provide for public welfare. Fire stations, police stations, hospitals, and emergency shelters make up the first category. The second includes structures that Seattle's large employers need to operate and those that house important city services. The third contains hotels, large office buildings, stadiums, and schools.

Networks

Seattle has many networks it needs to function normally, e.g., transportation, power, water, sewer, telephone, natural gas, fiber optic and cable services. Unfortunately, networks, by their very nature are vulnerable to breaks and blockages. Most are broken down into trunk and distribution lines. Trunks carry large quantities of a substance into Seattle. They connect to distribution lines that feed it to still smaller lines that supply end users of the product. If a break or blockage in the network occurs, service beyond the problem will stop until the service can be re-routed or the problem is solved. Furthermore, the closer the problem is to the front-end of the network the wider the disruption will be. This problem can be countered by redundancy and re-rerouting possibilities. Figure 6 indicates how the water, power and sewer networks are configured.

Structures

Seattle is a young city, but over half of its housing units were built prior to the adoption of building codes in 1949 that introduced seismic standards. The majority was built before the city upgraded its seismic codes in 1992 (Seattle Planning Dept., December 1992). Table 7 shows the age distribution of the housing stock.

Table 7. Age of Housing Units (2000)

Year Built	Number of Units	% of Total
Built 1990 to March 2000	24,488	9.47%
Built 1980 to 1989	23,266	9.00%
Built 1970 to 1979	25,762	9.97%
Built 1960 to 1969	31,644	12.24%
Built 1950 to 1959	36,297	14.04%
Built 1940 to 1949	32,507	12.57%
Built 1939 or earlier	84,546	32.75%
All Years	**258,510**	**100%**

Source: U.S. Census Bureau, Census 2000, Summary File 3 (SF 3) sample data. [Table HCT 6]

Most of the stock is wood frame construction, which generally performs well in earthquakes. The City of Seattle, the Port of Seattle, and Seattle Public Schools have or are all in the process of surveying their facilities for seismic safety. A Department of Construction and Land Use survey of the older areas of the city uncovered approximately 500 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.

Social Environment

Seattle's social environment - its local economy, demographics, and history - all mold how the people of the city plan for and respond to disasters.

Economy

Seattle is part of the larger Puget Sound economy. Any attempt to analyze Seattle's economy must acknowledge the city's dependence on the $50 billion per year revenues of the Boeing Company. During the 1980's, 76% of Washington State's job increases were tied to it (Seattle Planning Dept., August 1991). Yet, there is more to Seattle's economy than one company. There are other large employers in the city like the University of Washington and the Port of Seattle. The City's economy is becoming increasingly diverse, which helped it weather the Boeing layoffs of the early 1990's.

Most of the city's economy centers on Downtown and the Duwamish Valley, although other economic centers exist along the Ship Canal and at Interbay, Northgate, and the University District. Many of the Downtown businesses provide services to the region's big employers. It alone maintains 165,000 jobs or 35% of the total in the city (City of Seattle, July 1994). However, unlike major international service centers like New York or LA, Seattle does not export many of its services outside the region making it more vulnerable to disruption in a local disaster (Seattle Planning Dept., August 1991).

The central business district, the manufacturing areas, and suburban employers drive the local economy. By understanding their role it becomes easier to gauge the effects of a disaster, especially indirect impacts. Unfortunately, this work has just begun and the relationship between physical and economic vulnerability is not totally understood.

The geographic concentration of Seattle's economy is dangerous. Most of its industry sits in a liquefaction zone. Many of these companies are much smaller than Boeing and cannot draw on the same resources to recover. An event such as an earthquake that could seriously disrupt business would have a huge impact on them. The service economy of the central business district is also vulnerable, since it relies heavily on communications networks and transportation to move people, commodities, and documents.

Demographics

Seattle has a larger share of vulnerable populations than the rest of the County. The distribution of these groups across the city is not even. Figure 7 shows their location by census tract. Many researchers have discovered that the elderly, poor, disabled, and linguistically isolated all have a greater vulnerability to disasters. Despite this general observation, not much research has been done in Seattle on demographic issues.

The only vulnerable group that is not over represented in Seattle is children. Table 8 gives the numbers of people in certain at risk categories. One person may appear in several groups in the table. A poor, elderly, and disabled person who is living alone would appear in four groups. It shows the number of people in each category and their percentage of the total population.

Table 8. Special Needs

	1990	2000	Change
Total Population	**516,259**	**563,374**	**9.13%**
The Elderly (65+)	78,402	67,807	-13.51%
Lingistically Isolated	21,503	29,940	39.24%
In Poverty (Individuals)	57,526	64,068	11.37%
Persons with Disabilities	*No Data*	90,999	N/A
In Group Quarters (excluding college dorms and military)	12,260	15,781	28.72%

Source: 1990 and 2000 U.S. Census

Each of these groups has special needs during emergencies and a demand for certain services far beyond their actual numbers. Additionally, some, like prisoners, will pose extra challenges. Currently, not enough has been done to relate these numbers to emergency operations planning.

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 original location in Pioneer Square and 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 early. 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 outlining areas.

Past disasters have created a filter through which residents and city leaders perceive the area's hazards. The moderate earthquakes of the mid-1990's 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

The field of emergency management is just beginning to understand the subtleties of disaster impacts on urban systems (Godschalk, 1991). Here in Seattle, there is still not enough information on the demographics, building stock, infrastructure, transportation, the economy and how they all interact during disasters. This situation is changing as the city moves toward a long-range view of hazard mitigation and response. The establishment of the Emergency Management Section points in this direction. This chapter is a first step towards understanding how Seattle is equipped for emergencies, but more information is needed to understand how Seattle would be impacted by a major disaster.

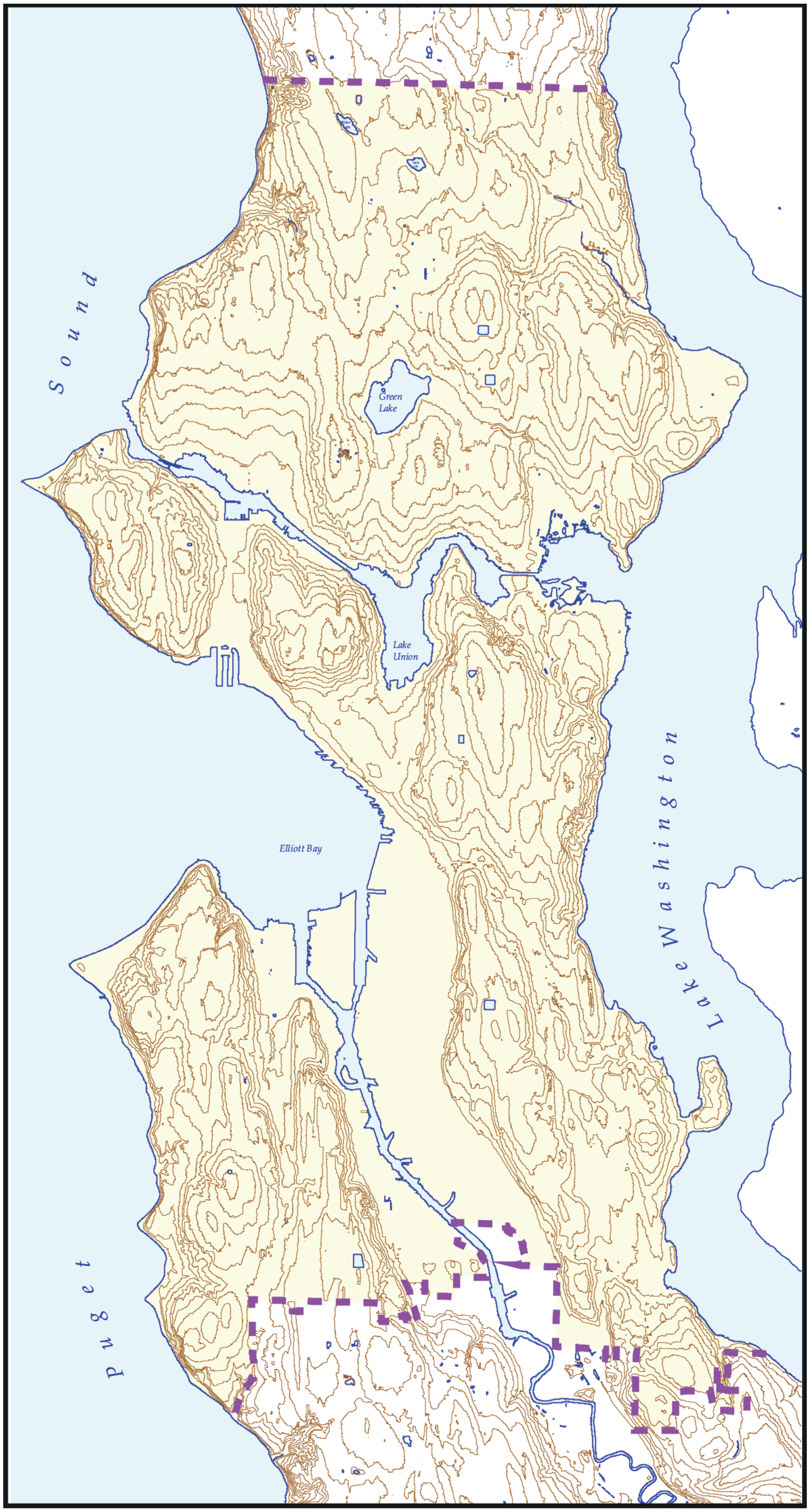
Figure 1. Seattle Neighborhood Names

Legend

Neighborhoods

1 0 1 Miles

Figure 2. Seattle Topography

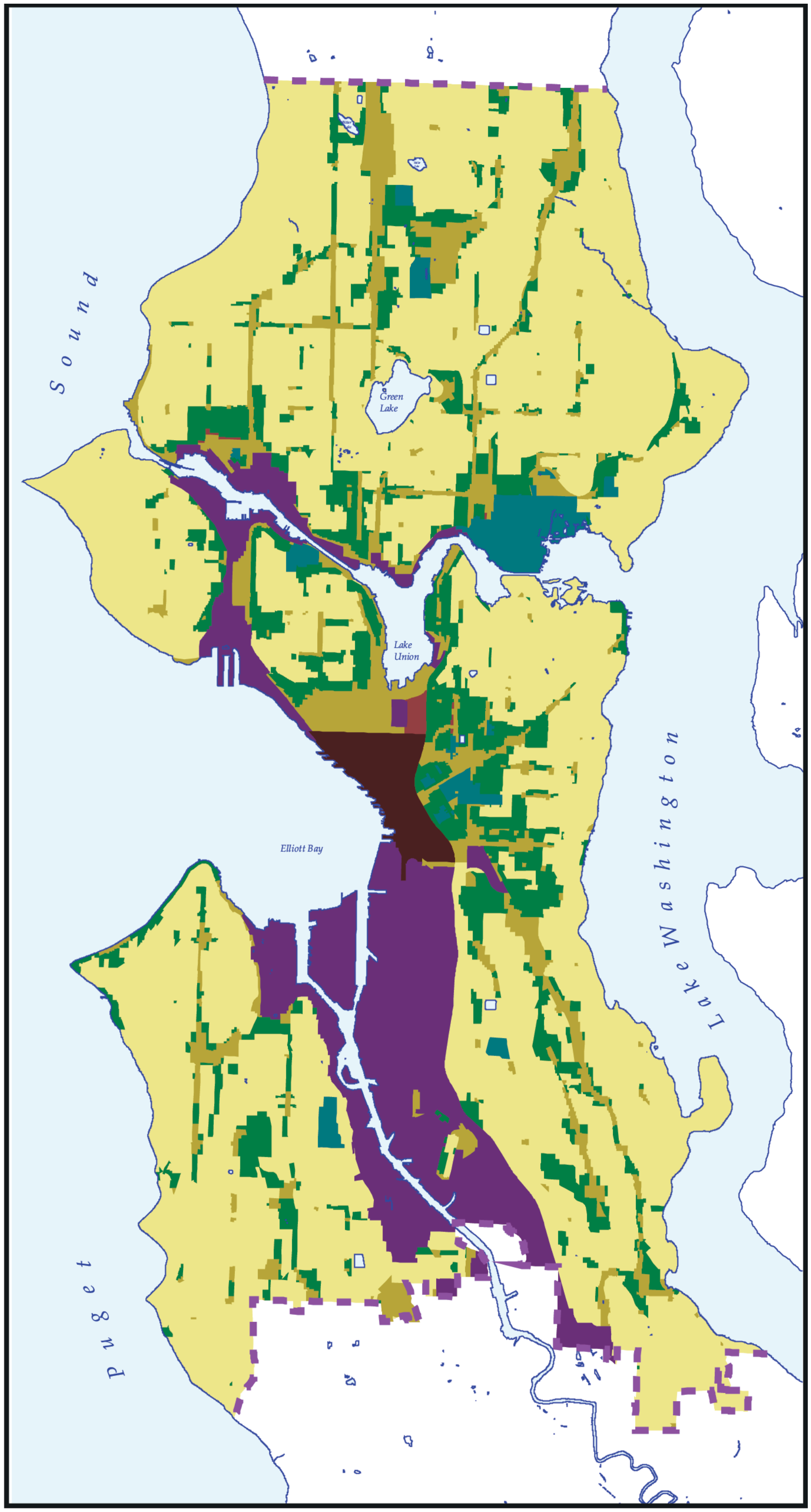


Legend

50ft contours

1 0 1 Miles

Figure 3. Seattle Generalized Zoning



Legend

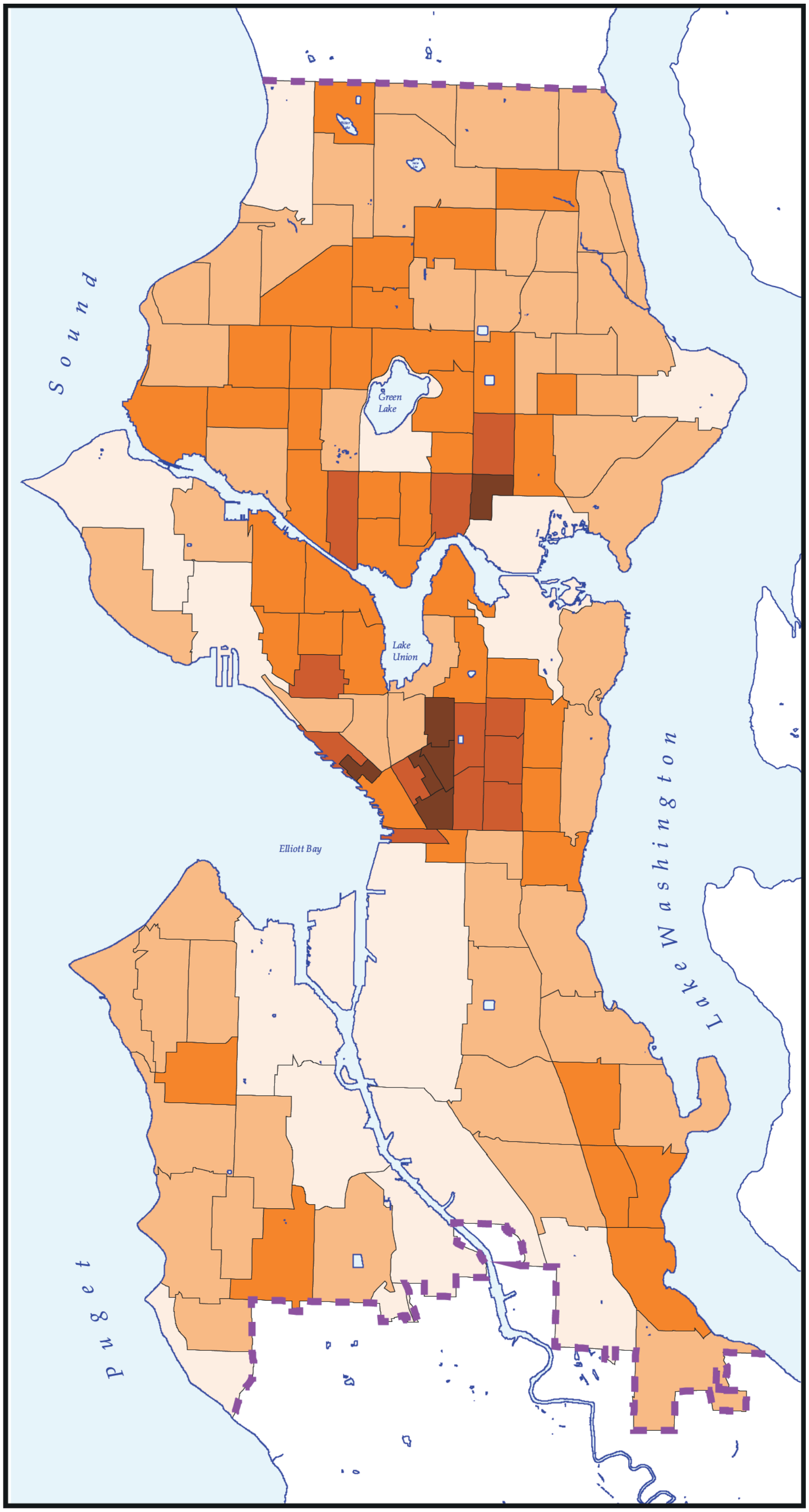
Zoning (Generalized)

- Downtown
- Major Institutions
- Manufacturing/Industrial
- Multi-Family
- Neighborhood/Commercial
- Residential/Commercial
- Single Family

1 0 1 Miles

Figure 4. Seattle Residential Population Density

Source: U.S. Census Bureau, Census 2000



Legend

Persons per Sq Acre (Census 2000)

- 0 - 6
- 6 - 12
- 12 - 20
- 20 - 34
- 34 - 67

1 0 1 Miles

Figure 5. Emergency Resources

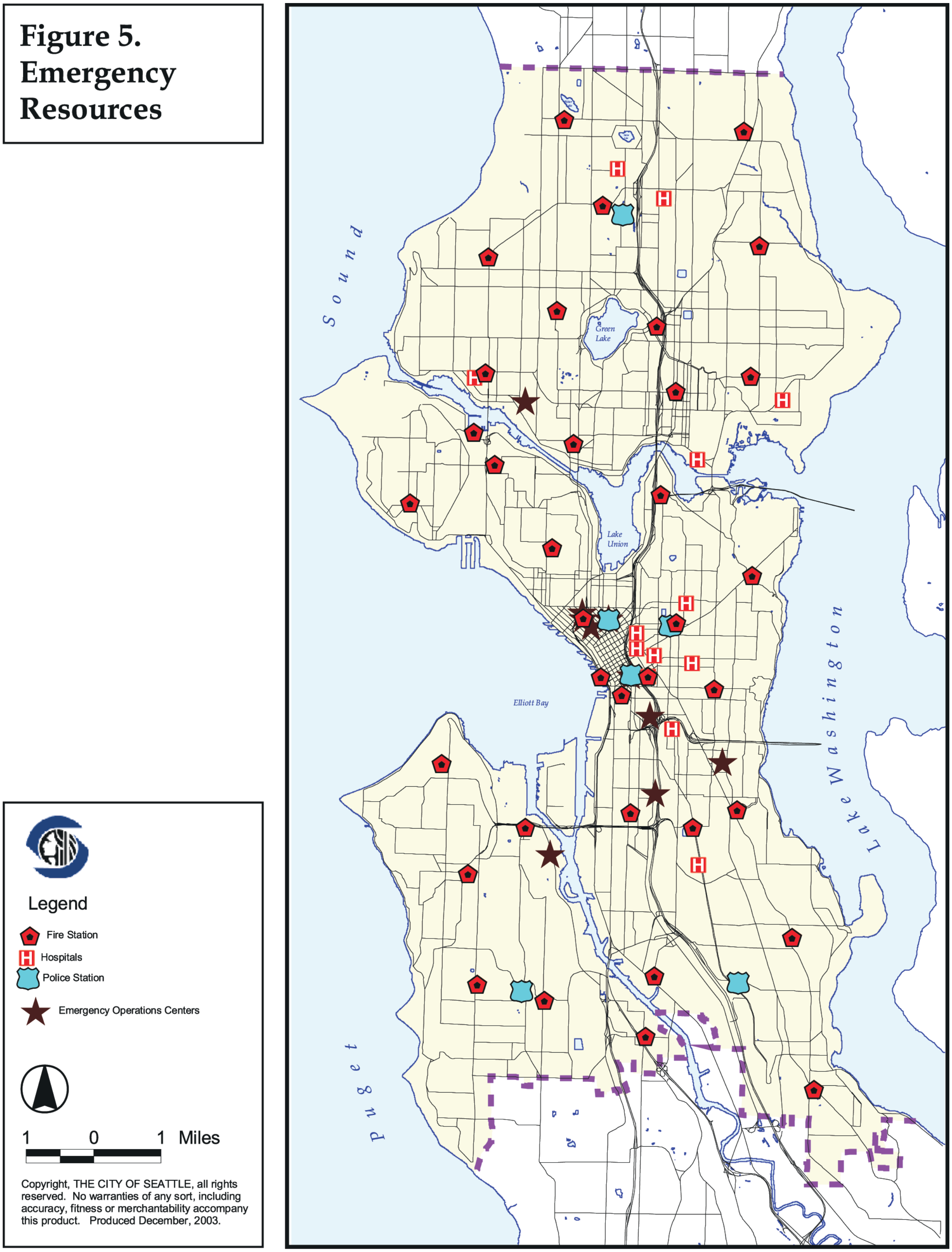
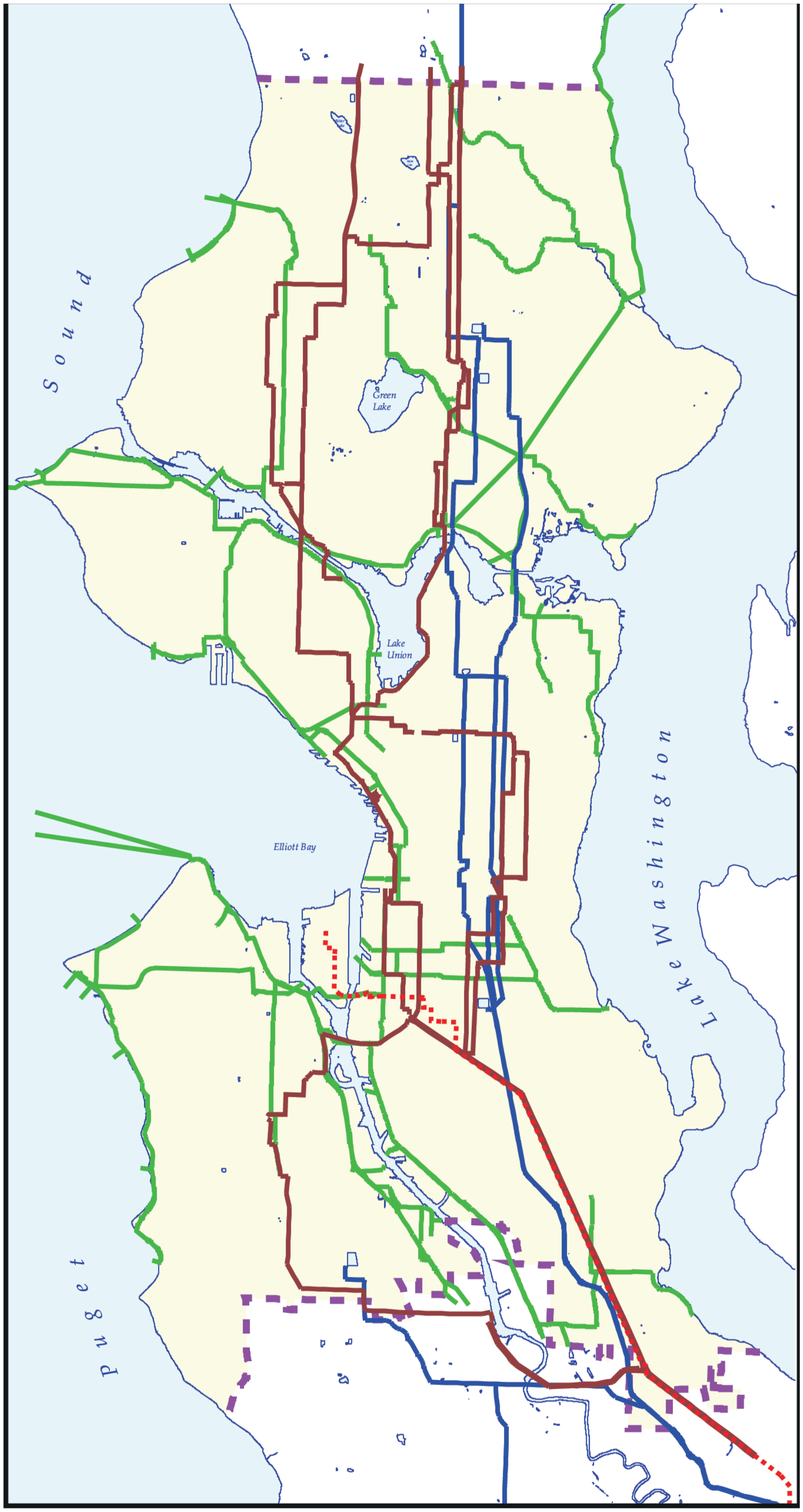


Figure 6
Utility Mainlines



Legend

BP-Olympic Pipeline
City Light Transmission Lines
Water Supply Lines
Metro Wastewater Mainline

1 0 1 Miles

 Produced December, 2003.

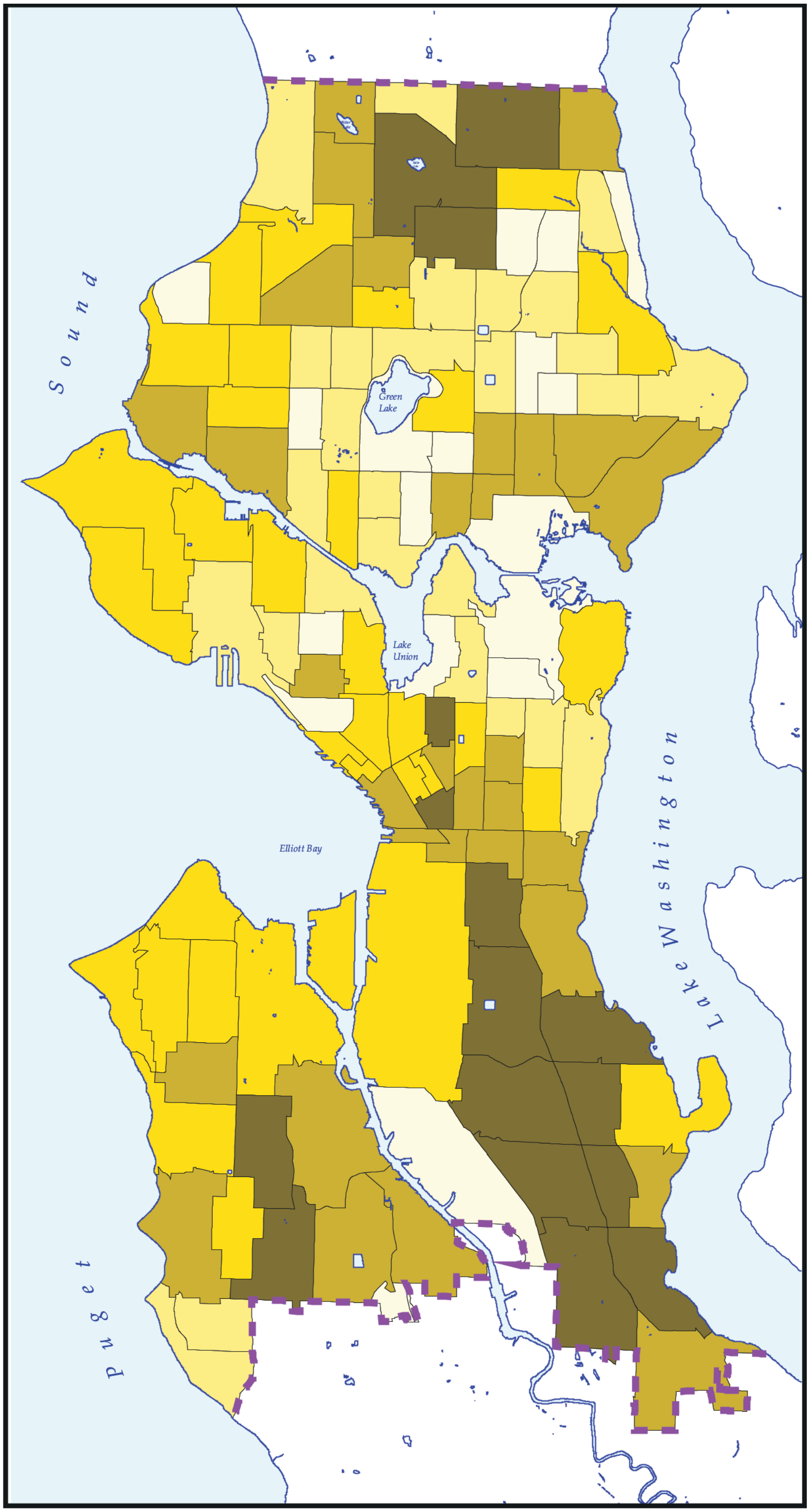
Figure 7. Count of Special Needs

Shown is a count of conditions that make people more vulnerable to disaster. These are:

1. Age (over 65)
2. Disability
3. Institutionalized
4. Below poverty level
5. Linguistically isolated

A person can be counted more than once.

Source: U.S. Census Bureau, Census 2000



Legend

Count of Special Needs
- 0 - 991
- 991 - 1709
- 1709 - 2560
- 2560 - 4109
- 4109 - 7647

1 0 1 Miles

Aircraft Accidents

The remains of a military C-46 cargo plane after crashing in the Georgetown area on July 19. 1946. Seven people were killed and 33 injured. Credit: John T. Closs / Seattle Time. (original photo retouched).

Aircraft Accidents

Highlights

- *Having two airports within several miles of each other creates an opportunity for a mid-air collision, but the possibility is reduced by the division of commercial and general aviation traffic between the two airports.*
- *Crashes are most likely to occur near flight corridors that overly the middle part of the city and within five miles of an airport.*
- *Weather patterns that contribute to crashes are low frequency events in the Puget Sound Area.*
- *Accidents would be localized emergencies with primary impacts on safety and would probably not have a large economic impact.*
- *The vulnerability is highest during the day, when the Duwamish Valley is heavily occupied.*

General

The Seattle-Tacoma International Airport runway expansion and recent high-profile aircraft crashes have caused many Seattle residents to wonder what would happen if a major accident occurred in Seattle. Especially worrying is the prospect of casualties on the ground - people who did not accept the risk of air travel, but just happened to be in the wrong place.

Seattle is served by two major airports, Sea-Tac and King County International Airport (Boeing Field). Sea-Tac is the major passenger facility and is located south of the city. However, many of its flights pass directly over Seattle. King County International Airport is in the Duwamish Valley and overlaps the municipal boundary. Most of its flights are general aviation, charter, cargo and aircraft industry activity.

Trends in airline safety are debated. The controversy began with the Airline Deregulation Act of 1978. Since it was enacted, airline competition and air traffic have grown dramatically. Critics argue that these conditions have made air travel more dangerous (Nader and Smith, 1994). Others, citing empirical studies that show accidents have actually decreased, say air travel is safer (Oster, Strong, and Zorn, 1992).

Seventy-five 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.

Despite the large number of planes that fly over urban areas, the number of crashes that have killed or injured non-passengers is very small.

History

There have been three major aircraft accidents within the city involving ground casualties. Two were military aircraft and the third was a charter. All of them came down in the Duwamish Valley. None occurred since 1951.

Feb. 18, 1943	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 (Seattle Times, Feb. 4, 1973). It caused a large fire, cut major cross-town power lines, and released enough ammonia from the slaughterhouse to kill one fireman.
Jul. 19, 1949	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	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 11 people, six in the plane and five on the ground (Seattle Times, Feb. 4, 1973). 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.

Since 1951 there have been no major crashes within Seattle, but there have been some close calls. NTSB data indicate that on 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. Two months later, on December 19, 1984, a DeHavilland DHC-3 helicopter crash-landed on an athletic field and slid into a nearby street. Nobody was hurt in either incident, but they revealed that despite an excellent record over the last 45 years, a crash outside the airport is always a possibility.

Effects

General and commercial planes are separated in Seattle, with King County International Airport handling most of the general aircraft and Sea-Tac most of the commercial. This arrangement helps reduce the chance of accident, since most serious collisions involve general and commercial aircraft trying to use the same space. It also reduces congestion around Sea-Tac where most of the large planes land. Finally, the distance of Sea-Tac from the city reduces the chance of a crash, since the planes fly over Seattle at a relatively high altitude.

Besides the two airports, Lake Union and Lake Washington are also potential crash sites. Seaplanes use Lake Union as a base, yielding the possibility of an air/marine collision or a crash into one of the buildings surrounding the lake. Lake Washington is also used for seaplanes, but the planes are mostly small single engine aircraft.

The areas that are most likely to be hit are the ones under or close to the flight paths, especially if they are within five-miles of an airport. Figure 8 shows the area within 5 miles of both airports. Only Seattle's most southern sections (White Center, South Park, Dunlop, and Rainier Beach) are within five miles of Sea-Tac and none are directly under the flight paths, but King County International Airport is in the city itself. Often, planes approach for landing from the North, over the Duwamish Valley and Georgetown, flying quite low as they near the landing area.

The weather further reduces the chance of a crash. Thunderstorms and the sudden downbursts that often accompany them are rare in Seattle. The hilly terrain breaks up many strong wind gusts and there are seldom icy conditions in winter (National Research Council, 1993).

Congestion is a problem. Currently, King County International Airport averages 400,000 flights per year while Sea-Tac is reaching its design capacity with 350,000 flights per year. If the third runway is built, congestion will be reduced, but the total volume of flights over Seattle will probably increase, offsetting some of the benefits of the reduced congestion.

Vulnerability and Potential Effects

There are two scenarios in which Seattle could be affected by a plane crash. First, a plane could go down near or in the city without producing any casualties on the ground. The second prospect is a plane going down in a populated part of the city. In both cases there would a significant demand on the city's emergency resources. In any crash, safety would be the city's highest concern. Most accidents would be localized emergencies with few effects beyond the immediate area, but they could affect a wider area if they cut utility lines or major roads.

If a plane did crash into the city, the effects would depend on where it went down. In the Duwamish Valley, the highest number of casualties would result during the day when the largest number of people is working in the area. The only residential area near King County International Airport, Georgetown, would be most vulnerable at night when people are home. The rest of the areas under the flight paths are residential and would be vulnerable at night.

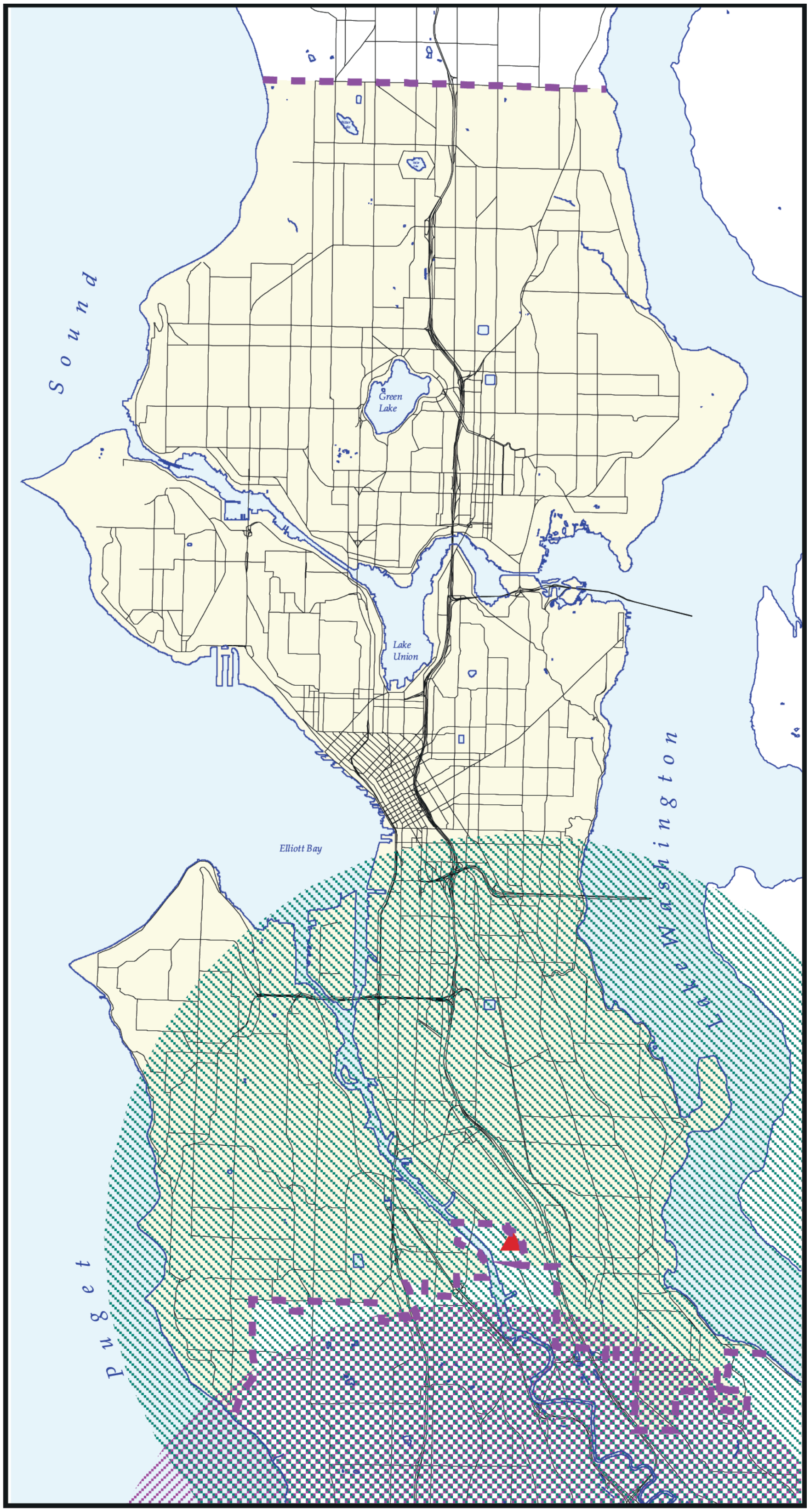
A crash could cause an explosion and fire, during which large amounts of toxic material would escape. Additionally, many of the buildings in the Duwamish Valley store hazardous materials making this area more vulnerable than other parts of the city. All the utilities have networks that run through the area and I-5 and rail lines run alongside King County International Airport. These secondary impacts have been an issue historically. All previous crashes damaged the City Light network (Seattle Times, Feb. 4, 1973).

Conclusions

Future accidents will probably involve general aviation. Fortunately, it is highly improbable that a general aviation aircraft could provoke a citywide emergency. However, the presence of large planes over the city keeps a large crash as a possibility.

Most of the factors that govern risk are beyond the city's control. Boeing Field and Sea-Tac will continue to handle major traffic, and flights will continue over the city out of necessity. The federal government directs aircraft flight patterns, limiting Seattle's involvement.

Figure 8.
5 Mile Buffers Around Area Airports



Legend

- Airport
- 5 Mile Around King County Int'l Airport
- 5 Mile Buffer Around Sea-Tac Int'l Airport
- Arterials

1 0 1 Miles

Civil Disorders

Crowd moving away from police lines after tear gas dispersed on November 30th, 1999 during the WTO demonstrations.
Credit: Gavin Schrock

Civil Disorders

Highlights

- *Disorders often occur in areas that are crossroads and natural gathering places: Downtown, Capitol Hill, and the University District.*
- *The most damaging disorder in Seattle occurred during the 1999 World Trade Organization conference when police battled protesters in downtown and Capitol Hill.*
- *Past Seattle disorders indicate most violence is aimed against property rather than people.*
- *Looting is the most common form of property damage, but fires will be set in any disorder.*
- *Rock- throwing, sniping, and other severe personal assaults have not been common in Seattle disorders, and are not expected to be frequent threats in the future.*
- *There does not seem to be any economic backlash against the city because of disorders.*
- *Response to large disorders could require an enormous expenditure of money and time to control.*

General

Civil disorder has been an episodic presence in the United States since its founding. The most widely held theory of modern American disorders, distinguishes between 'communal' and 'commodity' riots. The first type involves 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 1920's. 'Commodity' riots started within the heart of a community instead of the fringe. The violence is not generally aimed at people, but at symbols of the prevailing social structure. Because property is the most common target, casualties tend to be lower in commodity riots. The majority of the commodity riots happened during the 1960's (Janowitz, 1969).

Disorders in Miami and Crown Heights, Brooklyn during the 1980's and 1990's were marked by interethnic violence, suggesting a return to communal type disorders (Porter and Dunn 1984, Girgenti, 1993). 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. The basic foundations of Janowitz's theory holds, but 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 1960's 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 1960's, rioters used more firearms and assaulted fire department personnel more frequently. When it was over, 55 people died. Unlike riots in the 1960's 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 (LA Times, 1992).

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 (Webster, 1992; Girgenti, 1993). The official studies of the mid-60's 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.

Historically, the most dangerous civil disorders occurred spontaneously without planning, but planned demonstrations have also led to violent conflict. The 1968 Democratic Convention is the archetype of this type of disorder. In these cases, the goals of the protest leaders, their control over the demonstrators and their relationship with law enforcement were good indicators of the level of violence.

History

No social group is involved in civil disorders consistently. This is especially true for Seattle where nearly every wave of disorder has included different groups of people and revolved around different issues.

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 (Sale, 1976).

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 (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.

After World War I, there were no large incidents of civil disorder until the 1960's. Like many other cities, it was the scene of protest. There were several large marches against the Viet Nam War, but these were mostly peaceful. Most of these happened from 1969 to 1973. In the last large protest a crowd closed I-5.

The city was caught up in the wave riots during the summer 1967. There was at least one incident that the Kerner Commission (a commission that studied the nationwide wave of riots in 1967) labeled as 'minor' (Kerner, 1968). While there was never another large-scale disturbance during the period, several police officers were shot during the late 1960's and early 1970's and tension remained high.

Inter-generational conflict was also an issue. It flared up in 1969 when youths and police confronted each other in the University District over two nights.

From the early 1970's to 1992, the city was relatively peaceful. This peace was broken by 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 people feared 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. It was largely peaceful, but protesters did occupy I-5 for a while, shutting down traffic. (Inside the LA Riots, 1992).

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 northern portion of downtown. It quickly turned ugly. Some 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 and 89 were treated at local hospitals. The Mayor declared a state of emergency in the afternoon 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 controversial 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. Downtown was divided 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 were violent and were joined by non-politically motivated hoodlums 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.

In February 2001, chaos erupted for two nights in a row during Mardi Gras celebrations when police in riot gear shot rubber bullets and tear gas into crowds of unruly revelers in Pioneer Square.

Vulnerability

Most disorders in Seattle occur in gathering places and have relatively young populations, e.g., Downtown, Capitol Hill, and the University District.

Frequently, when the numbers of rioters is moderately large, they break into small groups. The Kerner Commission noted this phenomenon, and it happened here in

1992. The challenge for police is to track these groups as they roam. Large numbers of police personnel are required to deal with them and spread police resources thin. Unfortunately, normal staffing levels do not give the police the necessary numbers. Pre-planning is necessary and it helps when police commanders can anticipate trouble. Organizational barriers can compound these problems. During the 1992 disorder, police pushed rioters out of downtown, but stopped at the West Precinct border according to an account in the Seattle Weekly. This action allowed the crowd to surprise officers in the East Precinct and disperse into the neighborhoods (Scigliano, 1992).

Property has been the main target of Seattle's disorders. In most cases the damage was limited to window smashing and minor looting, but the fires that were set during the Rodney King event and the WTO protests show the potential for greater damage does exist.

It is possible that 'communal' type riots could happen here, but there has been no evidence to support that notion. The most prudent action the city could take is simply to be aware that the potential theoretically exists and pay attention to the developments.

The WTO protest was a watershed event. Previous protests in Seattle followed national events. Seattle was never in the spotlight because there was always a bigger story elsewhere. This was the first time Seattle was under the microscope of international attention on an intensely controversial issue. As Seattle grows, it is more likely to host events that draw protests. Keeping them orderly will continue to be a challenge for this mid-sized city with its mid-sized police force.

Effects

All disasters raise social tensions, but civil disturbances are especially troublesome because they are so divisive. With other types of disasters, a community will pull together, at least initially, but following a civil disturbance, most people in a community feel violated regardless of their opinion of the issues at hand. The amount of live media coverage today magnifies these feelings. People watching events on their TV sets feel personally connected to the violent events they are witnessing. This mood of mass victimization is the most widespread effect of a civil disturbance.

One person died in the 2001 Mardi Gras violence. Other than that, there have been no deaths in Seattle related to civil disturbances since the early twentieth century. However, people have been injured. Many people claim they were injured during the WTO protests, but the total is not known. The examples given in the press include bruises, sprains and some broken bones.

It is probable that future disorders will again be directed mostly against property. Furthermore, the destruction of property seemed to be selective in the past, so it 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 the controversy that sparked the disorder. Response to large disorders could require an enormous expenditure of money and time to control.

The possible indirect effects should not be ignored. 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 riots and some areas have yet to fully recover. Seattle's disorders have never been as scrutinized as those in other locations. If Seattle's disorders continue to be side events to larger disturbances elsewhere, it is unlikely the city will suffer any economic backlash.

Conclusions

The ability to respond quickly to disturbances is especially noteworthy. Official reports on both the Crown Heights and Los Angeles riots mentioned slow official response as a factor that exacerbated the disturbances (Webster, 1992; Girgenti, 1993). Currently, when the city expects an event where crowd control may be needed, the Seattle Police Department draws up an operational order that details control plans.

Conflagration and Other Large Urban Fires

The Hotel Ozark after a March 20, 1970 fire that killed 20 people.
Credit: Seattle Times

Conflagration and Other Large Urban Fires

Highlights

- Wildfires are unlikely, but probably have a slightly higher chance of occurring in North and West Seattle.
- Large structural fires are a substantial risk and are most likely to occur in areas with older buildings: Downtown, the International District, First Hill, Ballard, and the University District.
- Vault fires will be a continuing risk until a City Light upgrade program is completed. When they do happen, they often cause widespread and extended power outages.
- Any fire can become disastrous because any one can cause high casualties and induce secondary impacts such as hazardous materials releases and damage to utility and transportation networks.
- The worst-case fire would probably follow an earthquake or riot.

General

The heading 'fires' includes three distinct hazards: conflagrations, large structural fires, and vault fires. Conflagrations are large multi-structure fires that cover at least one square block or urban brushfires like the 1991 Oakland fire. Large single structure fires can become city-scale emergencies if they occur in large, high occupancy buildings such as hotels, office complexes or sports stadiums. Finally, there are electrical vault fires that can cause prolonged power outages.

Conflagrations were a major hazard in the nineteenth century. Seattle's most devastating disaster was the 1889 fire that destroyed most of the downtown area. Similar fires destroyed large sections of several other cities during the same time period. Driven by pressure from the insurance industry, local governments took steps to limit fire damage. The results have been impressive, but the 1991 Oakland fire shows that problems still exist.

National Fire Protection Association data show a decrease in the number of multi-fatality fires and in the number of victims in them. Despite this empirical evidence, development pressures place homes and offices in high risk locations or in large buildings so vulnerability to fire is likely to remain significant.

Fighting a fire effectively means detecting and responding to it quickly. 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 occur in places that are difficult to reach. Toxic chemicals are a newly recognized fire related danger and can prevent effective firefighting. A notable example was a transformer fire in a Binghamton, New York office building that coated everything in it with dioxins. Because of the contamination, the building was closed for years.

Fires can be an induced impact from another event. Most experts worry about fires after earthquakes and during riots. From 1900 to 1995 there have been nine large fires following quakes (Council on Tall Building and Urban Habitat, 1992). Kobe is just the most recent example. They can be extremely devastating. The 1906 San Francisco fire destroyed 28,000 buildings. The 1992 LA riots also produced many large fires including some that engulfed whole blocks.

History

The 1889 fire consumed 60 acres downtown (Sale, 1976). Nobody was hurt and it happened right before the biggest economic boom in Seattle's history. This boom allowed Seattle to totally rebuild the downtown within eighteen months and do it 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.

After this event, there were no disastrous fires until 1970 when the Ozark Hotel burned, killing 20 people (SFD multiple alarm summary). After the fire, the city's codes changed to introduce new active fire suppression technology, like smoke detectors, sprinklers and passive systems (i.e. improved fire engineering in building design). Since the Ozark fire, there has not been another fire with double-digit fatalities (SFD multiple alarm summary, n.d.).

Despite the success with buildings, other structures, most notably the underground vaults of the City Light system, have remained vulnerable. Many of Seattle's electrical distribution lines run underground, especially in the downtown area. Vaults act as switching points for these lines. On two occasions, in 1988 and 1993, the equipment in these vaults became overloaded and burned. The fires developed rapidly, destroying critical power connections and creating intense heat that prevented firefighters from approaching them for days. Power went out for extended periods in large parts of downtown. The 1988 outage was especially severe since the firefighter could not approach the underground site for days and it fed many high occupancy buildings. Many downtown office buildings could not function, silencing a large part of the city's economy for days.

Vulnerability

Fire vulnerability varies greatly within the city. Wildfires would be the most severe in North and West Seattle where the vegetation is thickest. Large structural fires have a greater chance of happening at construction sites or in locations with large, older structures, especially if they do not meet fire codes. These areas are Downtown, the International District, First Hill, Ballard, and the University District. Finally, vault fires occur where there are underground cables, mostly in Downtown.

There has never been a large wildfire in Seattle like the recent ones in Oakland and Malibu. The reason is probably that Seattle does not have vast areas of dry vegetation like the mountains surrounding many California cities, and does not have hot dry winds that can spread fires swiftly.

A multi-structure conflagration is another unlikely occurrence. Although the spread of fires is a constant danger, there have not been many fully developed multi-structure fires in recent years. In 1991, there was a 98-unit apartment fire that also damaged a nearby house (SFD multiple alarm summary). Fires spread if they go uncontained, so the fire department's response time is a key variable. A time under five minutes is considered good and Seattle's average is under four minutes. The other important factors are building design and fire codes. Many high-population areas are now made from fireproof materials like brick, steel, and concrete that reduce the risk of fire spread. However, most of the city's residential structures are wood, 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.

In large buildings, the key to successful fire fighting is not the timely arrival of the fire department, but 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. Other areas like the International District are probably more likely to have fires, but less likely to have massive casualties.

For electrical vaults, the risk of fire increases with the age of the equipment and the load that is placed on them. The Downtown's rapid growth in the late 1980's and the early 1990's strained the system. Residential growth in the downtown area and the Denny Regrade has increased dramatically in the same period. Most of the new structures are high-rise buildings that complicate fire fighting.

Effects

Even a large fire would not threaten the whole city, but responding to an event of this magnitude would be highly complex and require use of the city's emergency management system to help coordinate emergency activities.

In contrast, the worst case scenario would probably be connected with an earthquake or riot. These events could produce multiple ignitions that would overwhelm the fire department. The dangers would be even greater if the triggering event occurred during hot, dry weather while a wind was blowing. The effects of such a fire would be devastating. Without the resources to contain it, a fire could grow until it exhausted its fuel. It could burn hundreds or even thousands of structures. The most fearsome prospect is a multi-structure fire in the tall office buildings downtown. One writer speculates such a fire could start after a large earthquake if many automatic fire-fighting systems were damaged and fire crews were unable to confront it. If the fire grew out of control it could spread to other buildings like a crown fire in a forest (Council on Tall Buildings and Urban Habitat, 1992).

This type of event could result in heavy loss of life and property. Unlike other fires, it could produce profound economic and social effects, especially if it happened in the heart of the city. Businesses would close and many residents could find themselves homeless. While this scenario is improbable, the disturbances following the first Rodney King verdict produced thirty ignitions and three multiple-alarm fires within a couple of hours. Together they completely exhausted the resources of the Seattle Fire Department (Scigliano, 1992 and SFD multiple-alarm summary). One study about Seattle estimates there could be 80-100 fires after a large quake (EQE, 1994). Such a large number could overwhelm the city and outside aid might not be able to arrive in time to do much good.

Conclusions

The city's mitigation and response are both good. Its fire codes are up to date and the Fire Department's response time is under four minutes.

In the unlikely event one happened, a large wildfire would present a challenge, because Seattle has not experienced one and most of the city's personnel are not familiar with fighting them. However, they are not frequent in damp climates like Seattle's. Rioting and earthquakes could cause many large fires. The city should prepare a plan for using its resources most effectively during such events. This plan should include how the city will get information about ignitions, how to prioritize its response to them, and decide how it will allocate its fire-fighting equipment between them.

Earthquakes

Cars smashed by falling bricks during the Febuary 28, 2001 earthquake.
Credit: Renee C. Byer / Seattle Post-Intelligencer

Earthquakes

Highlights

- *Seattle area earthquakes fall into three categories: shallow quakes occurring in the North American plate, deep quakes occurring in the San Juan de Fuca plate, and subduction zone quakes that occur in both.*
- *Future shallow earthquakes could occur along the Seattle Fault zone, which extends east-west through the middle of the city, or along newly discovered faults running north-south through Puget Sound. A Seattle Fault quake could be as high as 7.5 to 8.0Mm, but less than 7.0Mm is more probable.*
- *A subduction zone quake would be centered off the Washington coast and could reach 9.0Mm+.*
- *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.*
- *The Duwamish Valley, Interbay, and Rainier Valley are vulnerable to ground failure and shaking because of the liquefiable soils in these areas.*
- *Seattle has at minimum 500 unreinforced masonry buildings, a building type considered highly vulnerable to earthquakes. Most are in older parts of the city such as Pioneer Square, Columbia City, and Ballard.*
- *The city is heavily dependent on its bridges. Damage to them would impair emergency services and the economy. Most have been seismically upgraded.*
- *Property damage for quakes in 1949 and 1965 in the region amounted to $200 million in 1984 dollars. As a result of the 2001 Nisqually Earthquake, damage to Seattle city buildings, infrastructure and response costs exceeded $20 million. Adding in the costs of repairing arterial road structures, the figure topped $36 million.*
- *In a large event, secondary impacts such as landslides, fires, and hazardous materials releases could produce as large an impact as the earthquake itself.*

General

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 a fault from slipping. In the Pacific Northwest, the relatively small San Juan de Fuca plate located off the Washington coast is sliding under the North American plate. Figure 9 shows how this process occurs.

Plate movement is primarily driven by very slow moving 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 mantel material rises, cooling as it nears the surface. The cooler material then begins to slowly sink down, which creates a convection cell.

This process is pushing plates together in the Pacific Northwest. When plates collide, the thinner, denser ocean plate is usually forced under the thicker, lighter rock of the continent. This subduction process 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 subduction zone earthquake.

Pacific Northwest quakes are of three types: shallow, deep, and subduction:

- ❏ Shallow. Shallow earthquakes occur in the North American Plate as it adjusts to the build up of strain along the plate interface. Their depths vary from 0 to 30km. They are usually felt very intensely near their epicenter, but their effects usually diminish quickly with distance. There is an active shallow fault system running through the middle of Seattle (the Seattle Fault). However, there is no consensus on the frequency with which this type of large earthquake might occur.
- ❏ Deep. Deep earthquakes occur in the San Juan plate, usually at depths between 35 and 70km. Since they are farther from the surface, they are not felt as intensely, but are experienced over a wider area than shallow quakes. Deep ruptures in the Juan de Fuca Plate produced the 1949, 1965 and 2001 Western Washington earthquakes, causing major losses.

- ❑ Subduction. Subduction zone earthquakes result when pressure at the interface between the San Juan plate and North American plates unlocks. They occur along a sloped plain from where the plates meet off the Washington coast to just under the coastal area. This fault is over 1,000 km long. Subduction zone earthquakes are the largest type of quake, with magnitudes from 8.0 to over 9.0. They have occurred at intervals ranging from 200 to 1,100 years (State of Washington, 2001).

There are four ways to measure an earthquake:

- ❑ Richter Scale. The most common measure mentioned in the media is the Richter scale (abbreviated Ml) even though contemporary seismologists rarely use it. It is based on the amplitude of ground motion at a seismometer adjusted by the distance to the source. Since the displacement is related to the amount of energy released, it is an attempt to measure the energy released by an earthquake. Other magnitude scales have been developed using different data to achieve faster and/or more accurate measurement of the earthquake's energy. A "moment magnitude measurement" is generally agreed to be the best single measure of size available, but it requires a large amount of data to be determined. Often different techniques will produce slightly different measurements of magnitude, which can cause some confusion.

- ❑ Modified Mercalli Intensity Scale (Table 9). This is a subjective measurement of earthquake effects. The Mercalli scale has twelve steps, which describe damage to structures. Each step is a stronger intensity. Maps drawn from felt reports are useful in determining areas of damage concentration.

- ❑ Acceleration. Another common measure, especially in structural engineering, is acceleration. It is the velocity at which a reference point moves during ground motion and is expressed as a fraction of gravity (g): 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.

- ❑ Duration. The time of ground shaking for each shock is a strong indicator of potential damage, especially in soft soils.

Geology

Besides the power of the earthquake itself, the geology of the area in which it occurs plays a major role in determining the amount of damage. The amplification and directionality of seismic waves depends on soil type, soil stiffness, soil thickness and soil geometry (Weaver,

Table 9. Modified Mercalli Intensity Scale

I.	Not felt except by a very few under especially favorable circumstances.
II.	Felt only by a few persons at rest, especially on upper floors of building. Delicately suspended objects may swing.
III.	Felt quite noticeably by person indoors, especially on upper floors of building. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV.	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars may rock noticeably.
V.	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI.	Felt by all; many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII.	Damage negligible in buildings 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 persons driving motor cars.
VIII.	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, and walls. Heavy furniture overturned.
IX.	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.

2003). Seismic waves ease as they move away from the epicenter, but can change amplitude as they move through different types of soil and rock. Soft soils amplify seismic waives, causing more vulnerable soil farther from the epicenter to shake more intensely than less vulnerable soils closer to 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.

Looser, fill soils are present in Seattle's Duwamish area, including Harbor Island, the east side of West Seattle, Interbay area, University of Washington 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 10). The Duwamish area is considered the best site in the nation to study liquefaction (Weaver, 2003).

Landslides are historical problems in Seattle. They are a common occurrence in earthquakes, which trigger landslides by shaking unstable or steep slopes. Wet conditions can exacerbate slide potential, since water-logged soils are less able to resist sheer pressures in slopes. Landslides are discussed more fully in their own chapter.

Extent

The east-west Seattle Fault zone is at least 5 km wide in the Seattle area. It encompasses the Duwamish area and generally the southern portion of Seattle and West Seattle. Large earthquakes with epicenters relatively close to Seattle, such as the 1949 earthquake and 2001 Nisqually Earthquake, also cause damage in Seattle. FEMA ranks Washington second to California for states susceptible to earthquake loss in the United States. Seattle is the seventh most vulnerable city on the FEMA list (State of Washington, 2001).

History

The Puget Sound region does not experience earthquakes as frequently as Southern California, but when they do happen they can be just as severe. From the time record keeping began, the Puget Sound region has been the most seismically active area in Washington (USGS, 1994). Of the earthquakes recorded, ten quakes of magnitude 4.9 or greater occurred in western Washington. Eight of them were centered in the Puget Sound region:

Dec. 1872	Magnitude 7.4 shallow quake shook the North Cascades. It triggered a huge landslide that temporarily blocked the Columbia River.
Jan. 1909	Magnitude 6.0. centered in the San Juans.
Nov. 1939	Magnitude 5.75. Centered near Olympia. Chimney and building facade damage near the epicenter. No damage reported in Seattle.
Apr. 1945	Magnitude 5.5. Centered under North Bend. Chimney and building facade damage near the epicenter. Boy hit by falling brick in Cle Elum. No damage reported in Seattle.
Feb. 1946	Magnitude 6.3. Centered under mid-Puget Sound. Damage in Seattle mainly limited to the Duwamish Valley and structures built on pilings.
Apr. 1949	Magnitude 7.1. 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 $150 million in damages (measured in 1984 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. 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 $50 million (1984 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 (Rasmussen, 1974). However, these rates are highly speculative.
Jan. 1995	Magnitude 5.0; 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 (Nisqually Earthquake).

Figure 10 indicates the location of ground failures resulting from the 1949, 1965 and 2001 Puget Sound area earthquakes.

Damage Sustained in the Nisqually Earthquake of February 2001

Significant public and private damage occurred in this disaster. In addition, the northern end of the Boeing Field runway was closed for two weeks after the earthquake. Not including damage to arterial roads and bridges, the Nisqually Earthquake caused in excess of $20 million in response costs and repairs to city-owned facilities and systems.

The quake also caused damage to structures serving vulnerable populations. 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, and 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's seismic upgrade is slated to begin in 2004. 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 (Meszaros and Fiegener, EDA 2002). 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 shake, similar to the shake experienced in heavily damaged areas in the 1994 Northridge, California earthquake. Nearly 40% of Harbor Island firms had direct losses exceeding $20,000. They also suffered high rates of indirect losses from disruptions to operations (Meszaros and Fiegener, EDA 2002).

Probability of Future Occurrences

Based on historic seismicity, deep earthquakes are the most common type of damaging earthquakes. Large events of deep earthquakes with a magnitude of 6.0 or greater are believed to recur every 30 to 50 years. The frequency intervals for the other types of quakes are less certain. The USGS estimates the colliding plate events repeat every 200 to 1,100 years, with an average recurrence interval of 550 years. At present, estimates of the repeat rates for shallow quakes in the Puget Sound area are tentatively placed at 500 years for magnitude 6.0 events (USGS).

The Seattle region has not experienced a Seattle Fault or subduction zone quake in modern times. However, a subduction quake did occur roughly 300 years ago, and there is evidence that the Seattle Fault moved 1,100 years ago. Deposits from massive block landslides into Lake Washington and a tsunami dated at approximately the same time led scientists to conclude they most likely had a common cause - a Seattle Fault earthquake. Since these quakes have happened in the past, they will probably happen again.

Vulnerability

Table 10 indicates the characteristics of each of the three types of large earthquakes. The highest estimated magnitude for a deep quake is 7.5, although the most likely event would probably be less intense. They typically last 10-30 seconds, create ground accelerations of 0.20-0.35g, and do not generate any aftershocks. Their epicenters can be anywhere in Puget Sound and would be felt over a large area. The 1949 earthquake was centered around Olympia, but did substantial damage in Seattle.

In contrast, a large subduction zone earthquake would be centered farther away (off the coast) and could be huge. The USGS expects magnitudes of 8.0 to over 9.0. In Seattle, it could cause one to three minutes with accelerations of up to 0.5g and would be accompanied by many aftershocks.

Table 10. Seismicity Summary

Source Zone	How Big?	Where?	Rate of Occurrence? Next Event?	Why do they occur?	Precursors Aftershocks	Shaking Effects
Interplate or Benioff Zone	7.1 largest known (1949 Olympia)	At depths of 45-60 km in the juan de Fuca & Gorda Plates	2 magnitude 7 events in 130 yrs. 5 events > mag. 6 since 1909	Gravitational stress & phase changes within subducting plates.	None expected	15-30 secs strong shaking.
"Deep"	7.5 largest expected		?		None recorded after 1949, 1965. None expected	Acceleration of 0.20 - 0.35 g
Interface of Subduction Zone	1992 Petrolla mag. 7.1 may be on Interface	From offshore deformation front to western Coast Range & Olympic Mts.	Every 300-500 yrs. Last event about 300 yrs ago.	Convergence at locked interface between Juan de Fuca & N. American Plates	Probable	Mag. 8, 1 - 3 min. of strong shaking; accel of 0.5 g in urban areas
	8.0 - 9.0 mag. Expected.		?		Many expected mag. To 7.5+	Mag. 9, duration & accel need study
Crustal	1872 N. Cascades largest known, approx. mag. 7.5	Known on Vancouver Isl., N. Cascades & Seattle Fault	Uncertain, 4 known in last 1000 yrs. From Vancouver Isl. To Seattle	Uncertain	Unclear	Accel. > 0.5 g but not studied.
(N. American Plate)	Largest expected < mag. 8.0	Other areas are possible - Portland Fault	?		Many expected mag. To 6.5+	Durations not studied, but 20 - 60 secs likely.

Source: USGS Open-File 94-226B

A large quake along the Seattle Fault is the worst-case earthquake scenario for the city. Magnitudes could reach 8.0 with accelerations of over 0.5g for 20-60 seconds. The epicenter could be directly under the city, causing Seattle to take the direct brunt of the ground motion.

The Earthquake Engineering Research Institute conducted a Seattle Fault Scenario that modeled a magnitude 6.7 quake, with a depth of approximately 5 miles and a break length of approximately 25 miles. The 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. A rupture on the Seattle Fault zone could severely disrupt north-south lifeline systems, including utilities and transportation routes (EERI, 2003).

The most damage-prone parts of the city are where vulnerable geology, structures, and populations coexist in areas that could be easily isolated due to breaks in the transportation network. These locations produce vulnerabilities for the whole city because of their social, political or economic importance.

Seattle's most vulnerable areas geologically are its liquefaction and landslide prone areas (see figure 11), which generally experience more ground motion and higher accelerations than other areas. The city has mapped these areas. The major liquefaction zones are in the Duwamish Valley, Interbay, and the Rainier Valley where the land uses are mainly commercial. 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.

Vulnerable structures are also 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 at least 500 URMs, mainly in the older areas of the city: Downtown, Ballard, Capitol Hill, Columbia City, and the U-District. The number of concrete frame and tilt-up structures is not known; however a 1992 report found them throughout the city, including more recently developed areas like Lake City Way (EQE, 1994). Most of these buildings are commercial and older multi-family dwellings.

Most of Seattle's housing stock would perform relatively well in an earthquake. Although a majority of the housing units were built prior to the introduction of modern seismic codes in 1949, many of them (and nearly all of the single-family units) are wood-frame, a type that performs well in earthquakes from a safety standpoint. Areas with large concentrations of older, multi-family structures may be more vulnerable because taller buildings experience more lateral force during an earthquake and more people occupy them. The older central areas such as Downtown, Belltown, First Hill, Capitol Hill and Queen Anne have the largest number, but significant numbers also exist in the University District and Ballard.

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 of the first nineteen surveyed, thirteen had a high probability of catastrophic failure (Seattle Engineering Department, 1992). By the end of 1999, all city-owned bridges were studied. Since that time, many have been upgraded. Even with the improvements, these bridges are not designed to withstand a strong Seattle Fault or large, deep quake (shaking over 0.3g for more than a few seconds). In addition, the upgrade program does not cover bridges maintained by the Washington State Department of Transportation, which include such critical bridges as the I-5 Ship Canal Bridge and the Aurora Bridge. Furthermore, 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 considered to be at risk of failure in a major earthquake.

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

Most earthquakes damage utility networks. Figure 12 shows the location of water pipe breaks during the 1949, 1965 and 2001 quakes. Underground systems 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 (Cygna, 1990). Other systems (power, sewer, telephone, and gas) have not been recently studied and 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 (Bolin, 1989). This performance is quite good, but it is important to recognize that the epicenters in these quakes were far from the areas studied.

Secondary impacts from earthquakes have a major bearing on a location's overall vulnerability. The most important are fires, landslides, hazardous materials releases, tsunamis, and seiches.

Fires are the most dangerous of the secondary events. Most of the 28,000 buildings destroyed in San Francisco in 1906 were destroyed in the conflagration that followed the earthquake. Multiple ignitions are the most dangerous post-earthquake fire hazard. 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 (1992). 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 an 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.

Tsunamis are less possible, but could be highly dangerous. A subduction zone or Seattle Fault quake could generate a tsunami, although only a locally generated tsunami would damage Seattle. Quakes usually have a magnitude of 7.0 or greater before they generate a tsunami (Byrant, 1991; Noson, 1988). They are extremely dangerous since they can occur with little warning, crush buildings, and flood coastal areas. Seattle never considered itself a possible tsunami target, but the discovery of tsunami-deposited sand on Bainbridge Island indicates they can happen here. Damage in some areas would have indirect effects on the rest of the city. They are covered in their own chapter.

Landslides and hazardous materials releases are a strong probability in any large earthquake. These hazards are described in their own chapters.

Effects

Any large earthquake could cause hundreds or thousands of deaths depending on the time of day, the day of the week, the weather, and the amount of secondary events. During past quakes, casualties were light, but Seattle could receive a shock much bigger than it has in the past. If this were to happen, many more casualties could result. One study estimated that more than 140 buildings are likely to collapse catastrophically, which would produce anywhere from 300 to 1700 dead or seriously injured persons (EQE, 1993). This number does not include those who would be injured by falling debris, landslides, fires, or a tsunami.

Any large earthquake damages the built environment and hampers city service delivery. One of the first post-quake tasks, searching for victims, would be an overwhelming challenge for the city. The same 1993 EQE study estimates that 1,400 search and rescue personnel will be needed to look through the rubble. Seattle does not have this kind of manpower, and the amount of outside help from private, state, and federal sources could be stretched thin if other areas are also hard hit. These facts led the study to conclude that the emergency responders would face 'significant shortfalls' in their capacity to respond to post-earthquake demands (EQE, xiii).

Most utility services would be interrupted in large parts of the city. Another deep quake would probably cause only minor interruptions, but they could be severe if the epicenter was closer to Seattle or if the region experiences a larger shallow or subduction zone quake. 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.

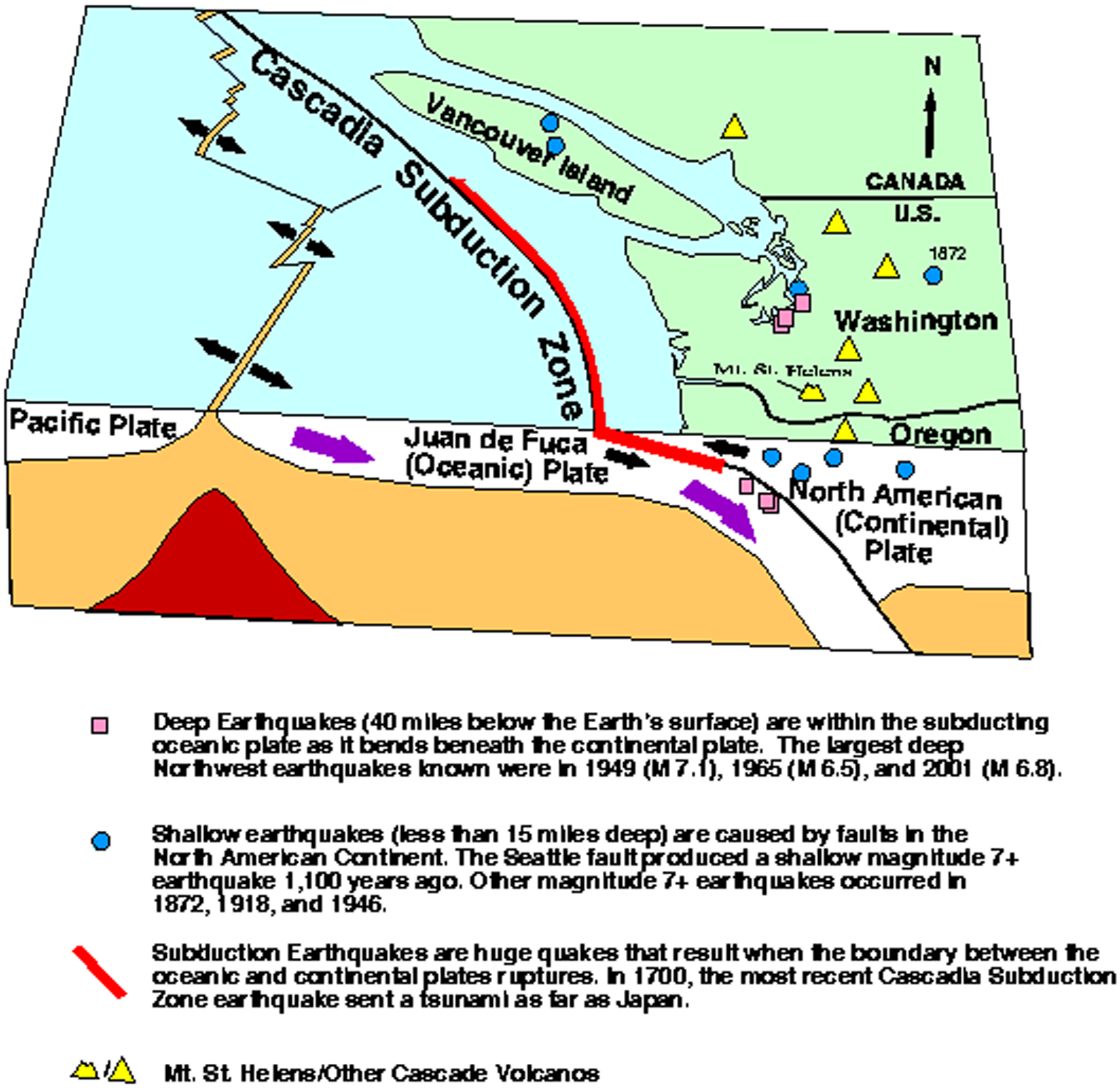
Transportation problems would be another widely felt inconvenience. If any of the bridges or overpasses goes down, the city and state would probably depend on the federal government to help fund the reconstruction. Given the increasingly political nature of this funding, any transportation infrastructure damage could persist for months or even years. Traffic in Seattle is already annoying to many residents and would only get worse with the loss of a bridge or freeway ramp serving thousands of vehicles daily. The loss would shift those vehicles onto other bridges and ramps, increasing congestion.

The economic impacts of a large earthquake could be enormous. Many of the city's most vulnerable structures (unreinforced masonry) 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.

Conclusions

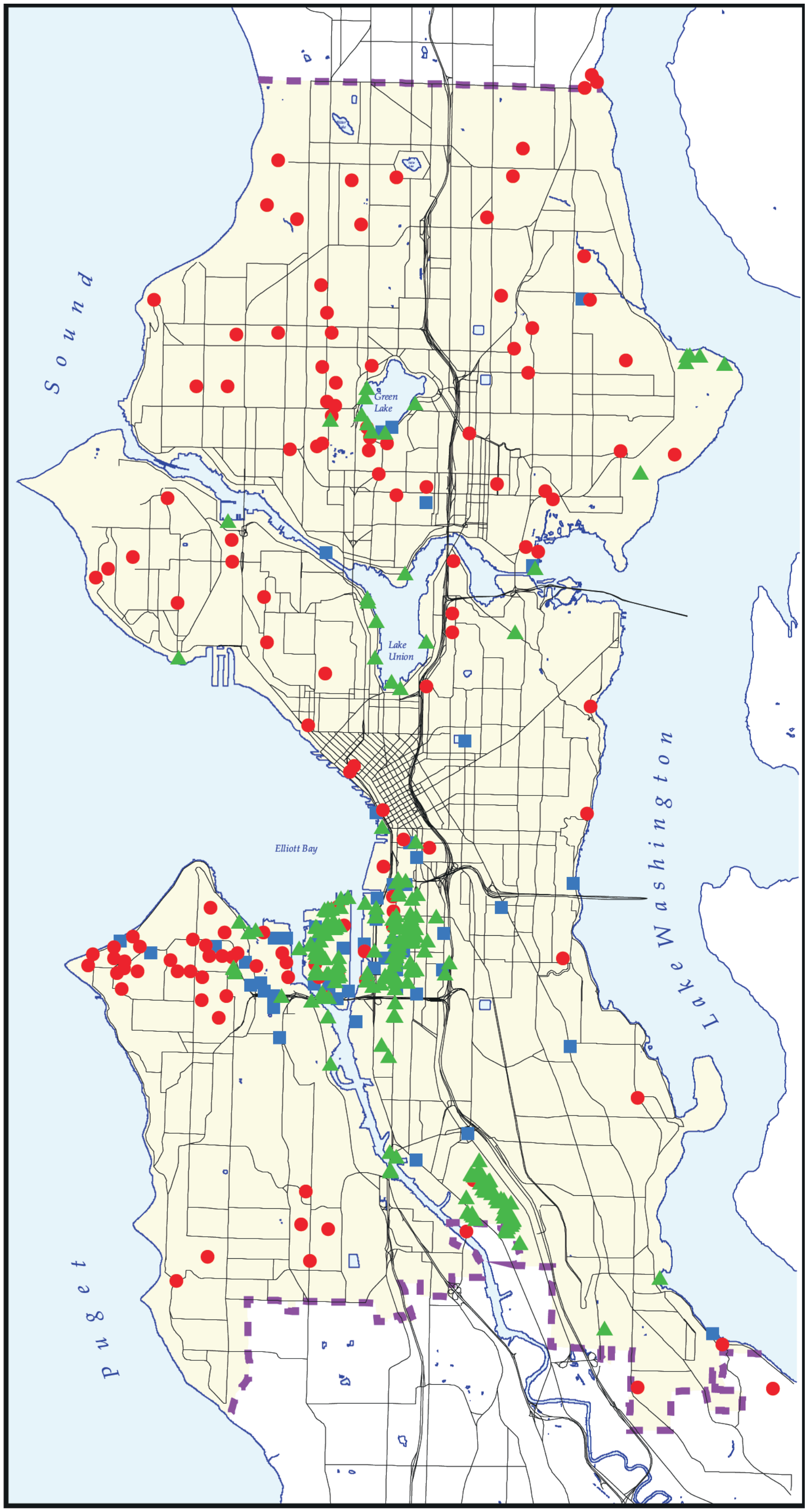
Earthquakes are both high probability and high impact events in Western Washington, making them the most likely cause of the most damaging disaster Seattle will face. A large earthquake could cause hundreds of deaths and lasting damage to the city's economic base. They could spawn hazardous materials spills, landslides, conflagrations, seiches, or even a tsunami. Each of these secondary events would cause additional damage and casualties.

Figure 9. Cascadia Subduction Zone



Source: UW Pacific Northwest Seismograph Network (PNSN)

Figure 10. Earthquake Related Ground Failures for the 1949, 1965 and 2001 Earthquakes

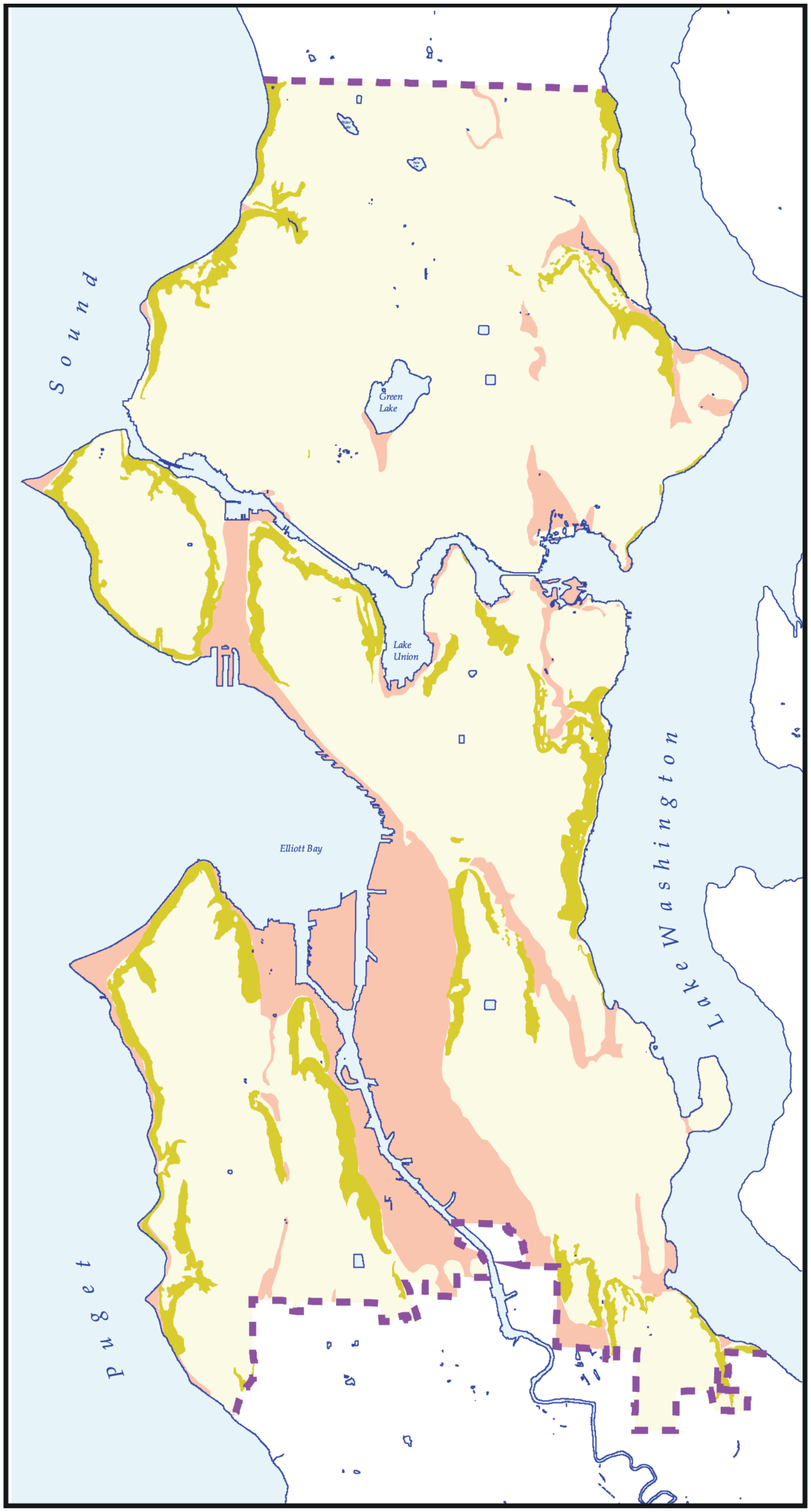


Legend

- 2001 Ground Failures
- 1965 Ground Failures
- 1949 Ground Failures

1 0 1 Miles

Figure 11. Seattle Areas Prone to Liquefaction and Landslides

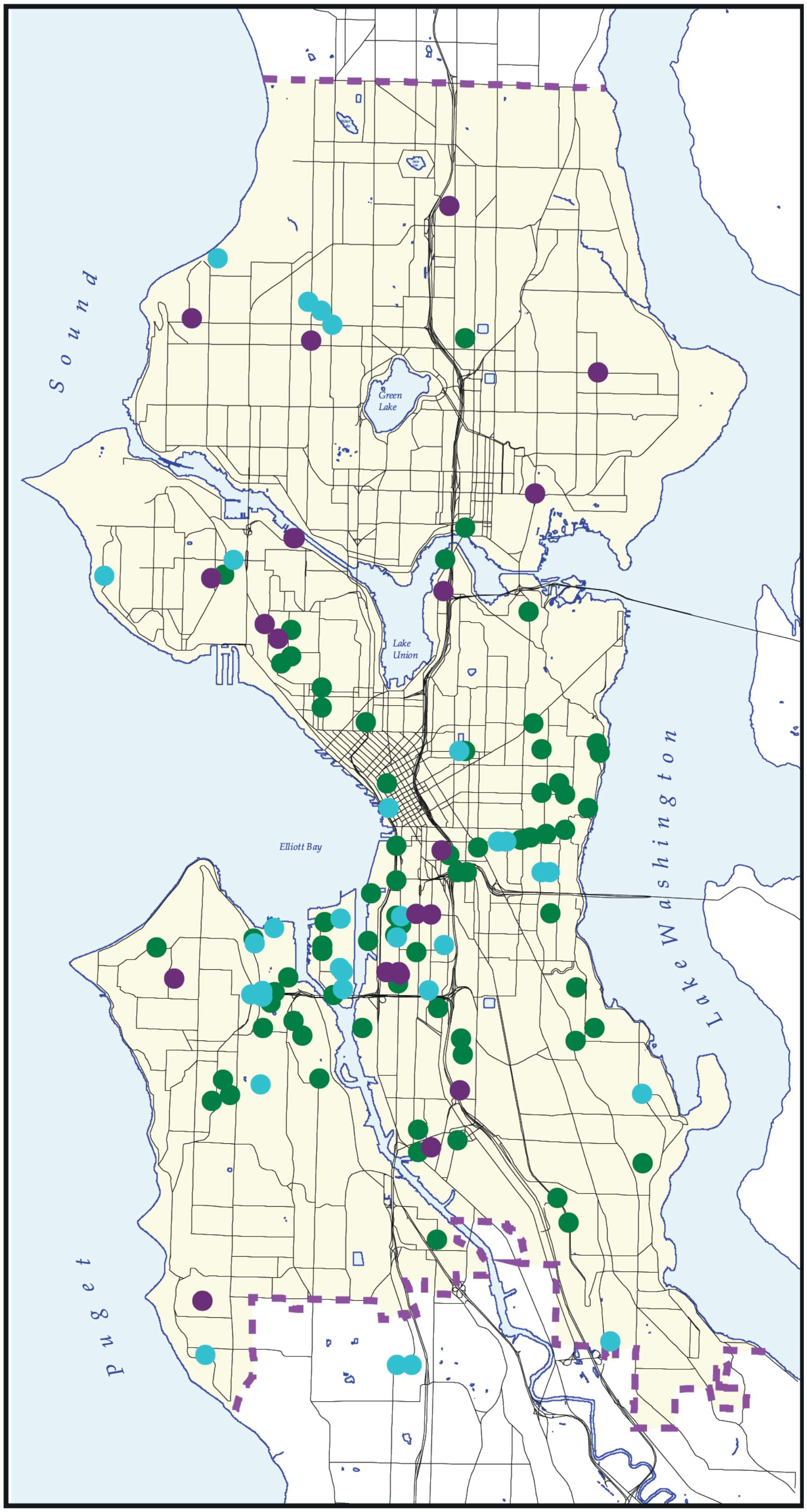


Legend

Potential Slides Area
Liquefaction Area

1 0 1 Miles

Figure 12. Earthquake Related Water Leaks



Legend
- Leaks following 2001 Earthquake
- Leaks following 1965 earthquake
- Leaks following 1949 earthquake

1 0 1 Miles

Flooding

A man watches flood waters rise toward the top of sandbags protecting his home during the 1990 floods. Credit: Harley Soltes / Seattle Times

Flooding

Highlights

- *The 100 year floodplains cover South Park, and the drainage basins for Thornton and Longfellow Creeks.*
- *Flood control structures have been built in all of Seattle's floodplains.*
- *Participation in the flood insurance program in Seattle is low.*
- *A break in the Hanson Dam, the closest dam to Seattle, is not projected to cause flooding in Seattle.*
- *Coastal flooding due to storms could produce some damage, but Seattle is not especially vulnerable to them.*
- *Flooding in the Duwamish Valley could affect industry, but this is unlikely.*
- *The most common type of flooding is shallow inundation in residential areas.*

General

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. Even flooding outside Seattle can have an indirect effect. Flooding along the Tolt and Cedar Rivers can decrease water quality to the point where it cannot be used.

There are three types of floods - riverine, flash, and coastal:

- ❏ Riverine flooding happens in a river or stream's floodplain and is caused by the rate and amount of water entering the drainage area, ground conditions, water levels in lakes and reservoirs, and obstructions in the river's floodplain.
- ❏ Flash floods are a type of riverine flooding, but occur after heavy storms when rainwater washes into a river's catchment area without being absorbed into the ground.
- ❏ Coastal floods are caused by storms moving onshore from the sea especially during high tides. Sometimes seismic activity produces it by creating tsunami or seiches (a disturbance similar to sloshing water in a tub) within enclosed bodies of water. Because seiches and tsunami have very distinct characteristics, they are covered in their own chapter.

The key factors determining the amount of damage in a flood are the depth and turbulence 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 U.S. Army Corps of Engineers. 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 .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 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. They 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. Storm surges as high as 23 feet have been reported in conjunction with tropical storms. Since they accompany storms, they 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.

Currently, all levels of government employ structural and non-structural means to reduce flood risk. In the past, structural methods, i.e., the construction of dams, levees, and bulkheads, were the most common. During the 1950's and 1960's, 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.

Other areas within the city have continued to have periodic minor flooding, especially the areas along 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 (FEMA, 1994). 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.

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 in 1975 and 1990. This flooding led to turbidity that threatened the quality of the city's water supply and overwhelmed the Water Department. Seattle was lucky these floods occurred in the winter, when demand for water is low. Even more frequent problems occur along the Tolt, but this system is used mainly to supply peak summer demand and shutting it down in the winter has not had a big effect.

Vulnerability

The National Flood Insurance Rate Maps and US Army Corps of Engineers inundation maps indicate areas directly vulnerable to flooding in Seattle. The latter shows the area affected by a potential break of the Howard Hanson Dam. These maps show that the locations prone to flooding are quite limited (see Figure 13). They seem vulnerable mostly during the winter. 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 Creek. However, each has its limits. The Thornton Creek diversion is effective up to the 100-year flood; however, the Longfellow basin was only partially effective during the January 1986 flood (FEMA, 1994).

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. Even then Seattle would probably not suffer since the areas upstream would flood before high water reached the city. The only exception might be the parts of South Park that are within the 100-year floodplain.

The failure of levees just outside the city limits could produce localized flooding at Boeing field and City Light facilities. 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.

Coastal problems are the final item on this list of possible flood hazards. Since the most powerful storms the area has faced did not produce any major flooding, it is unlikely that it would occur in the future. The National Flood Insurance Rate Maps, which show no coastal floodplains in Seattle, support this assessment.

Effects

The Duwamish Valley is the least likely place for a 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.

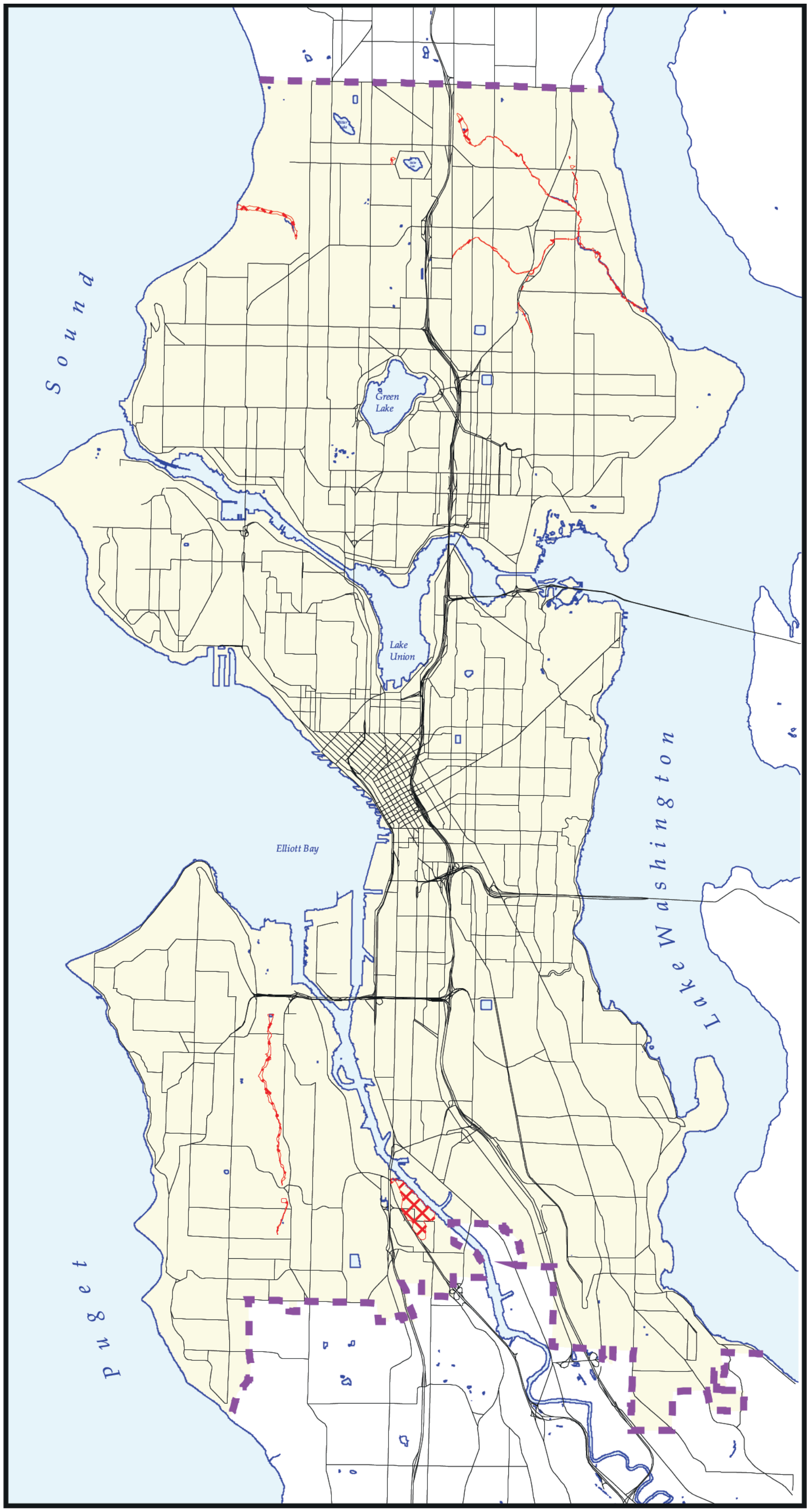
The most frequent flooding occurs in residential and open areas along Longfellow and Thornton Creeks. This residential flooding has a much less pronounced effect on the local economy, since the economic base remains unaffected. Nevertheless, a flood could make transportation difficult in the affected area. This type of flooding's low depth and water velocity 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.

Conclusions

Flood control is an old activity in 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. Instead of making major changes, the city should strive to maintain its present system.

Figure 13. Seattle 100 year Floodplains



Legend

Flood Prone AreaCritical Areas by Ordinance

1 0 1 Miles

Hazardous Materials Incidents

Officals discuss a derailed chemical train car under the Alaska Way Viaduct during the mid 1980's.
Credit: Jimi Lott / Seattle Times

Hazardous Materials Incidents

Highlights

- *Fixed sites are the most common locations for accidents, but the greatest vulnerability is to transportation accidents.*
- *Most transportation accidents occur in rural areas.*
- *Other disasters (e.g. earthquakes, landslides) could produce hazardous materials incidents.*
- *Areas up to one half mile downwind from an accident site are considered vulnerable according the US Dept. of Transportation, which could affect thousands of people in densely populated sections of Seattle.*
- *Casualties have been light in Seattle, but incidents in other locations demonstrate that a single hazardous materials incident can kill or injure hundreds of people.*
- *Most incidents would be localized emergencies without large economic effects.*

General

Since the rise of the environmental movement, there has been a growing understanding of the dangers posed by widespread chemical use. The problems vary widely in intensity and duration. This chapter covers only those incidents that pose an immediate threat to large numbers of people.

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, that runs a 24-hour hotline. 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 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, 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 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 Sante Fe Railway, Bank of America and a member of the public.

Large accidents almost always occur at fixed sites (i.e., factories and storage sites) or during transport. Usually transport incidents are the most difficult to fight, since they often happen in uncontained settings and/or populated areas. Responders do not have detailed site plans and chemical inventories during transportation accidents. Finally, hazardous waste dumps present other problems because they often house many uninventoried and unstable chemicals.

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.

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 emergencies. Constructing a detailed history is difficult. As a result, this section highlights major incidents.

One 1975 incident is typical of the problems posed by chemicals. A gasoline tanker traveling north on the Alaska Way Viaduct lost control, bounced sideways, and crashed against the guardrail. During the accident, the tank ruptured. Gasoline flowed down the side of the Viaduct where it was ignited by flares set coincidentally by a railroad crew. The resulting fire damaged several buildings, but there were no casualties (Seattle Fire Department, 1994).

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, or about 10.2%, of these involved transportation and 106, or 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 does not indicate if it occurred in King County. Additionally, 29 incidents resulted in the evacuation of nearly 1400 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.

Complementing these data is information kept by the Seattle Fire Department. The records for 1993 indicate there were 57 events in Seattle. Unfortunately, there is no way to connect the 1992 data for the county and the 1993 city data.

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

The mass of data on hazardous material can be confusing, but it does suggest some patterns of vulnerability and it is possible to construct a profile of locations that could suffer from a hazardous materials event.

Vulnerability

Using the general information available on catastrophic hazardous materials incidents and the local geography, it is possible to speculate about the location of a future event. The broadest type of information suggests 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. Figure 14 shows the location of Combined Sewer Overflows, where the sewer system discharges runoff during storms. Finally, 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, as well as the 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 refines 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.

Places that are currently contaminated are likely sources of future releases. Figure 15 shows some of the main locations where hazardous materials incidents have occurred in the past. Figure 16 shows the major transportation routes in the city. Together these two maps give some idea of the areas that a hazardous materials emergency could affect.

Effects

The effects of a large hazardous materials incident are unpredictable, because there is not a long history of such large incidents in Seattle. In general, hazardous materials emergencies are 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.

The immediate effects of individual incidents will probably not reach the level of a citywide emergency. The most common sources of large accidents are petroleum, metal, and chemical plants. There are relatively less of these facilities in Seattle compared to other U.S. cities, decreasing the probably of a large event (Seattle Planning Department, August 1991). Despite being low probability incidents, transportation accidents would be difficult to handle and could produce many casualties among persons not directly involved with the chemicals.

The effects of a hazardous material event could be extremely serious. Nationally, many accidents have caused fatalities, especially when there has been a negligent response. Many bystanders have been injured because people were not removed quickly enough or allowed to return in a prolonged evacuation (Cashman, 1988).

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.

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.

Figure 14. Combined Sewer Overflow Locations

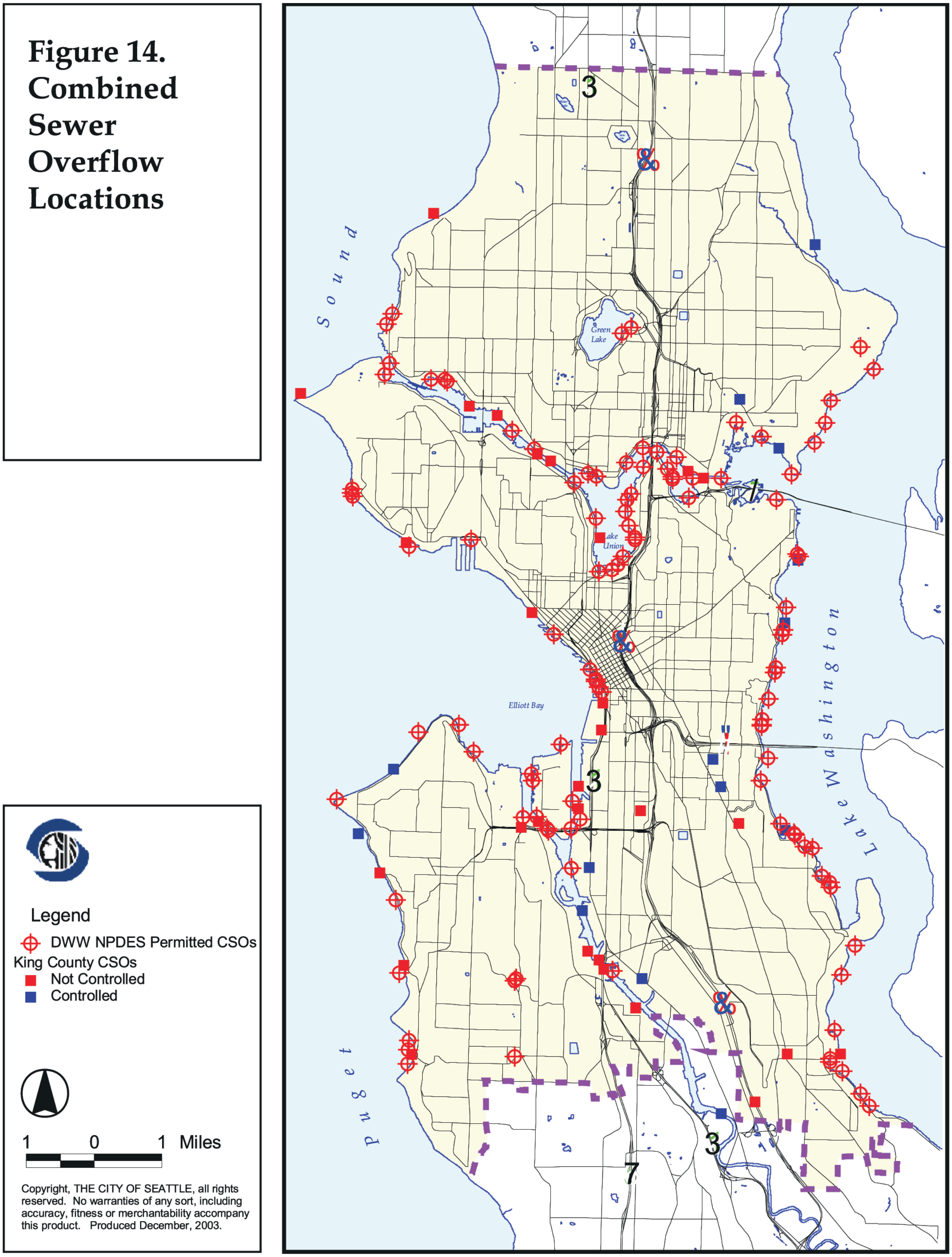
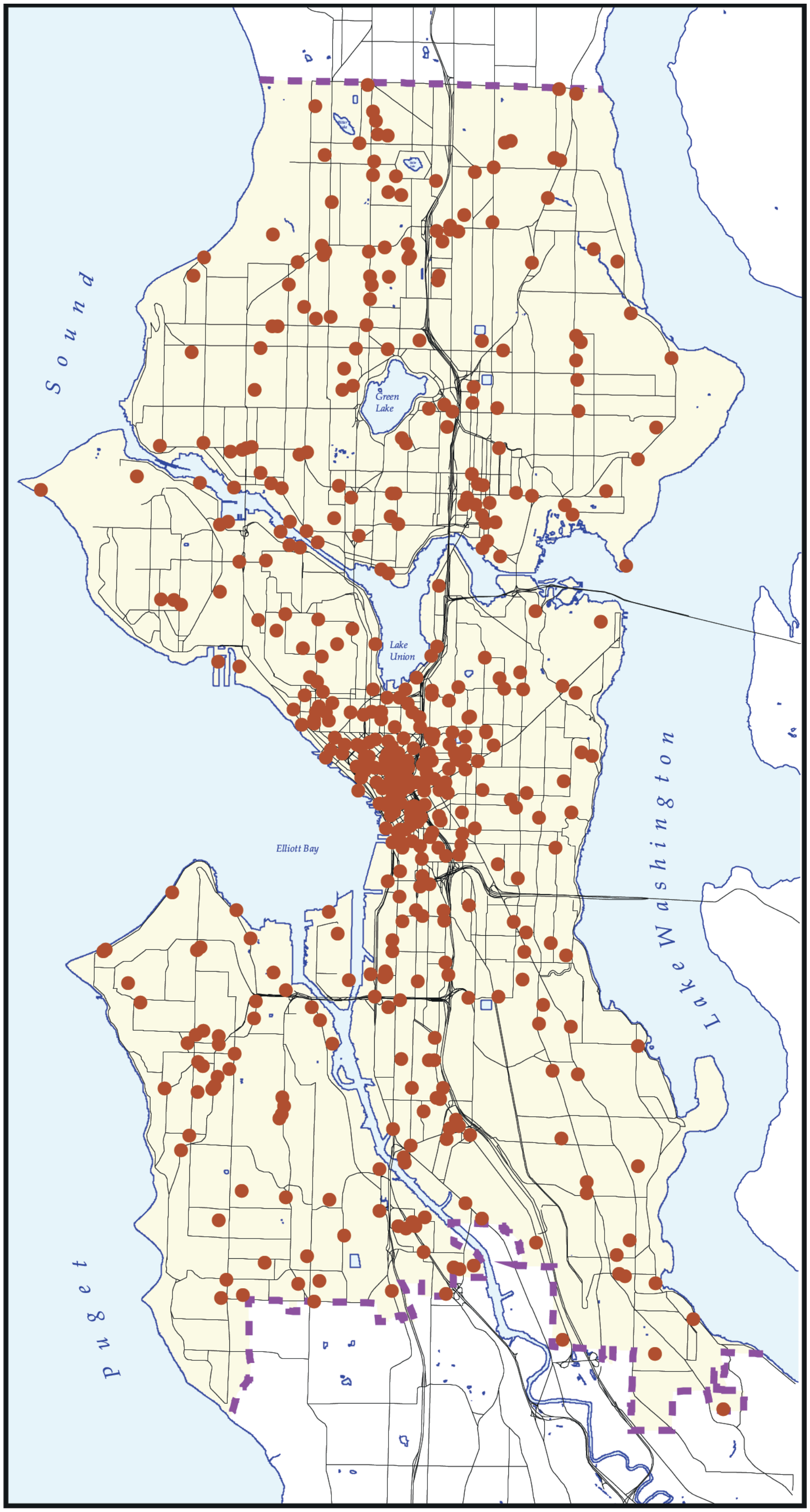


Figure 15. Haz-Mat Incident Locations 1998-2003

Note: This list includes calls on which no actual hazardous materials were found.

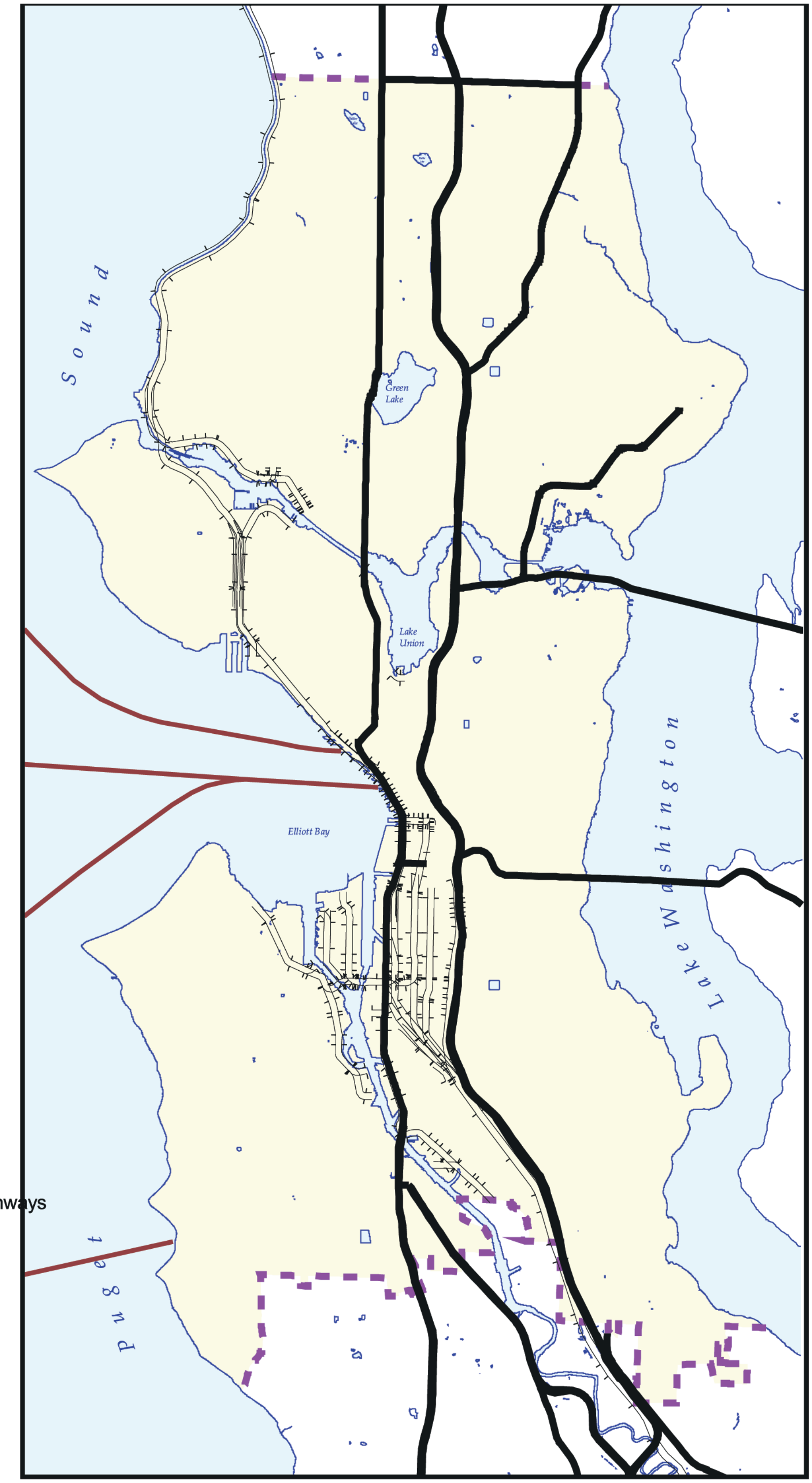


Legend

● Haz-Mat Incident Locations

1 0 1 Miles

Figure 16. Major Transportation Corridors



Legend

- Ferry Routes
- Railroads
- Freeways and State Highways

1 0 1 Miles

Landslides

A 1997 Landslide next to Magnolia Bridge. This slide closed the bridge for several months. Credit: Tim Walsh, WA St Dept of Natural Resources.

Landslides

Highlights

- *Slides are high frequency events. Some, like the 1972 and 1997 slides, caused millions of dollars in damage.*
- *Individual slides do not appear to cause city-scale emergencies, but multiple slides, especially when distributed throughout the city do seem to cause severe problems.*
- *Slides do cause fatalities occasionally, but most of the damage they do is to property.*
- *Winter and spring are the most probable times for slides.*
- *Residences are the structures most affected.*
- *Landslides can precipitate other emergencies, most notably flooding and hazardous materials incidents.*

General

Landslides are common in Seattle. They occur when there is tension between the stresses pulling down on a slope and the resistance holding it in place. The slope becomes more and more unstable as the forces of resistance and stress converge. The change in these forces is caused by dynamic factors. Some develop gradually, such as normal erosion and weathering. Others occur suddenly, such as earthquakes and torrential rains that increase water pressure within a slope. Usually, the most catastrophic landslides occur on slopes that already have a low margin of safety (often due to weathering and erosion) and are struck by a sudden event (i.e., an earthquake, rain, or human alteration of the slope). Determining a slope's slide potential rests on discovering the inherent stability of the slope and the intensity of forces that undermine its stability.

Four kinds of slides occur in Seattle (Shannon & Wilson, 2000):

- ❏ High Bluff Peeloff – blocks of soil fall from the high bluffs primarily along the cliffs of Puget Sound;
- ❏ Groundwater Blowout – groundwater pressure built up at the contact between pervious and impervious soil units causes a catastrophic groundwater and soil burst;
- ❏ Deep-seated Landslides – deep, rotational or translational slides and slumps caused by groundwater pressures within a hillside;
- ❏ Shallow Colluvial (Skin Slide) – shallow and rapid slides on a slope, which may result in a debris flow.

Late winter and early spring are the most common times for slides, although most of the documented slides in Seattle have occurred in January (Shannon & Wilson, 2000). According to Tubbs (1975), the probability of sliding rises after a wet, cold winter, especially if a freeze occurs in late winter and early spring. 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 result when water is involved, and the majority include human influence (Shannon & Wilson, 2000).

USGS scientists are now comparing current rainfall (or a rainfall forecast) with conditions that have historically caused landslides in order to determine a "rainfall threshold" that suggests when rainfall conditions are likely to cause landslides.

In addition, the USGS, City of Seattle and Shannon & Wilson are partnering in producing maps that identify "hazard zones" which correspond to areas of potential land instability.

Location

Landslides in Seattle result from a combination of steep slopes, glacial and post-glacial soils, and a pronounced wet winter season (Shannon & Wilson, 2000). Our area's landslides typically occur at the trace of the contact between the Esperance Sand and either the Lawton Clay or pre-Lawton sediments (Tubbs, 1975). Figure 17 indicates soil layers at varying elevations.

The city's information about landslide prone areas is based on Donald Tubb's work in the mid-1970's and the

2000 Seattle Landslide Study database of 1,326 landslides dating back to 1890. Tubb's work is the basis for the city's original map of landslide prone areas. The City of Seattle's update indicates potential and known slide areas based on historic landslides, and a zone around many of the hills and ridges where the Esperance Sand/Lawton Clay contact was mapped by Tubbs in 1974.

Landslide-prone steep slopes mapped by the city are those slopes steeper than 40% with a rise exceeding 10 vertical feet (Shannon & Wilson, 2000). Data challenges include the lack of information linking the magnitude of past slides to their location.

Landslides occur in approximately 1% of Seattle, near the edges of steep and predominantly linear hills (see figures 2 and 11). 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 (Shannon & Wilson, 2000). 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 (Shannon & Wilson, 2000).

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 (Shannon & Wilson, 2000).

History

The events listed below were found in numerous newspaper articles and city records. The most frequent are small events that do not require an activation of the city's emergency plan. 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 (2000) indicated that Seattle's three worst years for landslides were 1966/67, 1985/86 and 1996/97.

1921 Six major slides occur during one weekend (Seattle Times, 12/6/64).

1934 More than 400 Seattleites battle slides in ten areas of the city. These slides prompted numerous repair projects (Seattle Times, 1/22/34 and 7/6/34).

1941 Several slides occur during December around Sand Point (Seattle Times, 12/2/41 and 12/19/41).

1947 Several children die when a slide destroys their home (Seattle Times, 2/3/47).

1948 Multiple slide events in Magnolia and Yesler Terrace (Seattle Times, 2/26/48).

1950 Many slides occurred in the spring. They may have been connected with heavy snowfall as the 1997 events were (Seattle Times 4/13/50).

1961 Slides occur in many areas of the city during the spring (Seattle Times: 2/7/61, 2/27/61, 3/3/61, 3/14/61, and 4/12/61).

1965 SR 520 threatened, one lane closed, Roanoke interchange closed (Seattle Times 12/31/65).

1969 Large slides occur on Magnolia Bluff (Seattle Times 1/8/69).

1972 Slides destroy homes in Madrona causing about $1.8 million in damage. These slides were also probably connected with snowfall (Seattle Times 1/23/72, Tubbs, 1975).

1974 West Seattle experiences multiple slides in the winter. Golden Gardens was also damaged. The mayor authorizes assistance (Seattle Times, 4/13/74).

1983 Queen Anne slide closes Aurora for a day. Mud travels as far as Lake Union (Fox, 1993).

1996 A large slump along Perkins Lane in Magnolia destroys five homes (January).

1997 Over 100 slides reported in the city (January). These slides and the accompanying snow caused approximately $100 million in damages.

1997 More slides occurred in a continuation of the wet winter (March).

Figure 18 indicates major landslide locations of 1996, 1997 and 1998. Shannon & Wilson (2000) indicated that landslides west of Beacon Hill occurred prior to the 1960's. However, since then landslides in this area have not occurred, probably because the construction of I-5 stabilized the Beacon Hill landslide areas.

On occasion, landslides have resulted in fatalities in the Seattle area. The most destructive landslides, the deep-seated ones, tend to affect several properties and may cover one or more city blocks. The areas prone to landslides also may experience clusters of smaller landslides or types other than deep-seated slides.

Vulnerability

Landslides are a frequent occurrence in Seattle. As the city has grown, the pressure to build in vulnerable areas has also grown. With more people living and working in these areas, the exposed population and capital invested there have also increased. Following the slides in 1997, the city began to study its regulations of development in slide prone areas.

Landslide prone areas are mostly in either open space or residential areas. 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.

In the past, the greatest vulnerability has been to property rather than public safety. However, the deaths of a Bainbridge Island family and the sudden damage to a Seattle daycare in 1997 suggest that public safety threats from slides may be increasing.

Landslides can disrupt roads and other lifelines. Seattle's roads are vulnerable, since many major highways and arterials run along slopes prone to landslides. The Burlington Northern tracks along Puget Sound are also frequently blocked by slides. If the proposed Sound Transit commuter rail link is run on these tracks, there will be a further increase in the population exposed to slide dangers. To reduce the risk, the USGS has installed monitors in Woodway north of the city.

Late winter and early spring are the most common times for slides to occur. According to Tubbs (1975), the probability of sliding rises after a wet, cold winter, especially if a freeze occurs in late winter and early spring. 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 stress to the slope by adding weight and by increasing pore pressure within the soil.

Effects

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.

The most frequent private damage was to residences. Unfortunately, there is little information about 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.

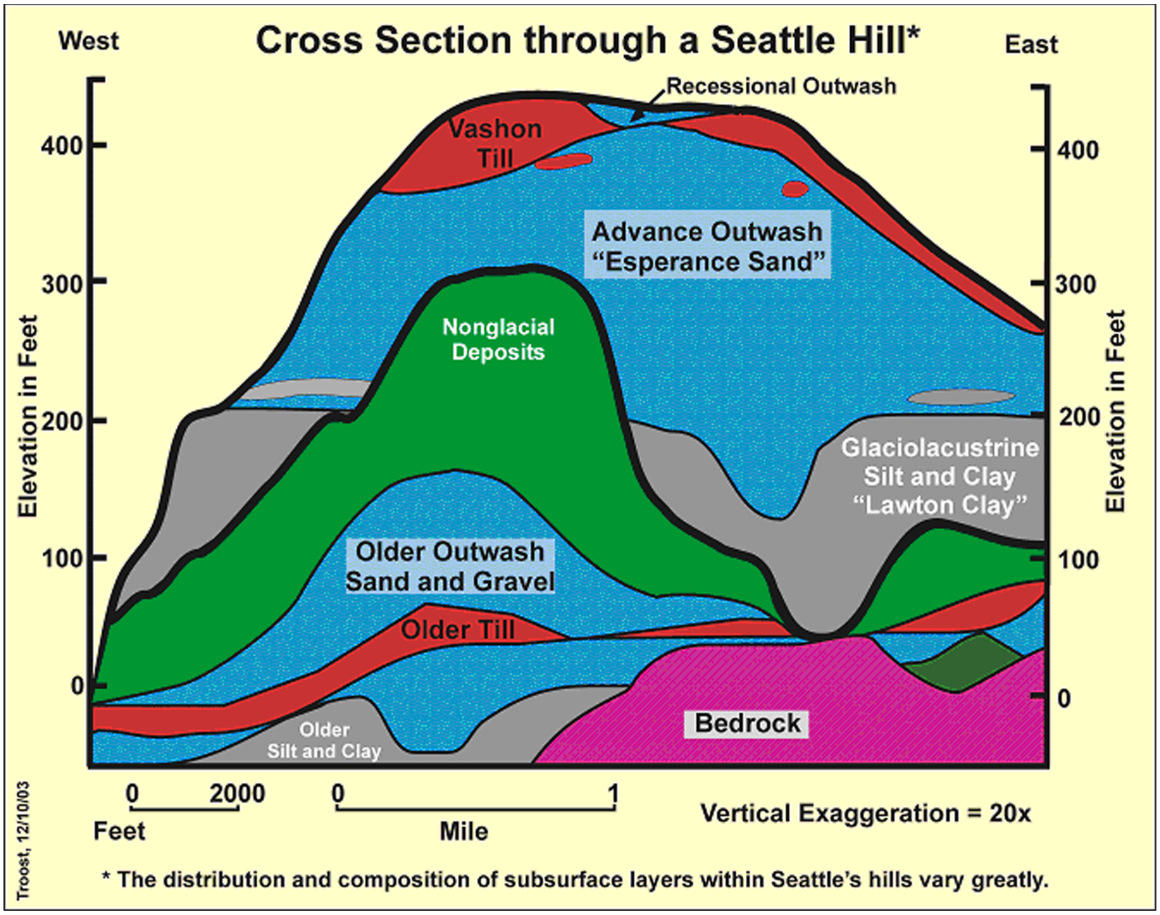
Transportation corridors could very well be blocked by future slides. Both I-5 and I-90 run through a large slide area around Beacon Hill. Aurora has been blocked by slides along the east face of Queen Anne Hill several times. Since each one of these routes handles thousands of vehicles every day, slides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

Landslides can induce other disasters. They can cause flooding by blocking rivers, streams and storm drains and lead to releases of hazardous materials by destroying waste and storage sites. The highest probability of the latter occurrence is where 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.

Conclusions

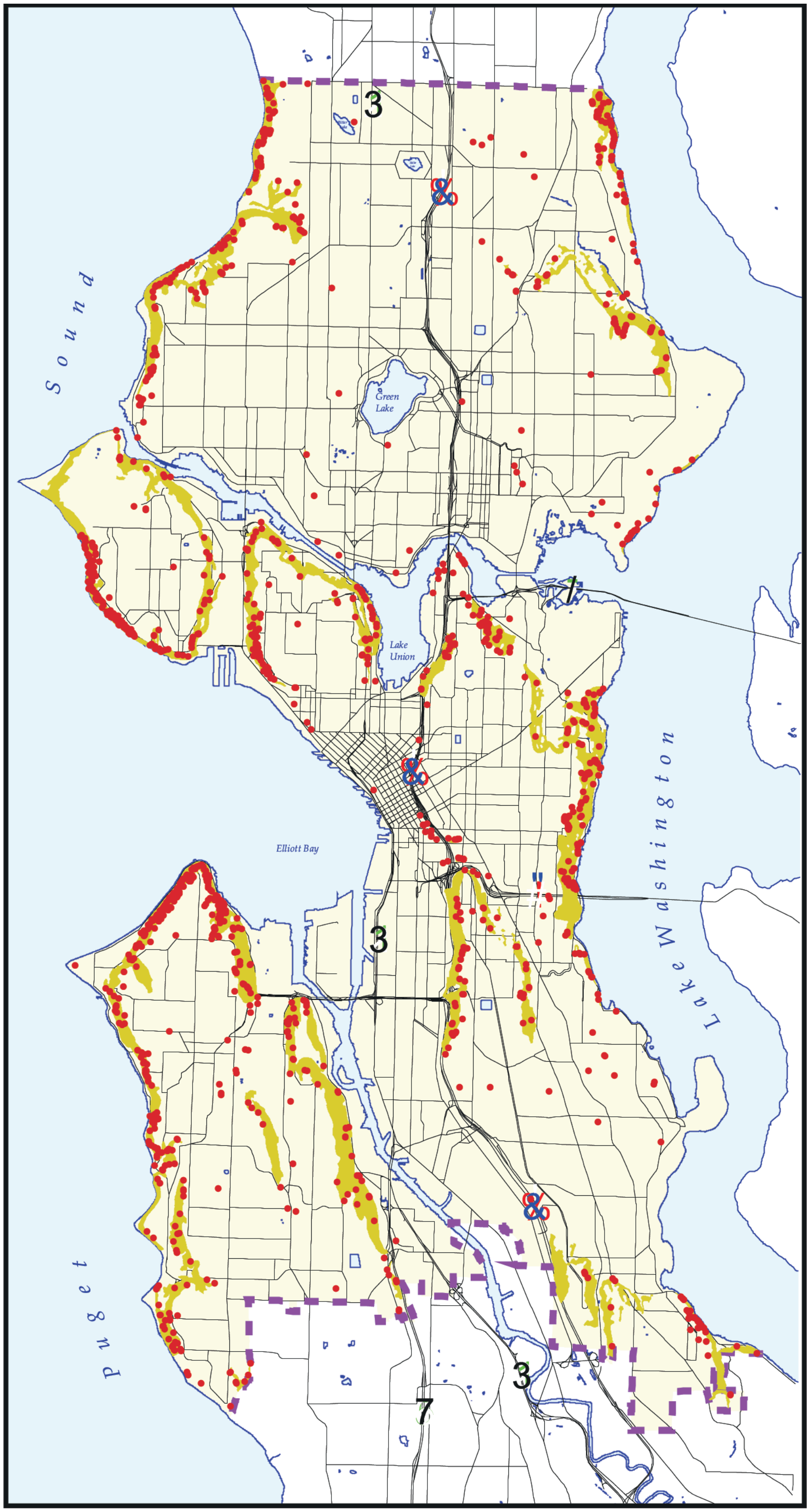
Landslides are a common and complex problem in Seattle – and are secondary to other hazards, such as earthquakes and storms. Landslides normally develop slowly and the soil tends to moves a slab, coming to rest at the bottom of the hill or bluff. Unlike with debris flows, there is usually time to warn people in vulnerable areas. Most slides are small enough that they do not create city-scale emergencies, but occasionally weather and soil conditions cause slides throughout the city within a short period of time. Slides can destroy buildings, block roads and sever lifelines. The main impacts are economic. Following the major slides of 1996/97, the city convened an Interdepartmental Landslide Team to address the problem. Since, then a number of both 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.

Figure 17. Soil Layers



Source: UW Department of Geology Seattle Geologic Mapping Project

Figure 18. Landslide Event Inventory



Legend

Slide Event Inventory (Shannon & Wilson 2002)
Potential Slides AreaCritical Areas by Ordinance

1 0 1 Miles

Snowstorms

Motorists stuck in the snow along I-5 during a 1990 snow storm
Credit: Mike Siegel / Seattle Times

Snowstorms

Highlights

- *Snowstorms are high frequency hazards in Seattle.*
- *Their effects are citywide, but areas served by major roads that cross steep slopes suffer greater impacts.*
- *The heavier the snowfall, the greater the safety risks and costs of the storm.*
- *Snow and cold weather endanger lifelines through direct attack and by increasing demand on some systems, most notably power.*
- *Both ground and air transportation halt in heavy storms. Sometimes vehicles are abandoned.*
- *Snow removal costs can run into millions of dollars.*
- *Substantial economic losses result from work stoppages.*

General

The warm maritime climate usually keeps Seattle warm in the winter. The prevailing westerly winds keep cold arctic air from reaching the area most of the time. Occasionally, a powerful front moves south out of Alaska over the Pacific just long enough to pick up moisture without getting too warm before the westerly winds blow it into Seattle, producing snow (Renner, 1993).

While Seattle's snow never accumulates throughout the whole winter season, individual storms can drop a lot of snow on the city. The threat of infrequent, heavy storms creates planning dilemmas for the city. Since snowfall can vary widely from one season to the next, it is hard to determine the optimal amount of snow removal equipment. The city stocks sand, salt, and CG-90 de-icer - but it has no vehicles dedicated to the task (Seattle Transportation Department, 1998). Instead, it uses vehicles that are normally used for other purposes. Whenever snow threatens, it outfits them with plows, sand, salt, and de-icer. This practice can cause both delays in starting snow removal and unnecessary preparation if the snow fails to fall. City trucks begin by plowing prioritized routes and cover non-priority streets only if they have the time. To help, the Washington State Department of Transportation (WSDOT) plows I-5, I-90, and SR 520.

During major snows storms the transportation system shuts down, trapping people at home or work. Accidents rise among those who try to drive. During exceptional storms structures can be damaged. This happened in the 1996/7 storm when a number of roofs collapsed. Energy use skyrockets, placing a demand on power generation and distribution systems. In other parts of the country energy drains 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.

A blizzard's effects are not limited to residents. Businesses, retail and entertainment establishments especially, lose large amounts of business when customers cannot reach them. From a municipal perspective, responding to snowstorms can be a major unbudgeted expense for local governments. Some have even had to issue emergency bonds to cover recovery costs.

History

Finding detailed records about the effects of past snowstorms is difficult. This section provides a summary of the most significant events based on the Seattle Almanac, a compilation by the Seattle Public Library based on newspaper accounts. It is the best single source, but is not exhaustive. The unofficial record for the most snow in one winter is 64 inches in 1880. The single day record is 21.5 inches, set in 1916.

Dec. 1861	Very cold, with an unofficial -4 degree temperature. Newspapers mentioned ice-skating on Lake Union.
Winter 1880	Usually regarded as the snowiest winter in Seattle. An unofficial 64 inches fell during the season. Snow drifted 3-5 feet at the waterfront, possibly indicating even bigger drifts at higher elevations. Most significantly, roofs collapsed throughout the city.

Jan. 1893	45.5 inches fell in less than two weeks.
Feb. 1, 1916	Single day snow record set at 21.5 inches. The roof of the St. James Cathedral collapsed.
Jan. 1920	A sledding accident on Queen Anne killed four children and injured five more.
Feb. 1923	16 inches of snowfall.
Jan. 1943	Total of 18.4 inches in a week closed schools and caused power outages.
Jan. 13, 1950	Near record one-day snowfall of 21.4 inches at Sea-Tac accompanied by 25-40 m.p.h. winds. 63.6 inches fell the entire month at Sea-Tac.
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.
Dec. 1964	8 inches fall.
Dec. 1968	10 inches fell on New Year's Eve. Despite the chances for increases in alcohol related accidents, there was not a reported increase.
Jan. 1969	19 inches accumulated at Sea-Tac on the 28th. Nearly 46 inches fell during the month.
Jan. 1972	Intense cold. Nine inches of snow fell at Sea-Tac. Schools closed. This storm was connected to landslides later that year.
Dec. 1974	Nearly 10 inches of snow fell as the power went out in many parts of the city.
Nov. 1985	Eight inches fell on Thanksgiving Day.
Dec. 1991	Snow closed Sea-Tac and brought traffic to a halt.
Dec. 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.

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 (less than 1 inch) and 22 had heavy snowfall (more than 1 inch) (Seattle Transportation, 2003). Figure 19 indicates the snowfall per winter (October through March) between 1948 and 1998.

Vulnerability

Seattle's geology and climate work against it during snowstorms. First, the hilly topography makes many areas of the city impassable even during light snows. 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 difficult 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. Older people are indirectly affected, since they require medical care most frequently, and snow makes it more difficult for them to receive it. Children are another risk group as they play along dangerous streets. Several have been killed in sledding accidents.

The outlook for the future is uncertain. Detailed records in the Puget Sound region date back only 150 years, making predictions based on it uncertain. The effects of global warming are also uncertain, but many scientists believe that and El Niño could lead to an increase in dryer and warmer winters.

Effects

Snowstorms grind Seattle to a halt. The two biggest impacts are cold and immobility. The cold 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. Seattle is not prone to the extreme cold that plagues the East and Midwest, and so does not suffer the same consequences.

Immobility is the biggest problem associated with winter storms for most Seattle residents. It affects the convenience, safety, and economy of the city. For commuters, snow can be a huge problem. During past storms, many downtown workers have had to sleep in their workplaces. Hotels fill up in a matter of hours. Traffic comes to a standstill as cars jam the streets and steep roads are closed. Snowstorms can impair emergency services and make hospitals inaccessible. Finally, each time the city shuts down, it incurs economic losses from lost sales and missing shipments, workers losing pay, and snow removal. During the 1996 storm, the city estimated losses at $65 million.

Heavy snowfalls damage lifelines and structures. Above ground power lines are the most vulnerable, but water mains can also break. Extremely heavy snowfalls can damage buildings, mostly by destroying roofs. Flat roofs, common on many commercial and industrial buildings, and the roofs on older buildings are the most vulnerable. 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 (Gray and Male, 1981). Figure 20 indicates Seattle's primary and secondary snow and ice routes.

Conclusions

Seattle does not sit in the snow belt, so Seattleites do not have the experience of many Midwesterners and New Englanders. Yet, it is a northern city and can receive heavy snowstorms. This fact creates a dilemma for the government and the population. Extensive preparations become very costly if the snow fails to materialize; but if it does and the city has not prepared, significant transportation problems arise.

Figure 19. Snowfall per Winter for Seattle Metro Area

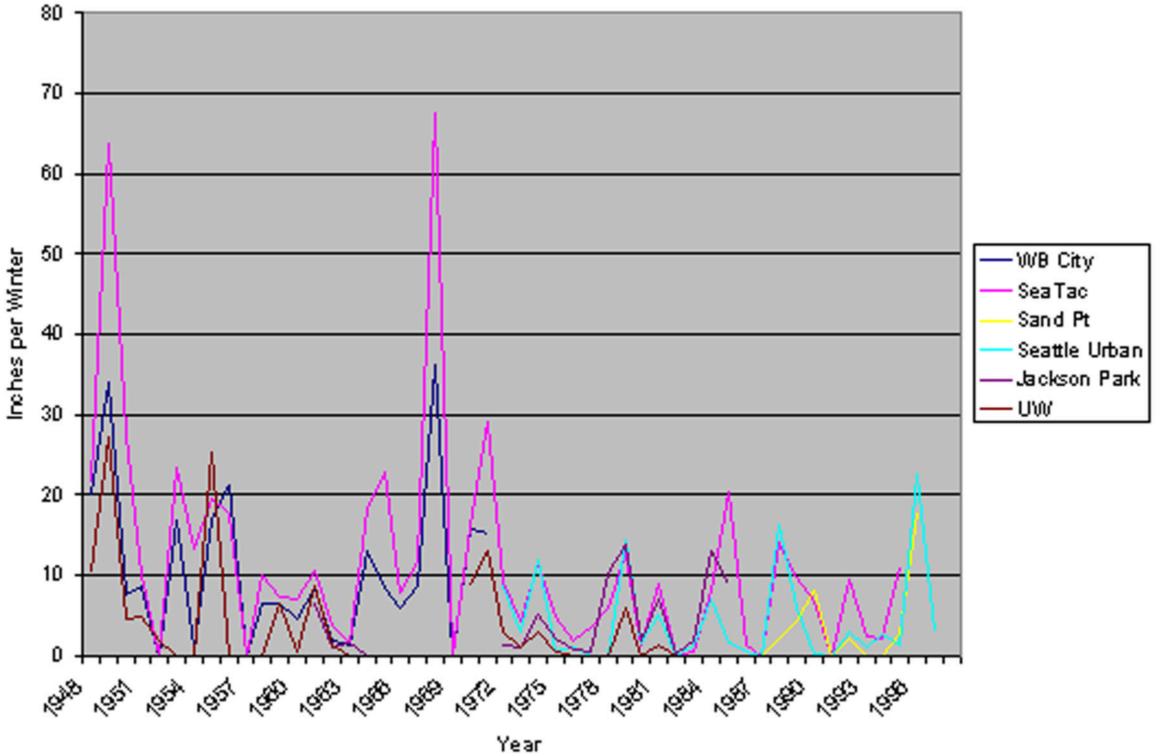
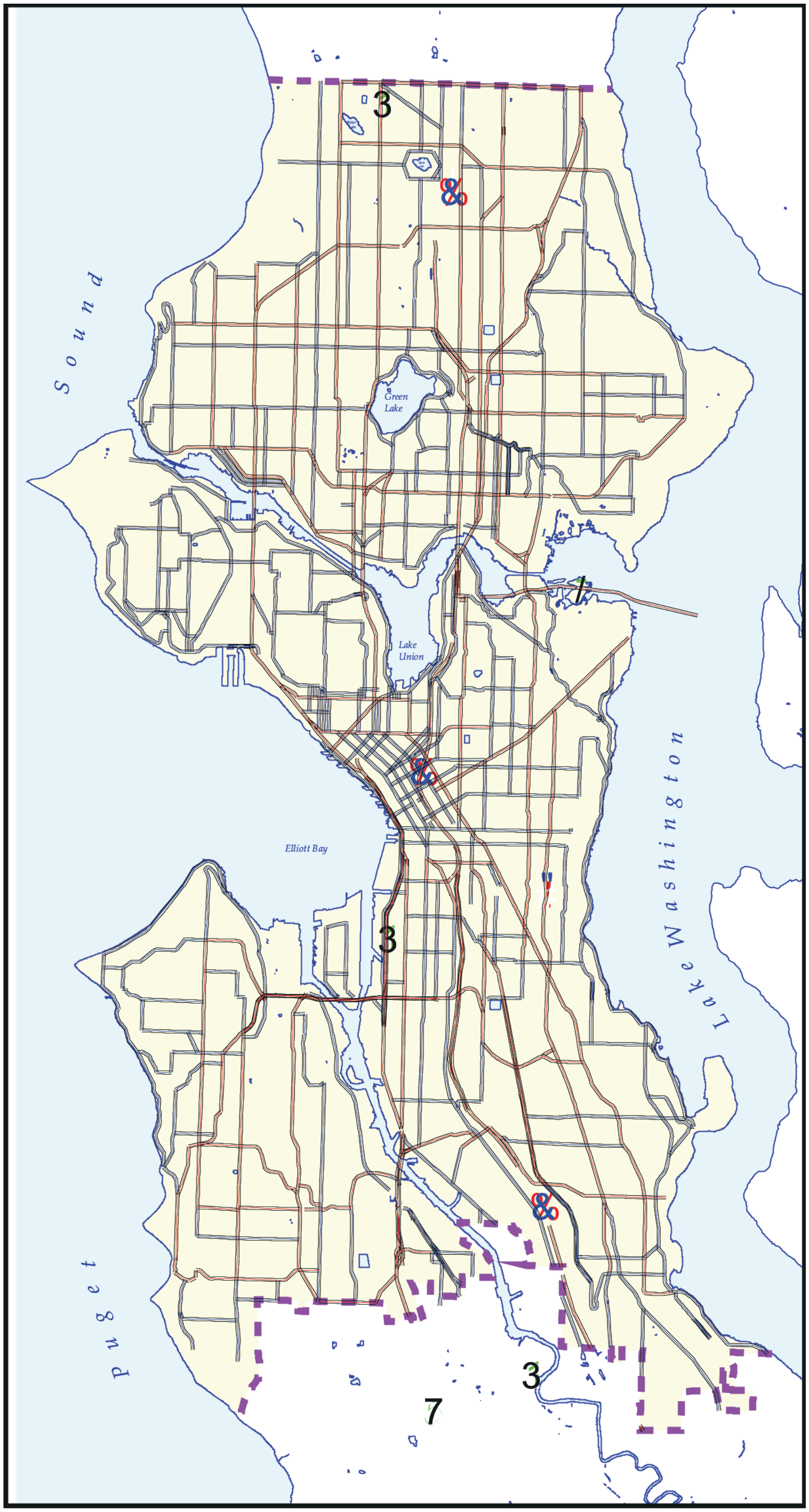


Figure 20. Snow and Ice Routes



Terrorism

1984 stand off with members of the Order.
Credit: Betty Udesen / Seattle Times

Terrorism

Highlights

- *There has never been a significant international terrorist incident in Seattle; however there have been several cases of domestic terrorism.*
- *Washington State has experienced terrorist incidents, including two bombings in Tacoma in 1993 and two in Spokane in 1996.*
- *Hate groups and militia organizations have a presence in Western Washington.*
- *Hoaxes are a growing problem nationwide, but the trend is not noticeable in Seattle.*

General

Terrorism has no universally accepted definition, however most writers agree that it is politically or socially motivated unlawful acts of violence designed to provoke fear or coerce the government, the civilian population, or some segment thereof. Often violent acts do not fit a narrow definition of terrorism, but local government must respond. Recent multiple homicides at workplaces, schools and other public spaces and the ensuing media coverage have raised public fears that the frequency of these rampages is increasing despite statistics that show the level of violent crime is decreasing (U.S. Department of Justice, 1998).

This section focuses on terrorist actions, but also addresses violent attacks that cause mass casualties. It evaluates the threats in the face of growing fears rising in the wake of the September 11th attack on the World Trade Centers in New York City, the Oklahoma City bombing, the continuing series of school and workplace shootings, and the recent emergence of cyber-terrorism.

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. (FBI, 1997) 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 anti-terrorism exercises in May 2003 underscore Seattle's need to confront the threat of terrorism.

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 (WTO) 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. Again, it can be difficult to discern the difference between a criminal act and a terrorist act, but our vulnerability to either is frequently demonstrated by worms, viruses and other cyber-threats.

History

Terrorism and mass violence have always been a part of American life. Incidents tend to occur in cycles. There have been a number of incidents in the state during the past twenty years, and there are active domestic terrorist groups in the Seattle area as witnessed by the following public incidents:

1984 Members of the Order, a racist Aryan Nations offshoot, robbed an armored car at Northgate mall. They fled to Whidbey Island and were subsequently killed in a confrontation with police.

1993 Regional. 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 Regional. Members of the white separatist 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. (FBI, 1996)

1996 Regional. Eight individuals were arrested near Bellingham. They had plotted attacks against a bridge, railroad tunnel and a radio tower. (FBI, 1996)

1996 Scare. Jason Sprinkle started a bomb scare when he parked his truck with a huge metal heart in its bed and the word 'bomb' printed on its bumper, in the middle of Westlake Park, slashed the tires and walked away. He intended the action as a protest to the reopening of Pine Street to traffic, but instead caused a massive bomb scare. Nine blocks were evacuated during a busy weekday afternoon while the police investigated.

1999 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 even though it was later determined that the actual terrorist target was Los Angeles.

1999 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. Millions of dollars in damage was caused.

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

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

2002 Terrorists 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 The Animal Liberations Front released 10,000 mink in Monroe, Washington, causing a loss of animal life and over $40,000 in damages.

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

2003 Emergence of Internet-based worms and viruses that attack computers and networks.

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 17 active hate groups and 6 patriot groups active in Washington State in 1999. (Southern Poverty Law Center web site, January 2000)

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 government facilities (federal, county and city), women's clinics, and Jewish organizations.

Vulnerability

Like any other city, Seattle has a larger exposure than suburban or rural areas, making it naturally more vulnerable to terrorist attacks. Most terrorist targets are chosen for symbolic importance and likelihood of producing casualties. Cities, with their concentration of governmental and corporate institutions and higher population density, provide a rich array of targets for terrorists.

Seattle's economic growth is also increasing its vulnerability. It is a major international trade center and is home to some of the most recognized corporate names in the modern economy. While this growth is certainly good for the city's economic health, it brings Seattle far greater visibility on the world stage than in times past.

The types of weapons available for use in a terrorist attack have multiplied recently. While bombs remain the most popular means of destruction, the Tokyo subway Sarin gas attack put the world on alert that homemade chemical, biological and radiological weapons have arrived. Despite a growing awareness of the threat posed by them, few governments have had to respond to their use. This lack of experience increases the chance they could cause a large number of casualties.

Several other recent trends seem to be emerging. One is the targeting of transportation systems. The militia members arrested in Bellingham in1996 had planned attacks on bridges and railways. In 1996, an Amtrak train was derailed in Arizona causing one death. The second trend involves the use of secondary devices designed to kill emergency responder. This has been a favorite tactic of international terrorists for many years and has been used domestically as well. They were used in two Atlanta area attacks and in a recent bombing in California related to animal rights extremism. Finally, the number of hoaxes has dramatically increased.

Like other governments and businesses across the nation, Seattle relies heavily on computers and networks to conduct its normal business. Microsoft operating systems such as Windows have a number of security vulnerabilities that rogue programs exploit. The SQL Slammer worm on January 25, 2003 rendered the police computer-aided dispatch system of a Seattle suburb inoperable for several hours and stopped some bank ATM networks nationwide. In August 2003, the MSBlaster and Nachi worms compromised Windows computers worldwide, including many within city government. Future terrorist attacks could target the computer systems and networks that control the electric power grid or water supply, or are used to dispatch and manage police officers, firefighters, emergency medical technicians, and utility workers.

Preparation reduces vulnerability. In response to the September 2001 attacks, Seattle created the Emergency Preparedness Bureau to enable the city to address the emerging terrorist threat in coordination with other emergency management functions. Seattle has engaged in planning to detect terrorist actions before they happen and how to react when they occur. It has used $500,000 in federal grant funding to conduct weapons of mass destruction planning and training. Three full-scale exercises have been conducted for emergency personnel. This preparation will help reduce the destructiveness of a potential attack. In May 2003, the city participated in the national “Top Officials 2” or TOPOFF2 anti-terrorism exercise. Funded by the Department of Justice, this exercise included both anti-cyber-terrorism and anti-terrorism components.

Ultimately, it is difficult to assess the city’s vulnerability given the infrequency of terrorist acts. However, counter-terrorism officials generally regard the City of Seattle as being in the “top ten” list of cities to be attacked by terrorists and was one of only seven cities designated for federal grant funding under the first Urban Area Security Initiative (UASI). This vulnerability is based on multiple factors, including the attractiveness and visibility of targets, such as internationally known corporations that have significant symbolic value, e.g., Boeing and Microsoft; our proximity to a porous international border previously used by terrorists; our below average level of law enforcement staffing, and the presence of vulnerable, but critical infrastructure, such as the largest ferry system in the world, major bridges, a major port, etc. In 2003, Seattle received two UASI grants to assess its vulnerability to terrorist attacks and to mitigate those vulnerabilities. The city’s Emergency Preparedness Bureau staff is presently conducting such assessments and will develop a strategy to mitigate the vulnerabilities.

Effects

While some terrorist actions aim to do only property damage, most target people. Unlike natural disasters that claim lives by accident, it is unlikely that loss of human life could be avoided if terrorists are determined to take them. Local governments must plan for mass causalities.

Bombs remain the most popular method of carrying out terrorist attacks, so significant property destruction would result. An attack would not necessarily have as devastating an impact as a large earthquake, but it would still likely cause significant disruption to transportation and economic activity. The Oklahoma City blast caused property damage more than two blocks away. The response closed a large part of the city’s downtown.

The reaction to the event itself can be very disruptive. Media attention will complicate the response, especially in a large event. Cyber-terrorists could spread disinformation to citizens and the media by hijacking web sites or sending counterfeit e-mail messages. The disaster area would be a crime scene requiring cooperation between rescue and law enforcement. Despite practice, a joint response would be more complicated than that for a natural disaster.

Cyber-attacks against computer systems could potentially shut down radio, telephone and computer networks used to control and manage city services, potentially resulting in loss of those services or the inability to properly dispatch public safety and other personnel to the scenes of crimes or physical terrorist attacks.

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 TV feel personally attacked. If the place attacked is an important landmark, a community may feel its own identity is under attack.

Finally, terrorist acts can cause permanent land use changes. Many will want to memorialize the site of an attack. The activities that used to be carried out at the site may need to be permanently moved.

Conclusions

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 finds itself in the unfortunate position of being a more attractive target than most cities in the United States, and thus the city has adopted a sense of urgency. The decision to cancel the 2000 New Year's celebration at the Seattle Center was difficult, but as Mayor Shell mentioned at the time, no other city had a bomb delivered to its door.

Like many other vulnerable cities, Seattle is actively planning to detect, deter, and prevent a terrorist attack and to better respond and recover should one occur. Seattle will continue to do so, but will not sacrifice preparedness for other more frequent emergencies in the process. Exploiting points of synergy between different types of emergency response is a good place to start. Seattle has already used this approach, modeling a terrorist response on a hazardous materials response and developing a good all-hazards plan. Finally, the 2003 and 2004 Urban Area Security Initiatives will materially improve Seattle's and the urban area's readiness for a terrorist attack.

Tornadoes

Damage in the Kent Valley caused by the December 12, 1969 tornado.
Credit: Richard Heyza / Seattle Times

Tornadoes

Highlights

- *The seasons with the highest probability for a tornado seem to be late spring and early fall.*
- *Lightly constructed buildings such as mobile homes are most vulnerable, but Seattle has less than 1000 of them.*
- *The most likely tornado in the Seattle area would have wind speeds of 40 to 72 miles per hour, but at least one Puget Sound area storm had wind speeds between 158 and 206 miles per hour.*
- *Local damage would consist of structural damage to houses, cars, smashed windows, and uprooted vegetation.*
- *There is a small chance a tornado could strike major lifelines causing larger problems.*

General

Tornadoes can occur anywhere, including the Northwest. Small tornadoes can develop in severe thunderstorms or along convergence zones (Church et al, 1993). They are not the same as the killer Midwestern storms that form supercells.

Tornadoes occur when a layer of cold air covers a pocket of warm air. The cold air pushes down, allowing the warm air to funnel up into the resulting void. This violent updraft of warm air can create a funnel cloud. When a funnel cloud makes contact with the ground it becomes a tornado.

The most common scale of tornado intensity, the Fujita or F-Scale, estimates wind speed from the type damage done. It ranks tornadoes from F0 (moderate damage to signs and small buildings) to F5 (incredible damage that disintegrates even strong frame houses). Tornado wind speeds range from 40-72 mph in an F0 to 73-112 mph in an F1, on up to 261-318mph in an F5 storm. Most tornadoes worldwide are in F0 and F1 range.

History

There has never been a tornado in Seattle that has caused wide spread damage, but a 1972 storm killed six people in Vancouver, Washington. The two Seattle storms were related to more general windstorms that were occurring about the same time. Both of them were probably F0. It is possible that other tornadoes occurred prior to this date, but they were not recorded.

1962 The area's first confirmed tornado (F1) touches down west of Sand Point, severely damaging several homes. It picked up a carport and tossed it down onto the neighboring house. Everyone in the house was caught by surprise, but there were no casualties (Seattle Times, 9/29/62).

1964 A tornado funnel is observed during a rainstorm, but it fails to touch down (Seattle Times, 8/19/64).

1966 Another tornado funnel is seen, but again fails to touch down near Sea-Tac (Seattle Times 9/12/66).

1969 A tornado (F3) in South King County topples signs and damages buildings causing $500,000 in damage (Seattle Times, 12/13/69). This tornado occurred during a regional windstorm. It started as a waterspout then moved inland. (Ted Buehner, private communication)

1972 This storm did not occur near Seattle, but proves that deadly tornadoes have happened in the Northwest. An F2 tornado developed as part of a regional windstorm near Portland, Oregon. It moved across the Columbia River and killed six people, injured 300 more and caused $6,000,000 in damages in Vancouver, Washington on April 5, 1972 (Grazulis, v.2, 524).

1997 Four F0 tornadoes confirmed in western King County. None caused damage. The National Oceanic and Atmospheric Administration attributes this rash of sightings to increased development in King County and a more knowledgeable population.

Vulnerability

Tornadoes are rare events in the Pacific Northwest. National maps of tornado incidence show that Seattle is one of the areas least likely to experience tornadoes. There is no data for Seattle specifically, but in Oregon they occur most frequently in April, May and June, but can also occur in October and November (Church et al, 1993). This information seems to conform roughly with the observations in the Seattle area.

Tornadoes can happen anywhere so every area in Seattle has the same likelihood of suffering one. Mobile homes and other buildings with poorly anchored roofs or foundations are the most vulnerable. The number of poorly constructed homes is not known, but there are less than 700 mobile homes among the 250,000 housing units in Seattle (Seattle Planning Dept., 1992). Most other buildings do not suffer major roof damage until a tornado reaches F1 strength, something improbable in Seattle. Because tornadoes develop suddenly, adequate warning is critical to ensure public safety. All this information points out that there is a minimal, but not negligible risk of tornado damage in Seattle.

Effects

All previous Seattle tornadoes affected only a small number of homes and these were only damaged. A future tornado would probably produce a similar pattern of damage. F0 damage is largely limited to toppled signs, smashed windows (including car windows), uprooted trees, and crushed garages. Nationally, only 4% of all fatal tornadoes are rated as weak (F0 and F1 combined), so the probability of a killer storm is very small (Grazulis v.1, 1991). The only scenario that would affect a large area would be if the storm struck some lifelines.

Conclusion

Most Seattleites assume that tornadoes can never happen here, but they do occur. Many people are likely to be unprepared for this type of event. While it is minimal relative to the Midwest, there is still a risk. Because the risk is small, the city should not spend a large amount of money on preparation.

Tsunamis and Seiches

Residents inspecting damage to Lake Union docks and boats caused by the seiche that followed the 1964 Great Alaskan Earthquake. Credit: George Carkonen / The Seattle Times

Tsunamis and Seiches

Highlights

- *Either a subduction zone or Seattle Fault earthquake could produce tsunamis, but the latter would be much more damaging to Seattle. Based on geologic evidence, there is no recurring "characteristic" tsunami event.*
- *A quake would probably need to be over 7.0 Mm to cause a significant tsunami.*
- *Seattle is vulnerable to seiches caused by subduction zone quakes. However, the more frequent event would probably be an event along the Seattle Fault.*
- *A large tsunami could produce heavy casualties and destroy large amounts of infrastructure.*
- *Seiches would probably not be as destructive, but could produce landslides and affect the floating bridges.*

General

A tsunami is a sea wave produced by an offshore earthquake, volcanic eruption, landslide, or potentially from a meteorite impact. Tsunamis are hard to detect in deep waters. Their wavelengths are very long (between 93 and 155 miles). Most tsunamis damage open coastlines, rather than enclosed bodies of water like Puget Sound.

Offshore, tsunamis travel at speeds of approximately 500 miles per hour (mph) with amplitudes of one foot or less (NOAA, 2002). They generate multiple waves, with a distance between crests of 60 or more miles. As the waves approach the shoreline, they tend to slow down and increase in height. Subsequent waves tend to "pile up" with the preceding waves, increasing the potential for damage. Because a single event generates multiple waves, and the waves interact with each other, the effects can last for several hours. Tsunamis can rise to 100 feet in height and move at a speed of 30 mph as they near the coast. Generally, a quake must have a magnitude of 6.5 (Bryant, 1991) to 7.5 (Noson, 1988) to produce a dangerous tsunami.

Not all 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 of the tsunami, its speed, as well as the coastal area's form and depth are all factors that affect its 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 (Myles, 1985).

Tsunamis rarely crash ashore in one huge wave. Frequently, coastal flooding precedes them, 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.

Seiches have different causes. They develop when an enclosed body of water is shaken. The water literally sloshes around in its 'container' like water in a cup. The biggest seiches develop when the period of the ground waves matches the frequency of oscillation of the body of water. When it does, resonance effects build up wave height with each oscillation. 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 (Myles, 1985). The biggest danger is from subduction zone earthquakes that cause powerful, low frequency groundwaves. The waves that a seiche can generate may cause secondary disasters such as the boat damage in Lake Union from the 1964 Great Alaska earthquake.

History

Studies of the geologic record indicate that the Puget Sound area of Washington is susceptible to the effects of tsunamis generated by distant sources, local faults such as the Seattle fault, and the regional larger scale Cascadia Subduction Zone (CSZ). The CSZ is an active convergent margin along the Pacific Northwest of the United States and Canada as shown in Figure 9. Convergent plate margins are capable of generating significant and destructive tsunamis.

Since European settlement, there has never been a damaging tsunami in the Seattle area, although a tsunami from the 1964 Alaskan Earthquake was detected here. Documented impacts from that earthquake include seiching in Lake Union, caused by earthquake vibration (National Academy of Sciences, 1972). The actual tsunami caused by the 1964 earthquake impacted the Puget Sound area less than the coastal communities of Washington, Oregon and California. Although the maximum rise in water height for Seattle was only about 0.8 feet, communities of 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.

Local studies of the Seattle Fault indicate a potential for tsunamis. Scientists interpret the evidence of irregular sand sheets in the Northern Puget Sound area found at the West Point Sewer Treatment Plant, Alki, and Restoration Point on Bainbridge as the result of a tsunami generated by an earthquake on the Seattle fault about 1,000 years ago (Atwater and Moore, 1992).

Similar evidence in Lake Washington sediments suggests a recurrence interval of 300 to 400 years (Karlin and Abella, 1996). Several areas of the Seattle Fault show evidence of episodic fault rupture of about 6 feet that could produce a tsunami (Weaver, 2003; Sherrod, 2000). Continued studies of Seattle Fault traces suggest that the fault may have ruptured in different segments and at different times (Sherrod, personal communication).

Seiches are more common than tsunamis, but have not caused extensive damage so far. In 1891, an earthquake near Port Angeles caused an eight-foot seiche in Lake Washington (USGS, 1975). Both Lake Union and Lake Washington experienced seiches during the 1949 earthquake, but they did no damage (Noson et al, 1988). The 1964 Alaskan earthquake also produced a seiche that damaged boats by battering them against docks and moorings Lake Washington and Lake Union.

Vulnerability

Either a large subduction zone quake off the Washington coast or one along the Seattle Fault could produce a tsunami. However, research suggests that the most serious tsunami would result from an earthquake along the Seattle Fault rather than from a subduction zone quake (EERI scenario working papers 2003).

In the case of a subduction zone quake, the tsunami would travel from the coast through the Straight of Juan de Fuca into Puget Sound and south to Seattle. Because of the shielding effects of the Olympic Peninsula and the islands in Puget Sound, the tsunami expected from a magnitude 8.5 quake would be less then 2 feet high when it arrived at Seattle's shores (Whitmore, 1993). It may also lose much of its velocity.

The National Oceanic and Atmospheric Administration (NOAA)'s Center for Tsunami Inundation Mapping Efforts has developed a tsunami inundation model for Seattle's Elliott Bay using a magnitude 7.3 Seattle Fault earthquake as an initiating event. (This model simulates the earthquake event 1,000 years ago, which is considered by NOAA to be the credible worst-case scenario.) The area modeled includes communities within one kilometer of the Puget Sound coast, such as portions of Seattle, Riverton-Boulevard Park and White Center. The model projects a potential at-risk population of 11,056 (Washington State Hazard Mitigation Plan August 2003 draft).

The impacts of a tsunami generated by the Seattle Fault are conjectural. If a 6.7 event on the Seattle Fault results in 2 M of displacement, it is reasonable to assume that it could generate a tsunami or seiche. Earthquakes of approximately 6.5 magnitude are more frequent occurrences than the larger events; therefore, the Earthquake Engineering Research Institute (EERI) considers this as the more acceptable "planning" event (EERI scenario working papers 2003).

Several factors could influence its size, shape, volume, and potential destructiveness of a tsunami generated by the Seattle Fault. First, 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 (Bryant, 1991). Second, Puget Sound's steeply sloping seabeds tend to increase the chance that a tsunami will break on the shore, thus enhancing the tsunami's destructiveness (Myles, 1985; Shuto, 1991). Finally, the shape of Elliott Bay could increase damage by funneling waves together, increasing wave height (Myles, 1985). 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.

Both Puget Sound and Lake Washington could experience a seiche as they did in 1891, 1949 and 1964. In those years, there was not as much development near the waterfront as there is now. Since the tsunami and seiche threat were not recognized until recently, most of the structures located near the water were probably not engineered to withstand them.

Effects

Although tsunamis are rare, they can be very destructive when they reach coastlines. The Seattle Fault runs off the northern end of West Seattle through Elliott Bay towards the Kingdome and then across toward Bellevue. Since no historic record exists that documents damages from locally generated tsunamis on the Seattle Fault, impacts are purely conjectural. A 2M wave is not expected to overtop the Elliot Bay Seawall, but a wave could propagate up the Duwamish (EERI Seattle Fault Scenario 2003 working papers). 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.

A seiche could affect a larger area because of the city's extensive shoreline. It could also affect the floating bridges across Lake Washington. The bridges have withstood waves up to eight feet, but waves from a seiche could be larger. A seiche's rapid onset could hamper the ability of motorists to exit the bridge before it began.

Seiches can cause landslides. Bluffs surround a large part of Seattle and many of them are prone to landslides, as shown in Figure 11. Most of them are in residential areas, so the risks at night could be very high. In addition, Port of Seattle facilities and the Burlington Northern Railway tracks are likely to suffer damage because of their proximity to the shore.

Conclusions

Although the geologic evidence for previous tsunamis is sparse, there is reason to believe that one could happen again. Mitigating strategies should focus on the effects of either tsunamis or seiches, which could include loosening of piers, especially in Lake Union and other enclosed waterways such as the Duwamish.

Volcanic Eruptions

Mt. St. Helens erupting on May 18, 1980.
Credit: Rick Perry / Seattle Times

Volcanic Eruptions

Highlights

- *Mudflows are the mostly deadly volcanic hazard, but they have negligible chance of reaching Seattle.*
- *Ashfalls could reach Seattle from any volcano, but Mt. Rainier and Glacier Peak are the most probable source because of their proximity. However, prevailing weather patterns reduce the chance ash from either of these volcanoes would travel west.*
- *The city's power and water supplies are vulnerable to ashfalls in the Cascades.*
- *Ash would cause health problems, paralyze the transportation system, destroy many mechanical objects, endanger the utility networks, and cost millions of dollars to clean up.*

General

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 sized plates move, the heavier ocean plates slip under the lighter continental plates. This slipping causes friction along the plate faces. Typically, the hottest part of the subduction area is under the continental plate just inland from the coast, where the heat and pressure melt the plates into magma. The hot, molten rock forms reservoirs near the surface. Normally, the constraining pressure of the surrounding rock keeps the expansive force of the molten rock in check. However, sometimes an increase in pressure from tectonic activity causes the magma to blow out the surface. On other occasions water mixes with the magma, gets superheated, and produces enormous steam explosions.

Washington's volcanoes are capable of producing the most violent type of eruptions (call "Plinian" in scientific terminology) that eject huge amounts of ash, rock, and gas and trigger rockfalls and mudflows. Their explosive force makes them extremely dangerous. The 1980 Mt. St. Helens blast ejected one quarter cubic miles of material. Plinian eruptions send material straight up in the air or along a volcano's sides. The lateral explosions contain deadly clouds of debris, called pyroclastic flows, that hug the ground flattening most everything in their path. The ejected material often heats up the glaciers and other snow covering the volcano and mixes with it. 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.

The most deadly effects happen only in the volcano's immediate area and in the river valleys leading away from them. The most widespread eruption impact is ash, which can cover hundreds of square miles. It is not nearly as dangerous as pyroclastic flows, but is a health risk to people with respiratory problems. It also has many indirect effects on health by causing hazardous driving conditions, damage to mechanical equipment, and interference with wireless communications.

History

Four of the five active volcanoes near Seattle have erupted since 1780 (Mt. Baker, Glacier Peak, Mt. Rainier, Mt. St. Helens and Mt. Hood) (Harris, 1988). 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 since pioneer settlement, but all these events were small scale. Several post-ice age eruptions have produced mudflows near the mountain but only light ashfalls. Large volume events during the past 600 years have occurred about once every 150 years (Cascade Volcano Observatory, 1994).

Glacier Peak. 11,000 to 12,000 years ago it produced some of the largest ashfalls in post-glacial Cascade history. Twice falls were a foot and a half thick up to 40 miles from the mountain. Its 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 (Harris, 1988; Cascades Volcano Observatory, 1994).

Mt. Rainier has erupted in the historic period. Explorers and pioneers tell of smoke and earthquakes near the mountain, but there is no indication of major mudflows or ashfalls. Stephen Harris investigated these stories and suspects most were steam eruptions and not the more violent Plinian type. Despite the lack of historical evidence, 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 did cause large mudflows. 5,000 years ago the Osceola mudflow buried the area around Enumclaw. 500 years ago the Electron mudflow nearly reached Puyallup (Bullard, 1984). Most recently, in 1963 and 1967, large landslides crashed down the slopes of the mountain. Increased heat was responsible, suggesting renewed volcanic activity (Bullard, 1984).

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 eruptions in 1800, 1831, 1842 and 1857, although these were smaller than the 1980 eruption (Bullard, 1984).

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 (Bullard, 1984; Scarth, 1994; Cascades Volcano Observatory, 1994).

Mt. Hood is more of a threat to Portland than Seattle, but it also 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, but the ashfall and pyroclastic flows have been limited to Oregon and southern Washington (Harris, 1988; Bullard, 1984).

Vulnerability

A major eruption of any volcano is a rare event. The USGS estimates the chances of an explosive eruption at Mt. Baker at .01% per year and Glacier Peak at .02% per year (Cascades Volcano Observatory, 1994). The United States Geological Survey maintains the Cascades Volcano Observatory (CVO) to monitor the mountains' activity. Since an eruption is usually preceded by a swarm of small earthquakes, the CVO would be able to give some warning to cities that could receive damage.

Seattle is west of the Cascades. River valleys lay to the north and east of it. As a result, it is fairly safe from mudflows, but could get large amounts of ash or gas, especially if Glacier Peak erupted violently again. Seattle is just sixty miles away from Glacier Peak and fifty-five miles from Rainier. Although the prevailing winds blow from west to east, they can reverse. The ash from Mt. St. Helens' May 25, 1980, and June 12, 1980, eruptions went west (Saarinen and Sell, 1985). Gas is less probable. Not all eruptions seem to produce it, but there have been a few cases in North America. Most is limited to within a few miles from the eruption site, but occasionally it combines with rain and travels farther (Blong, 1984). As for mud and pyroclastic flows, only two peaks, Glacier and Rainier have generated flows that have come anywhere near Seattle. To the North, the Snoqualmie and Skykomish river valleys protect Seattle from an intrusion from a Glacier Peak flow. Rainier mudflows have buried parts of the Kent and Puyallup Valleys. However, the mud has always stopped short of Seattle. A future eruption would have to be larger than any past event to reach the city.

Seattle's vulnerability to ashfall is similar to its vulnerability to snow storms. The transportation system is the most susceptible to damage. Other infrastructure systems (sewer and water systems) are also likely to be damaged by acidic ash. Easily isolated areas on hilltops or on dead-end streets are the most vulnerable locations. People with respiratory problems are also vulnerable.

Although mudflows are unlikely, the Duwamish Valley, connected to the Kent Valley, is the most vulnerable. If a Mt Rainier mudflow was of unprecedented size, it could reach the mouth of the Duwamish. Since any mudflow would have to move through the Kent Valley, the effects in Seattle would be much less than in the cities to the south of it. Other areas of the city that are protected by hills and ridges would not be affected directly by mudflows.

Economically, Seattle is highly vulnerable. The costs of a heavy ashfall would include the halting of economic activity for several days or weeks, property damage, and clean up costs. Since an ashfall would affect the whole Puget Sound region, Seattle could not rely on aid from neighboring governments. A mudflow would increase the damage and probably stop port activity for several weeks. Seattle could be economically impacted even if there was no physical damage in the city.

Seattle's electric generation facilities and water resources in the Cascades are vulnerable to ashfall and possibly mudflows even if the city receives no direct damage. The Ross and Diablo dams that supply most of the city's power are 30 miles due east of Mt. Baker, making their reservoir an excellent target for ash. Additionally, mudflows from Mt. Baker and Glacier

Peak have hit the Skagit River below the Ross and Diablo dams. The Tolt and Cedar Rivers, which supply most of Seattle's water, are 30 to 35 miles from Mt. Rainier and Glacier Peak.

Effects

Ashfalls caused a "midnight at noon" in Eastern Washington when Mt. St. Helens erupted and mudflows swept away most of the buildings in their path along the Toutle River. If something similar happened in Seattle, it would have a huge impact on the area's health and economy.

An ashfall would have five potentially large impacts. First, it would irritate the eyes and throat, especially for people with existing respiratory trouble, but would rarely cause death (Blong, 1984). Many people had to wear masks in Eastern Washington or stay inside while the ash fell. The same could happen in Seattle, and blowing ash could prolong these problems, especially if it is very fine. Second, traffic would stop if ash covered the roads. Many people would be stuck. Accidents would probably increase. Although the general eruptive period could be predicted, an actual eruption could catch many people on the roads, making it worse that a snowstorm. Third, vehicles and other machines would break down as the ash clogged their moving parts. This would compound traffic and clean-up problems. Fourth, 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. It could also damage power generation facilities prompting expensive emergency power purchases (Blong, 1984). Wireless communications and public safety would be impeded. Finally, 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 (Blong, 1984). 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.

If the ash is acidic or if acidic rain falls, then the 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. They have also corroded metal and destroyed clothing. While these effects are alarming, there have not been many recorded cases, including the 1980 Mt. St. Helens eruption.

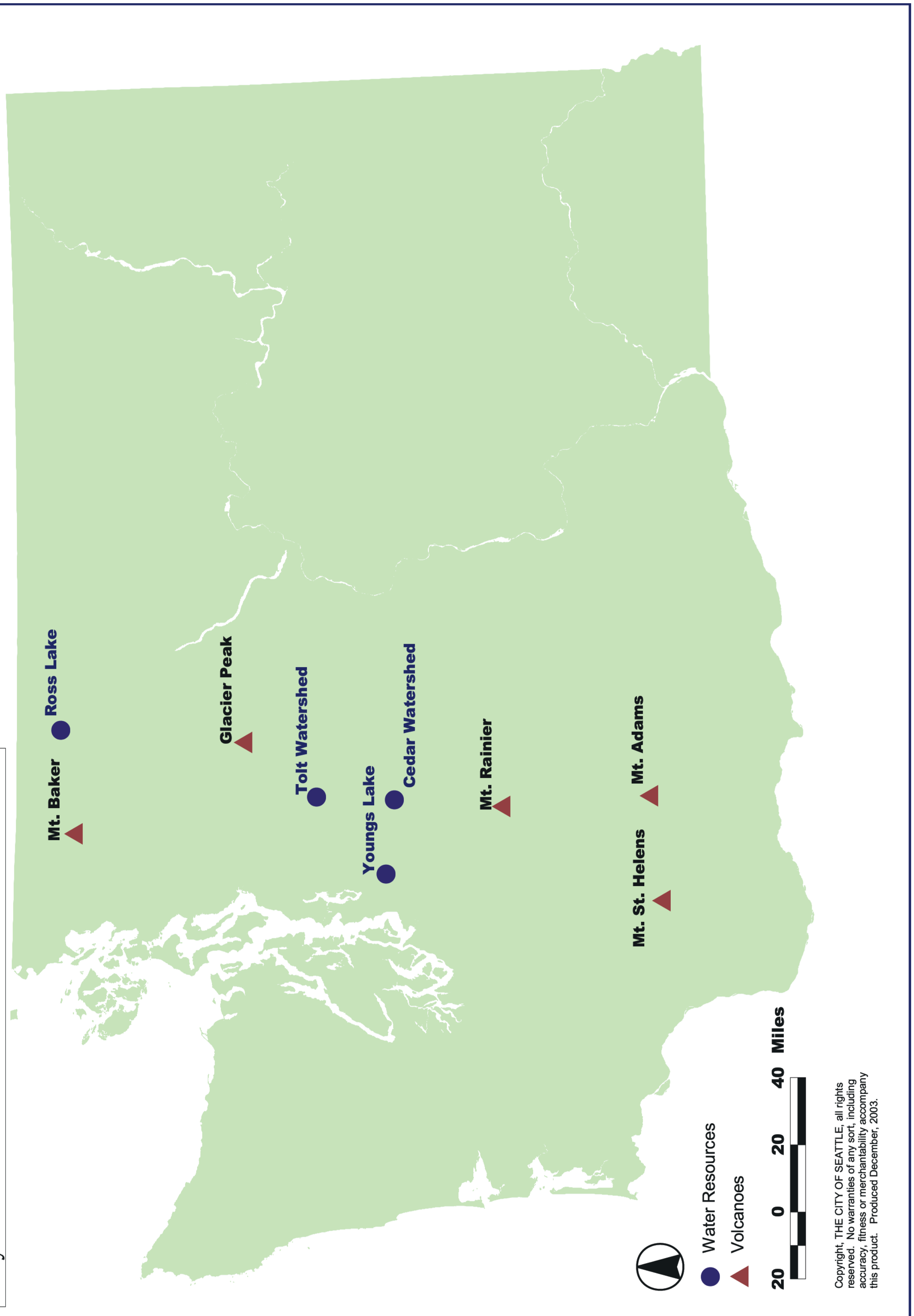
The main danger of a mudflow is to the industry and residences close to the Duwamish. If a mudflow did reach Seattle, there could be massive loss of life as mud swept buildings away. However, the probability of this scenario occurring is very low. More probable is that large amounts of debris and ash could float down to Seattle, clogging the Duwamish and Elliott Bay. The Port of Seattle might have to close. Even a short closure could be costly. Portland lost $5,000,000 when its port closed after the Mt. St. Helens eruption (Harris, 1988)

Conclusions

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 ashfalls 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. Seattle emergency planners should not assume that the prevailing westerly winds will keep ash out of the area. During the Mt. St. Helens eruption many cities were caught unprepared because they assumed they would not be hit and could not find accurate information to help them when they were. To prepare, the organizations with the highest risk (e.g. the Port of Seattle, Seattle Public Utilities) should conduct research on the effects of ashfall and create a plan to prepare for it.

Figure 21. Washington State Volcanoes and City of Seattle Watersheds



Water Shortages

Low water level in Seattle Public Utilities' Cedar River Reservior in early 2001.
Credit: Robin Friedman

Water Shortages

Highlights

- *The whole city shares the same likelihood of having a long-term shortage, but older parts of the city are served by older pipe and have a greater chance of experience short term water outages.*
- *Heavy water users like landscaping businesses are the most vulnerable to shortages.*
- *Rapid growth in suburban areas will make shortages worse by increasing demand on the Seattle Public Utilities Department.*
- *Shortage effects are mainly economic due to power and water utility rate increases.*
- *The utilities face financial difficulties during droughts.*

General

Water shortages develop when the supply of water is too low or the demand for water or power is too high. 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 over consumption or structural failures such as pipeline breaks.

Seattle uses water for direct consumption (e.g. drinking, washing, 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 uses its watersheds in the Cascades to manage its water supply. During the spring, it captures melting water from the winter snowpack and channels it into city-owned reservoirs. Water is stored in them until the demand is highest. 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.'

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 66% of the city's water, while the South Fork of the Tolt supplies 28%. The Highline wells provide 6%, mainly in the summer (Seattle Public Utilities Department, 1993). This water comes to Seattle and the Public Utilities Department's suburban customers through large diameter pipes. For power, City Light gets most of its power from dams on the Skagit River. Reservoirs behind the dams turn turbines that create electricity. When the amount of water in the reservoirs drops, City Light cannot generate as much power. Sometimes peak demand exceeds the amount the Skagit can supply. When it does, City Light must buy power from other sources. 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 it must make emergency purchases.

Water-shortages are slow-onset or 'creeping' disasters because their effects accumulate slowly over time. There is always doubt about when to adopt water conservation measures. Government must wonder if it is overreacting whenever it adopts usage restrictions preemptively. This doubt can cause government to delay action until the drought is well underway. Seattle, with its dependence on winter weather, knows what its supply will be before summer, but still cannot predict summertime demand.

To respond to a water shortage, the Seattle Public Utilities uses four levels of regulations: advisories, voluntary restrictions, mandatory restrictions, and finally, water rationing, in which the Public Utilities would set absolute limits on total water consumption by customers. As a shortage worsens, Public Utilities will enact progressively more stringent restrictions.

Droughts do not necessarily cause water shortages, so the existence of one should not be taken as proof of a shortage, but they often contribute to them. The most common measure of drought intensity is the Palmer 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 importance of snowpacks, like the one that gives Seattle its water (Wilhite, 1993).

Breaks in the supply and distribution system, or events that force the Public Utilities Department to shut down the system preemptively, such as contamination, also cause shortages. Breaks often result from other disasters like earthquakes, floods, and explosions, but can occur as a result of mechanical failure or human error. During floods the threat of contamination or turbidity often forces the closure of water supply systems. Shortages due to these other causes are included in the chapters on the hazards that forced the shutdown or effected normal pipeline flow.

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. Often drought conditions are cited as an indirect (and imperfect) measure of the shortage. Some short-term shortages were caused by pipeline breaks. None of them precipitated an immediate health danger in the city and none 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 until that time. It exacerbated the 1930 drought.
1930/31	Moderately dry weather occurred in Western Washington. The Palmer 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 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 Index reached -4. The lack of winter precipitation was a possible reason the state ordered power cuts for hydroelectric dams.
1965/66	The entire state was dry. King County recorded Palmer Indexes 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 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 (Forbes and Pond, 1977).
1987	Hot, dry summer weather increased water demand, causing a rapid drop in reservoir levels. Mandatory restrictions were adopted. Consumption dropped by 10%.
Nov. 1987	The Tolt pipeline broke, dropping the supply reaching Seattle Water Department customers by 30% temporarily. 10,000 customers were affected but only for several hours. Water was rerouted through the Cedar River pipeline, placing additional demands on the Chester Morse Lake. 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 Chester Morse Lake 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 in 1992.
Aug. 1988	The Tolt pipeline broke during a period of peak use. One hundred customers were threatened in suburban areas 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%. The emergency pumps that were installed in 1988 at Chester Morse Lake were used to extract water when the lake level fell below the elevation of its natural outlet.

Shortages seem to occur once every five to ten years. In most cases, the worst part of the shortage came during the summer. Unfortunately, the record is limited and the extent of the damages, as well as the causes, are difficult to determine. The most severe shortages were not the result of any single cause, but instead by the combined circumstantial effects of a low snowpack and unusually high summer demand. Often Seattle Public Utilities' Water Division was the only utility impacted, but in at least two cases (1952 and 1977) City Light was also affected. This data suggest some patterns of vulnerability that the next section will explore.

Vulnerability

The history of water shortages shows that the power and water supply systems have different vulnerabilities to drought. Their water demands differ and their reservoirs are located far enough apart that precipitation can be significantly different at each location (National Climatic Data Center, 1985). Often only one system is affected by dry weather. Overall, the water system seems to have a higher probability of being affected.

Shortages do not affect all power and water users evenly. The heaviest users, such as landscapers and greenhouses, endure the largest increases in utility bills and cutbacks on business if usage restrictions are imposed.

The entire region is becoming increasingly vulnerable to shortages. Demand for water and power is growing. Seattle Public Utilities proactively addressed the challenge with its Water Supply Plan. Its biggest challenge is the rapid development in the suburban areas it supplies. If demand increases faster than the forecasts, then demand driven shortages will result. City Light's demand is easier to predict, since its service area is already well developed and maintains a forecasting model.

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 recharged. During dry years, the amount of water they release can cause water reserves to drop significantly.

Effects

Seattle faces public inconvenience, increased fire vulnerability and economic hardship whenever a shortage occurs. Direct public health risks are very low, since less than a tenth of the water used in Seattle is for direct consumption (e.g. drinking, bathing, washing dishes) (Seattle Water Department, 1993). Nevertheless, usage restrictions are an inconvenience for many people.

Summer droughts impact public safety by drying vegetation and contributing the spread of grass and house fires. The problem is exacerbated if the city is undergoing a water shortage. During the summer of 1996 several acres burned along I-5 on the side of Beacon Hill, threatening several houses.

The economy suffers most during droughts and shortages. Many businesses depend on water, especially summer oriented ones like landscaping firms, the construction industry, and garden supply businesses. Large water users such as Boeing, the Seattle Parks and Recreation Department, and the University of Washington are also strongly affected. Unfortunately, it is very difficult to quantify the losses and we have no indication of their economic impact.

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. It is important to note that most residents define a shortage differently than city officials. While the city defines shortages by the amount of its reserves, the public defines them in terms of the severity of restrictions. Despite the lower reservoir levels in 1987, many residents seemed to perceive the 1992 shortage as more severe than the 1987 shortage because its restrictions lasted longer and had more bite.

Water shortages also harm the utilities themselves. Both Seattle Public Utilities and City Light are publicly owned utilities, so their financial difficulties are transferred to the taxpayers and their customers. Unfortunately, there is not much available information on this subject. A report by the First Boston Corporation indicated the City Council had to approve surcharges to enable City Light to meet its debt service requirements.

Perhaps future research can build an accurate picture of drought effects on municipal finance.

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. Nevertheless, some type of interdepartmental city involvement could assist the utilities in managing a severe shortage. As with other 'creeping' hazards, the city does not presently have a system in place for prolonged multi-department emergency management.

There is a lack of readily assessable information on which to justify such an exploration. To decide what the relationship between emergency management procedures and droughts should be, more accurate information is required. It would help determine if there are any thresholds beyond which a more intensive approach such as an emergency declaration is warranted. There are some excellent data sources like the Seattle Public Utilities' Water Supply Plan, and they should be expanded.

Windstorms

Waves crashing into West Seattle during the Inaugural Day Storm of January 20, 1993.
Credit: Grant M. Haller / Seattle Post-Intelligencer

Windstorms

Highlights

- *Universal Building Code maps of the US show that Western Washington can receive 70-80 mph winds and that the Puget Sound area is a 'Special Wind Region' where the speeds can go even higher.*
- *Mutual aid could be reduced since northwest windstorms are regional and affect the whole Puget Sound region.*
- *Areas with heavy tree cover and with limited street connections to the rest of the city are the most vulnerable to isolation due to tree falls.*
- *Floating bridges are a special concern, because they create vulnerability to storm generated waves and are of large economic and social importance.*
- *Windstorms halt normal economic activity and can cause widespread and extensive property loss.*
- *Structural damage can occur at wind speeds as low as 32 mph and destroy wood frame structures at speeds around 100 mph. Seattle's highest sustained winds were 85 mph.*
- *Power outages are common during windstorms and some can last for days.*

General

The Pacific Northwest is not subject to hurricanes like the East Coast, but it can sometimes receive violent windstorms that reach hurricane strength. Typically, loss of electrical services during a windstorm results from trees being blown onto power lines rather than from fallen power poles or lines.

Most Puget Sound weather comes from the Pacific. Normally, the Olympic Mountains shield the Puget Lowlands from the sea winds, but sometimes disturbances are able to get around these mountains and into the Puget Lowlands. Usually, this occurs when warm air blows into the region from the Southwest.

History

The greatest windstorm in the Northwest blew in on Columbus Day 1962. This storm is still considered a freak by many meteorologists. One theory is that a piece of Typhoon Frieda broke off from the main storm and moved Northeast as it entered northern waters (Lucia, 1963). By this point it was no longer a classic cyclonic storm. Instead, the winds rushed straight northward. Although the brunt of the storm was not felt in Seattle, local weather stations were reading sustained winds of 85 m.p.h. Records do not date back far, so it is difficult to estimate whether these strong winds are very unusual events or just part of life in the Northwest. A weather station at the Federal Building in downtown Seattle showed that between 1935 and 1959 wind speed exceeded 50 mph 37 times and 60 mph six times (US Weather Bureau, 1959).

Most storms happen in winter. Of the nine major storms to hit Seattle since 1962, seven have occurred in winter. The other two occurred in late fall and early spring. Nearly half happened in November, while two struck in February. The Seattle Public Library compiled a list of severe Seattle-area windstorms. The following are the most significant ones:

1943	Official records at the Federal Building show one occurrence of 65-69 m.p.h. winds (US Weather Bureau, 1959).
10/12/1962	'Columbus Day Storm'. It had 85 miles per hour sustained winds (equal to hurricane speed). Higher wind speeds (150 mph) on the coast demonstrated the protection that the Olympic Mountains give the region. Nevertheless, the damage was widespread. 46 people died throughout the region, 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.
3/26/1971	60 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.
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.
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 occur in Seattle, although the power was out the longest in the suburbs. Debris littered the road and traffic comes to a stop as traffic lights fail.

Vulnerability

The 1997 Uniform Building Code contains a wind hazards map of the United States. It shows Western Washington in an area that can get winds between 70 and 80 mph. Additionally, the Puget Sound area is shown as a 'special wind region' that can experience even higher wind speeds (UBC, 1997). In 2004 the city will be adopting a new model code—the 2003 International Building Code (IBC).

Based on the historical record shown above, Seattle can expect a big storm once every three to four years. Wooded areas are more vulnerable since falling trees can cause power outages and crush houses and cars. Additionally, 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.

The city's dependence on the floating bridges is another liability. They are often closed in large storms. On average, more than 260,000 vehicles move over these bridges daily (Seattle Department of Transportation, 2003). This traffic gives them enormous socio-economic importance. Their susceptibility to damage and their value to the local economy make them vulnerabilities for Seattle.

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; for example, both of the floating bridges across Lake Washington (I-90 and I-520) had damage to pontoons that keep the bridges afloat (FEMA, 1993). Extensive damage occurred from uprooted trees and brittle trees that broke or whose branches broke off and fell onto power lines, buildings and roadways. Such damage commonly occurs in windstorms.

Effects

Economically, a windstorm's effects are similar to those of a snowstorm. They halt most economic activity for several days. 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.

Even moderate wind speed can damage buildings. Wind speeds as low as 32 m.p.h. can drive objects through walls (Marshall, 1993). Other research shows that wood-frame and unreinforced masonry structures can be damaged or even destroyed at speeds less than 100 mph and that a home constructed according to any of the major codes in the US will lose its roof in winds from 80 to 120 mph (Liu, 1993). 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. Besides being an inconvenience to property owners and municipal governments who must clean up debris, falling trees are also a safety risk.

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. Luckily nearly all these storms are predicted and the bridges closed preemptively.

Conclusions

Windstorms are a common hazard in Seattle. The city has recognized the causes of such damage and now has a hazardous tree ordinance that requires removal of certain species of trees, including those that are brittle and tend to break during windstorms.

Bibliography

Ackoff, Russell L. Redesigning the Future: A Systems Approach to Societal Problems. New York: John Wiley, 1974.

Albala-Bertrand, J.M. Political Economy of Large Natural Disaster. Oxford: Clarendon Press, 1993.

Atwater, B.F., and Moore, A.L. "A Tsunami about 1,000 Years Ago in Puget Sound, Washington." Science, v. 258, 1992. 1614-1617.

Atwater, B.F., and Hemphill-Haley, E. Recurrence intervals for Great Earthquakes of the Past 3,500 Years at Northeastern Willapa Bay, Washington. U.S. Geological Survey Professional Paper 1576, 1997.

Ayre, Robert S. Earthquake and Tsunami Hazards in the United States. Berkley: University of California, Institute of Behavioral Science, 1975.

Blong, R.J. Volcanic Hazards. Sydney: Academic Press, 1984.

Bolin, Robert, ed. The Loma Prieta Earthquake: Studies of Short-Term Impacts. Institute of Behavioral Science, University of Colorado, Program on Environment and Behavior, Monograph #50, 1990.

Bolton, Patricia, Carlyn Orians, and Lynn Miranda. Vulnerable Buildings and Special Needs Populations. Seattle, Battelle Institute, 1990.

Brabb, E.E. "Landslides: Extent and economic significance in the United States." Landslides: Extent and Economic Significance. Brabb, Earl E. and Betty L. Harrod, eds. Rotterdam: A.A. Balkema, 1989.

Bryant, E.A. Natural Hazards. Cambridge: Cambridge University Press, 1991.

Bullard, Fred M. Volcanoes of the Earth. Austin: University of Texas Press, 1984.

Burton, Ian, Robert W. Kates and Gilbert F. White. The Environment as Hazard. New York: Oxford University Press, 1978.

Cashman, John R. Hazardous Materials Emergencies: Response and Control. Lancaster, Technomic Publishing Co., Inc., 1988.

Changnon, Stanley A. Jr., Richard J. Schicht, and Richard G. Semonin. A Plan for Research on Floods and Their Mitigation in the United States. Campaign, IL: Illinois State Water Survey Division, 1983.

Church C., D. Burgess, C. Doswell, and R. Davies-Jones, eds. The Tornado: Its Structure, Dynamics, Prediction, and Hazards. Washington D.C.: The American Geophysical Union, 1993.

Cigler Beverly A. "Current Policy Issues in Mitigation." Managing Disasters. Louise K. Comfort,- ed. Durham: Duke UP, 1988.

City Budget Office. Landslide Policies for Seattle. Seattle: City of Seattle, 1998.

City of Seattle. Toward a Sustainable Seattle. Seattle: City of Seattle, 1994.

—, Division of Emergency Management. Disaster Readiness and Response Plan. Seattle: City of Seattle, 1993.

—,—. Hazard Vulnerability Analysis. Seattle, City of Seattle, 1991.

Cochrane, Harold C. Natural Hazards and Their Distributive Effects. Institute of Behavioral Science, University of Colorado, Program on Technology, Environment and Man, Monograph #NSF-RA-E-75-003, 1975.

Comfort, Louise K. "Designing Policy for Action: The Emergency Management System." Managing Disaster. Louise K. Comfort, ed. Durham, Duke University Press, 1988.

Conradi, Ken. LiDAR and the City. Slide show presented to the Seattle Forum 2003.

Comerio Mary C. with Hamilton, Rabinovitz & Alschuler, Inc The Impact of Housing Losses in the Northridge Earthquake :Recovery and Reconstruction Issues University of California at Berkeley Publication number: CEDR-14-96 August 1996

Council on Tall Buildings and Urban Habitat. Fire Safety in Tall Buildings. New York: McGraw-Hill, 1992.

Crandell, Dwight. The Geologic Story of Mt. Rainier. United States Geologic Survey Bulletin 1293, 1969.

Crandell, Dwight R. and Donald R. Mullineaux. Volcanic Hazards at Mt. Rainier, Washington. United States Geologic Survey Bulletin 1238, 1967.

Crandell, D.R. 1976 Preliminary assessment of potential hazards from future volcanic eruptions in Washington. U.S. Geological Survey Miscellaneous Field Studies Map MF-774 1 plate, scale 1:1,000,000.

Crenshaw, Martha and John Pimlott, eds. Encyclopedia of World Terrorism. Armonk, New York: M.E. Sharpe, 1997.

Crozier, Michael J., ed. Landslides: Causes, Consequences, and Environment. Dover, NH: Croom Helm, 1986.

Decker, Robert W. and Barbara B. Decker. Mountains of Fire. Cambridge: Cambridge University Press, 1991.

Dorpat, Paul. Seattle: Now and Then. Seattle: Tartu, 1984

Drabek, Thomas E. "The Evolution of Emergency Management." Emergency Management: Principles and Practice for Local Government. Washington D.C.: International City Management Association, 1991. 3-29.

—. Human System Response to Disaster. New York: Springer Verlag, 1986.

—. "Taxonomy and Disaster: Theoretical and Applied Issues." Social Structure and Disaster. Ed. Gary A. Kreps. Newark: University of Delaware Press, 1989. 317-345.

Earthquake Engineering Research Institute. Seattle Fault Scenario. Slide show presented to Seattle Forum 2003.

Federal Bureau of Investigation. Terrorism in the United States 1995. Washington D.C.: U.S. Department of Justice, 1995.

Federal Bureau of Investigation. Terrorism in the United States 1996. Washington D.C.: U.S. Department of Justice, 1996.

Federal Bureau of Investigation. Terrorism in the United States 1997. Washington D.C.: U.S. Department of Justice, 1997.

Federal Emergency Management Agency. Hazard Mitigation Opportunities in the State of Washington: Report of the Wind Hazard Mitigation Survey Team. FEMA-981-DR-WA. Washington D.C.: Federal Emergency Management Agency, June 28, 1994.

Federal Emergency Management Agency. An Overview of Natural Hazards in the Vicinity of Seattle, Washington. Washington D.C.: Federal Emergency Management Agency, October 25, 1994.

Fogelson, Robert M. Violence as Protest. Garden City: Anchor, 1971.

Forbes, Ronald W. and Frank R. Pond. West Coast Utilities: Coping With the Drought. New York, First Boston Corp., 1977.

"Forging an Urban Fire Forum." Fire Command January 1990.

Fox, Howard. The Seattle Almanac. Seattle: Seattle Public Library, 1993.

Francis, Peter. Volcanoes: A Planetary Perspective. New York: Clarendon Press, 1993.

Frankel, Art, et. Al. New Product (2004): Seattle Urban Seismic Hazard Maps. Slide show presented to the Seattle Forum 2003.

Franklin, Dorothy Wilkins, ed. West Coast Disaster: The Columbus Day Storm of 1962. Portland, OR: Gann, 1963 or 1964.

Girgenti, Richard H. A Report To The Governor On The Disturbances in Crown Heights. Albany: New York State Division of Criminal Justice Services, 1993.

Godschalk, David R. "Disaster Mitigation and Hazard Management." Emergency Management: Principles and Practice for Local Government. Thomas E. Drabek, ed. Washington D.C.: International City Management Association, 1991. 131-160.

Godschalk, David R., David J. Brower, and Timothy Beatley. Catastrophic Coastal Storms. Durham: Duke University Press, 1989.

Gray, D.M. and D.H. Male. Handbook of Snow. Toronto: Pergamon Press, 1981.

Grazulis, Thomas P. Significant Tornadoes. 2 vols. St. Johnsbury, VT: Environmental Films Inc., 1991.

Gurr, Ted Robert. "A Comparative Study of Civil Strife." The History of Violence in America. Ed. Graham, Hugh Davis and Ted Robert Gurr. New York: Preager, 1969.

Halter, Richard. Oregon Tornado Chasers' Society. [World Wide Web site] (Corvallis OR, n.d. [cited 20 august, 1997]); available at http://www.proaxis.com/~rjhstorm.

Harris, Stephen. Fire Mountains of the West. Missoula, MT: Mountain Press, 1991.

Hewitt, Kenneth. "The Idea of Calamity in a Technocratic Age." Interpretations of Calamity. Ed. Kenneth Hewitt. Boston: Allen and Unwin, 1983. 3-32.

Hirschler, Marcelo M., ed. Fire Hazard and Fire Risk Assessment. Philadelphia: ASTM, 1992.

International Conference of Building Officials. Uniform Building Code, Short Form. Los Angeles: International Conference of Building Officials, 1991.

Harp Edwin L., Chleboard, A.F., R.L. Schuster, S.H. Cannon, Reid M.E. and Wilson R. C., Landslides and Landslide Hazards in Washington State Due to February 5-9, 1996 Storm U. S. Geological Survey Administrative Report.

Hoblitt, R.P. Walder, J.S., Driedger, C.L. Scott, K.M., Pringle, P.T. and Vallance, J.W. 1995. Volcano hazards from Mount Rainier, Washington. U.S. Geological Survey Open-File Report 95-273.

Isenberg, Jeremy, ed. Social and Economic Impacts of Earthquakes on Utility Lifelines. New York: American Society of Civil Engineers, 1981.

Janowitz, Morris. "Patterns of Collective Racial Violence" The History of Violence in America. Ed. Graham, Hugh Davis and Ted Robert Gurr. New York: Preager, 1969.

Johnson, David. Cascades Volcano Observatory. [World Wide Web site] (Vancouver, WA, n.d. [cited 31 May 1995]); available at http://vulcan.wr.usgs.gov/home.html.

Jones, Barclay G. "Assessing Dangers." Protecting Historic Architecture and Museum Collections from Natural Disasters. Barclay G. Jones, ed. Boston: Butterworths, 1986. 91-118.

Jones, Barclay G. editor Economic Consequences of Earthquakes: Preparing for the Unexpected, National Center for Earthquake Engineering Research –SP 0001, 1997

Jones, Barclay G. and James H. Mars. Regional Analysis for Development Planning in Disaster Areas. Ithaca, NY: Center for Urban Development Research, Cornell University, 1974.

Karl, Thomas R. and Richard W. Knight. Atlas of Monthly Palmer Hydrological Drought Indices (1931-1983) for the Contiguous United States. Asheville, N.C.: National Climatic Data Center, 1985.

Karlin, R.E., and Abella, S.E.B., "Paleoearthquakes in the Puget Sound Region Recorded in Sediments from Lake Washington, U.S.A." Science, v. 258, 1992. 1617-1620.

Kates, Robert William. Hazard and Choice Perception in Flood Plain Management. Chicago: The University of Chicago, 1962.

Kerr, Richard. "Big Squeeze Points to a Big Quake." Science 252 (April 5, 1992): 28.

King County. King County Flood Hazard Reduction Plan. Seattle: King County, 1988.

King County, Office of Emergency Management. King County. Commodity Flow Study. March 1994.

—,—. Database of SARA Title III sites in Seattle. Unpublished, n.d.

—,—. King County Draft Hazard Identification and Vulnerability Analysis. King County, 1997.

Kostof, Spiro. The City Shaped. Boston: Bulfinch, 1991.

Kwong, Peter. "The First Multicultural Riots." Inside the L.A. Riots. New York: Institute for Alternative Journalism, 1992.

Latter, John H., ed. Volcanic Hazards: Assessment and Monitoring. Berlin: Springer-Verlag, 1989.

Law, Margaret. "Fire Safety Design For Tall Buildings: Recent Developments." Second Century of the Skyscraper. Lynn S. Beedle, ed. New York: Van Nostrand Reinhold Company, 1988.

Liu, Henry. "Calculation of Wind Speeds Required to Damage or Destroy Buildings." The Tornado. C. Church, D. Burgess, C. Doswell, and R. Davies-Jones, eds. Washington D.C.: American Geophysical Union, 1993. 535-541.

Liu, Henry. Wind Engineering. Englewood Cliffs, NJ: Prentice-Hall, 1991.

Los Angeles Times. Understanding the Riots. Los Angeles: Times Mirror, 1992.

Lucia, Ellis. The Big Blow: The Story of the Pacific Northwest's Columbus Day Storm. Portland, OR: no publisher given, 1963.

Ludwin, R.S., C.S. Weaver, and R.S. Crosson. "Seismicity of Washington and Oregon." Neotechonics of North America, Decade Map Volume I. D.B. Slemmon, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds. Boulder, CO: Geological Society of America, 1991.

Marshall, Timothy P. "Lessons Learned From Analyzing Tornado Damage." The Tornado. Church, C., D. Burgess, C. Doswell, and R. Davies-Jones, eds. Washington D.C.: American Geophysical Union, 1993. 495-499.

Maskrey, Andrew. Disaster Mitigation. Oxford: Oxfam, 1989.

May, Peter J. Recovering from Catastrophes: Federal Disaster Relief Policy and Politics. Westport, Connecticut: Greenwood Press, 1985.

McCalpin, James P. An Improved Procedure for Mapping Landslide Potential Using A Geographic Information System, With Applications To The Puget Sound Region. Final Technical Report, Element III.3. National Earthquake Hazards Reduction Program, U.S. Geological Survey, 1997.

McHarg, Ian. Design with Nature. Garden City: Doubleday, 1971.

McLoughlin, David. "A Framework for Integrated Emergency Management." Public Administration Review 45: 165-172.

Meszaros Jacqueline, Fiegener, M Effects of the 2001 Nisqually Earthquake on Small Businesses in Washington State U.S. Department of Commerce Economic Development Administration October 2002.

Mileti, Dennis S editor Disasters by Design: A Reassessment of Natural Hazards in the United States, Joseph Henry Press, Washington D.C. 2001.

Mills, Edwin S. and Bruce W. Hamilton. Urban Economics. New York: HarperCollins, 1994.

Mitchell, James. "Natural Hazards Predictions and Responses in Very Large Cities." Predictions and Perceptions of Natural Hazards. Nemec, J., Joanne M. Nigg, and F. Siccardi, eds. Dordrecht: Klumer Academic Publishers, 1993.

Modle, Neil. "Hazard study dangerous." Seattle Times, 3 August, 1994.

Morgan, Lane and Murray Morgan. Seattle: A Pictorial History. Norfolk, Donning Company, 1982.

Morrow, Teresa. Seattle Survival Guide II. Seattle: Sasquatch Books, 1993.

Myles, Douglas. The Great Waves. New York: McGraw-Hill Book Company, 1985.

Nader, Ralph and Wesley J. Smith. Collision Course. Blue Ridge Summit, PA, TAB Books, 1994.

National Academy of Sciences (NAS). Oceanography and Coastal Engineering in the Great Alaska Earthquake of 1964. Washington, D.C.: National Academy of Sciences, 1972.

National Advisory Commission on Civil Disorders (The Kerner Commisson). Report of the National Advisory Commission on Civil Disorders. New York, Bantam, 1968.

National Fire Protection Association. Fire Protection Handbook. 16th ed. Quincy, MA: National Fire Protection Association, 1986.

National Flood Insurance Program. Flood Insurance Rate Map: King County Washington and Incorporated Areas. Map Numbers 53033C0010 D, 015 D, 017 D, 020 D, 036 D, 040 D, 160 D, 170 D, 175 D, and 310 E. Washington D.C.: Federal Emergency Management Agency, 1989.

National Governors' Association. State Comprehensive Emergency Management. Washington D.C.: National Governors' Association, 1979.

National Oceanographic and Atmospheric Administration (NOAA), "Tsunami, the Great Wave" (brochure). Washington, D.C.: National Weather Service, 2002.

National Research Council. A Safer Future: Reducing the Impacts of Natural Disasters. Washington D.C.: National Academy Press, 1991.

National Research Council. Wind and the Built Environment. Washington D.C.: National Academy Press, 1993.

Noson, Linda, Anthony Qamer, and Gerald Thorsen. Washington State Earthquake Hazards. Washington Division of Geology and Earth Resources Information Circular 85, 1988.

Olishifski, Julian B., ed. Handbook of Hazardous Materials. 2nd ed. Schaumburg, IL. Alliance of American Insurers, 1983.

Olshansky, Robert. Landslide Hazard in the United States. New York: Garland, 1990.

Oster, Clinton V., John S. Strong and C. Kurt Zorn. Why Airplanes Crash: Aviation Safety in a Changing World. New York: Oxford University Press, 1992.

Pavlak, Thomas J. "Structuring Problems for Policy Action." Managing Disaster. Louise K. Comfort, ed. Durham: Duke University Press, 1988. 22-36.

Perrow, Charles. Normal Accidents. New York: Basic Books, 1984.

Perry, Ronald W. and Alvin H. Mushkatel. Minority Citizens in Disasters. Athens, Georgia: University of Georgia Press, 1986.

Petak, William J. "Emergency Management: A Challenge for Public Administration." Public Administration Review. 45:3-7.

Peterson, C.D., Darienzo, M.E., and Clough, C. "Recurrence Intervals of Coseismic Subsidence Events in Northern Oregon Bays of the Cascadia Margin." Final Technical Report to the Oregon Department of Geology and Mineral Industries, Open-file Report 0-95-5, 1995.

Peterson, Mark D., William A. Bryant, Chris H. Cramer, Tianqing Cao, and Michael S. Reichle. Open-file Report 96-08. California Department of Conservation, Division of Mines and Geology, 1996.

Porter, Bruce and Marvin Dunn. The Miami Riot of 1980. Lexington, MA: Lexington Press, 1984.

Puget Sound Regional Council. 1990 Census: Characteristics of Aging: King County. Seattle, Puget Sound Regional Council, 1991.

—. 1990 Census: Characteristics of Disability: King County. Seattle, Puget Sound Regional Council, 1992.

Quarantelli, E.L. Organizational Behavior in Disasters and Implications for Disaster Planning. Emitsburg, MD: National Emergency Training Center, Federal Emergency Management Agency, 1984.

Renner, Jeff. Northwest Mountain Weather: Understanding and Forecasting for the Backcountry User. Seattle: The Mountaineers, 1993.

Revell, Oliver B. "Structure of Counterterrorism Planning and Operations in the United States." Terrorism. 14:3: 135 - 144.

Riley, Kevin Jack and Bruce Hoffman. Domestic Terrorism: A National Assessment of State and Local Preparedness. Santa Monica: Rand Corporation, 1995.

Robinson, Andrew. Earthshock. London: Thames and Hudson, 1993.

Rosenberg, Norman J. North American Drought. Boulder: Westview Press, 1978. (Published for the American Association for the Advancement of Science).

Rossi, Peter H., James D. Wright, Eleanor Weber-Burdin and Joseph Pereira. Victims of the Environment. New York: Plenum Press, 1983.

Rule, James B. Theories of Civil Violence. Berkley: U of California P, 1987.

Saarinen, Thomas F. and James L. Sell. Warning and Response to the Mount St. Helen's Eruption. Albany: State University of New York Press, 1985.

Sale, Roger. Seattle: Past to Present. Seattle: U of Washington Press, 1976.

Sanders, Russell E. "Urban Problems Confront Fire Service." NFPA Journal. March/April, 1993. 14.

Scarth, Alwyn. Volcanoes: An Introduction. College Station, TX: Texas A&M University Press, 1994.

Schultz, Neil. Fire and Flammability Handbook. New York: Van Nostrand Reinhold Company, 1985.

Scigliano, Eric. "Seattle's Little Big Riot." Inside the L.A. Riots. [New York]: Institute for Alternative Journalism, 1992.

Seattle Fire Department. Hazardous Materials Response Log. Unpublished, 1993.

—. Multiple Alarm Fires. Unpublished, n.d.

—. Metropolitan Medical Strike Team: Operations Plan. Seattle: City of Seattle, November, 1998

Seattle Planning Department. Community Services and Facilities/Public Utilities. Seattle: City of Seattle, December, 1990.

—. Economy and Employment. Seattle: City of Seattle, August, 1991.

—. Housing. Seattle: City of Seattle, December, 1990.

—. The Mayor's Recommended Comprehensive Plan. Seattle: City of Seattle, March, 1994.

—. Seattle 1990: Who We Are. Seattle: City of Seattle, December 1, 1992.

—. Seattle's Character. Seattle: City of Seattle, April, 1991.

—. Seismic Hazards in Seattle. Seattle: City of Seattle, June, 1992.

—. Transportation. Seattle: City of Seattle, December, 1990.

Seattle Water Department. Seattle Water Supply Plan. Seattle: City of Seattle, 1993.

Seattle Times. "City gloomy on arresting earth slide." Apr. 13, 1961.

—. "Crews clear slide in McGraw Street." Feb. 27, 1961.

—. "Damage heavy in wake of small tornado; both sides of lake hard hit." Sept. 29, 1962.

—. "Eleven slide repair projects will cost $317,104." Jul. 6, 1934.

—. "Family flees house caught in earthslide." Dec. 19, 1941.

—. "Four hundred more fight to gain control of city slides." Jan. 22, 1934.

—. "Freeway slide imperils water, gas, sewer lines; vigil kept." Jan. 2, 1966.

—. "Gales snaps wires; rains start slides." Feb. 26, 1948.

—. "Magnolia Bluff trembles." Jan. 8, 1969.

—. "More slides on Admiral Way feared." Mar. 3, 1961.

—. "Residents edgy as homes slide down Madronna hill." Jan. 23, 1972.

—. "Seattle's wettest week-end." Magazine Section, Dec. 6, 1964. p.2, col 1-3.

—. "Slide blocks W. Marginal Way." Mar. 14, 1961.

—. "Slide forces couple to seek new quarters." Feb. 7, 1961.

—. "Slide threatens approach to bridge; 1 lane closed." Dec. 31, 1965.

—. "Slide wrecks new building at Sand Point." Dec. 2, 1941.

—. "Slide wrecks train; car back on track." Dec. 28, 1959.

—. "Slipping porches." Apr. 13, 1950.

—. "Tornado smashes homes, barns in south King County area." Dec. 12, 1969.

—. "Tornado, torrent of rain hit area." Aug. 19, 1964.

—. "Twister near airport fails to touch down." Sept. 12, 1966.

—. "Uhlman orders city aid in slide areas." Apr. 13, 1974.

—. "Workmen search mud and debris in slide-crushed home for children's bodies." Feb. 3, 1947.

Seattle Transportation Department. Snow and Ice Response Plan. Seattle: City of Seattle, 2003.

Shannon & Wilson, Inc. Fax to Seattle Water Department, Jan. 21, 1993.

Shannon & Wilson, Inc. Seattle Landslide Study. Seattle: Shannon & Wilson, 2000.

Shinozuka, M., Rose A., Eguchi R.T. Engineering and Socioeconomic Impacts of Earthquakes: An analysis of Electricity Lifeline Disruptions in the New Madrid Area Multidisciplinary Center for Earthquake Engineering Research 1998.

Sherrod, B.L. "Holocene Relative Sea Level Changes Along the Seattle Fault at Restoration Point, Washington." Quaternary Research, v. 54, 2000. 384-393.

Shuto N. "Numerical Simulation of Tsunami - Its Present and Near Future." Natural Hazards 4 (1991): 171-191.

—. "Tsunami Intensity and Disasters." Tsunami in the World. Stefano Tinti, ed. Boston: Kluwer Academic Publishers, 1993. 197-216.

Sorkin, Alan L. Economic Aspects of Natural Hazards. Lexington: Lexington Books, 1982.

Steele, William P. The Nisqually Earthquake and the Evolution of the PNSN Information Products. Slide show presented to the Seattle Forum 2003.

Susman, Paul, Phil O'Keefe, and Ben Wisner. "Global Disasters, a Radical Interpretation." Interpretations of Calamity. Kenneth Hewitt, ed. Boston: Allen and Unwin, 1983. 263-283.

Sylves, Richard T. "Federal Preparedness for Hazardous and Toxic Waste Disaster." Managing Disaster. Ed. Louise K. Comfort. Durham: Duke University, 1988. 147-159.

Tannehill, Ivan Ray. Drought: its causes and effects. Princeton, Princeton University Press, 1947.

Technical Advisory Committee. Environmental Risks in Seattle. Seattle: City of Seattle - Planning Department, 1991.

Tierney , Kathleen J., Lindell, M.K., Perry R.W. Facing the Unexpected: Disaster Preparedness and Response in the United States Joseph Henry Press, Washington D.C., 2001.

Toppozada, T.R., C.R. Real, and D.L. Parke. "Earthquake History of California." California Geology, February 1986. 27-83.

The Tornado Project. Tornado Project Online. [World Wide Web site] (St. Johnsbury, VT, n.d. [cited 26 august 1997]). available at http://tornadoproject.com.

Thackrah, John Richard. Encyclopedia of Terrorism and Political Violence. New York: Routledge & Kegan, 1987.

Troost, Kathy Goetz. The Seattle-Area Geologic Mapping Project: Products, Uses, Findings. Slide show presented to the Seattle Forum 2003.

Tubbs, Donald. Landslides in Seattle. USGS, 1975.

Turner Keith A, Robert L. Schuster ed. Landslides Investigation and Mitigation Special Reporta 247 Transportation Research Board National Research Council, National Academy Press 1996.

Turner, Ralph H., Joanne M. Nigg, and Denise Heller Paz. Waiting for Disaster. Berkeley: University of California Press, 1986.

UNDRO. Case report: Iran, Kreman Earthquake, 28 July 1981. Geneva: United Nations, 1981.

United States Dept of Justice. National Crime Victimization Survey. Washington D.C.: U.S. Government Printing Office, 1998.

United States Dept. of Transportation. 1993 Emergency Response Guidebook. Washington D.C.: U.S. Government Printing Office, 1994.

United States Geological Survey. A Study of Earthquake Losses in the Puget Sound, Washington, Area. Open-File Report 75-375, 1975.

United States Water Resources Council. Regulation of Flood Hazard Areas, volume one, parts I-IV. Washington D.C.: United States Water Resources Council, 1973.

—. A Unified National Program for Flood Plain Management. Washington D.C.: United States Water Resources Council, 1979.

Upton, James N. A Social History of 20th Century Urban Riots. Bristol: Wyndham Hall P, 1984.

Varnes, David J. Landslide hazard zonation: a review of principles and practice. Darantiere, France: UNECO, 1984.

Ward, Roy. Floods. London: Macmillan Press, 1978.

Washington State Department of Health. Final Report: Hazardous Substance Emergency Event Surveillance System. January - December 1992.

Waddington, David. Contemporary Issues in Public Disorder. London: Routledge, 1992.

Washington State Department of Emergency Services. Hazard Vulnerability Analysis. Olympia: Washington State Department of Emergency Services, n.d.

Washington State Military Department, Emergency Management Division. Washington State 2001 Hazard Identification and Vulnerability Assessment, April 2001.

Washington State Library. Natural Disasters in the State of Washington: A Directory of Available Information Compiled for the Washington State Department of Emergency Services. 2nd Ed. Olympia, WA: Washington State Department of Emergency Services, 1975.

Waugh, William L, Jr. and Ronald John Hy. "Introduction to Emergency Management." Handbook of Emergency Management. Eds. William L. Waugh, Jr. and Ronald John Hy. New York: Greenwood Press, 1990. 1-10.

Weaver, Craig S. USGS Earthquake and Landslide Studies: New Products and what they mean for the City of Seattle. Slide show presented to the Seattle Forum 2003.

Webster, William. The City in Crisis: A Report by the Special Advisor to the Board of Police Commisioners on the Civil Disorder in Los Angles. Los Angeles, 1992.

Whitmore, Paul M. "Expected Tsunami Amplitudes and Currents Along the North American Coast for Cascadia Subduction Zone Earthquakes." Natural Hazards 8 (1993): 59-73.

Wilhite, Donald A. Drought Assessment, Management, and Planning. Boston, Kluwer Academic Publishers, 1993.

Wilhite, Donald A. and William E. Easterling with Deborah A. Wood. Planning for Drought. Boulder, CO: Westview Press, 1987.

Wright, James D. and Peter H. Rossi. Social Science and Natural Hazards. Cambridge: Abt Books, 1981.

Yeh, Harry H. "Tsunami Bore Runup." Natural Hazards 4 (1991): 209-220.

Yelin, Thomas S., Arthur C. Tarr, John A. Michael, and Craig S. Weaver. Washington and Oregon Earthquake History and Hazards. United States Geological Survey Open-File Report 94-226B.

Yevjevich, Vujica, Luis da Cunha, and Evan Vlachos. Coping with Drought. Littleton, CO: Water Resources Publications, 1983.

Záruba, Quido and Vojtêch Mencl. Landslides and their Control. New York: Elsevier Scientific Publishing Company, 1982.

Zurcher, Louis A. "Disaster Taxonomies: Service to Whom?" Social Structure and Disaster. Gary Kreps, ed. Newark, DE: U of Delaware Press, 1989. 359-364.