



Flooding

Key Points

- Nationally, floods are the most costly and destructive disasters. Most damage caused by Hurricane Katrina was caused by flooding. Western Washington is very prone to flooding. Seattle's flood profile is very different from rural areas of the state.
- Seattle has three distinct flooding hazards:
 - **Riverine flooding** – Heavy precipitation causes a river or stream to overflow its banks into the adjoining floodplain. Seattle's creeks, especially Thornton and Longfellow, have flooded more often than the managed Duwamish River. Failure of the Howard Hanson dam or the release of large volumes of water from the dam could affect the Duwamish River. (See Infrastructure Failures for more on dam failures). These areas are small for a large urban area comprising 388 acres.
 - **Coastal flooding** – Associated with storms. High tides and wind can push water into coastal areas. Coastal flooding can erode the toes of bluffs and are one factor in landslides. Some areas, like South Park, can experience drainage problems under the same conditions.
 - **Urban flooding** – Happens suddenly when intense rain overwhelms the capacity of the drainage system. Low lying, bowl-shaped areas like Madison Valley and Midvale are the most likely to flood.
- The area in the 100-year floodplains covers South Park and the drainage basins for Thornton and Longfellow Creeks. Flood control structures have been built in all of these areas. Small segments of two high-volume arterials cross the flood plain: SR99 crosses the South Park floodplain and SR 522 cross along three segments of Thornton Creek.
- Seattle has fewer than ten buildings that have had more than one flood loss.

Context

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

With over 200 miles of waterfront, flooding is a natural concern in Seattle. It is surrounded by Puget Sound and Lake Washington and contains the Duwamish River, a ship canal and several streams. Flooding outside Seattle can have an indirect effect. Flooding along the Cedar River can decrease water quality to the point where it cannot be diverted for drinking water supply and water stored in Lake Youngs needs to be used instead.

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

- **Riverine flooding** – Heavy precipitation causes a river or stream to overflow its banks into the adjoining floodplain. This is the classic flood. Seattle's creeks, especially Thornton and Longfellow, have flooded more often than the managed Duwamish River. Failure of the Howard Hanson dam or the release of large volumes of water from the dam could affect the Duwamish River. (See Infrastructure Failures for more on dam failures).
- **Coastal flooding** – Associated with storms. High tides and wind can push water into coastal areas. Coastal flooding can erode the toes of bluffs and are one factor in landslides. Some areas, like South Park, can experience drainage problems under the same conditions.



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- **Urban flooding** – Happens suddenly when intense rain overwhelms the capacity of the drainage system. Low lying, bowl-shaped areas like Madison Valley and Midvale are the most likely to flood.

The key factors determining the amount of damage in a flood are the depth and velocity of the water and the amount of time the water stays above flood level. To project the expected amount of damage, the frequency of high water in a particular area needs to be computed. Usually, this is done by the Federal Emergency Management Agency. They map area that floods on average once every 100 years and once every 500 years. A 100-year flood is simply one that has a 1% chance of happening in any given year. Similarly, a 500-year flood has a 0.2% chance of occurring each year. The elevation and shape of these floodplains, as well as historical and geological records, suggest probable flood depths and velocity.

Riverine floods often develop slowly and give floodplain residents ample time to evacuate. Casualties occur when people cannot or will not leave or try to drive across flooded roadways. Sometimes casualties occur when floods develop rapidly, as in a dam burst or a flash flood. Even small floods can cause heavy structural damage by rotting wooden frames and undermining foundations. More frequently they destroy moveable property and commercial stock.

Riverine floods can also affect city infrastructure when high water cuts transportation routes and pipelines. These lifeline losses can impact people beyond the immediate floodplain. If floodwaters inundate hazardous waste sites or buildings where dangerous chemicals are housed, they also generate secondary incidents such as hazardous material exposures. 1993 flooding in Texas cut several large oil pipelines, releasing oil that later caught fire.

Coastal flooding is usually more violent along open coastlines. Storms push water ahead of them creating floods along the coasts. Storm surges as high as 23 feet have been reported in conjunction with tropical storms. Since they accompany storms, storm surges have enormous destructive potential as winds drive waves ashore at high velocities. Few non-engineered buildings can survive a strong storm surge, especially those constructed of wood. Even stronger structures like port facilities, warehouses, and bridges are vulnerable to coastal floods. Surges are worse when they occur at high tide.

Currently, all levels of government employ structural and non-structural means to reduce flood risk. In the past, structural methods such as the construction of dams, levees and bulkheads were the most common means used. During the 1950s and 1960s, the emphasis began to shift because these structures failed to completely solve the flood problem. Recent catastrophic flooding like that on the Mississippi in 1993 has lead federal authorities to emphasize a suite of non-structural mitigation strategies, such as flood insurance, government buyouts and more restrictive land use planning.

History

Early in Seattle's history, low-lying areas near downtown and at the mouth of the Duwamish flooded. This prompted the construction of landfills and a drainage system downtown and the channeling of the Duwamish. Since that time, there has been no significant flooding downtown or near the mouth of the Duwamish. Because of these changes, listing very early events is irrelevant.

Areas along the city's streams experience periodic, localized flooding, i.e., limited to the blocks or neighborhoods immediately adjacent to the streams. These streams include Longfellow and Thornton Creeks. However, the depth and current velocity of the floodwaters have been low and they caused only localized structural damage and bank erosion¹. The record of flooding in these areas is limited, but FEMA indicated there were problems in November 1978 and January 1986. Limited urban flooding also occurred in the residential area near Thornton Creek during the winter storms of 1996/1997, and again in October 2003.

The South Park neighborhood that lies at a low elevation along the Duwamish is prone to flooding due to backups in the drainage system when there is a combination of heavy rain and high tide. During major storms, runoff can drain directly into the Duwamish. Because the Duwamish is a tidal river, its elevation rises with the high tide and due to higher stream



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flow during a storm. Occasionally, the water level in the Duwamish rises above the level of the outfalls that drain the neighborhood and the drainage system backs up until the tide recedes.

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

Both Seattle City Light and Seattle Public Utilities own and operate facilities located outside of the city limits on the Cedar and Tolt Rivers, the Skagit River and the Pend Oreille River. Flooding can be a concern in these areas during times of heavy rains and extraordinary snowpack.

The rivers in eastern King County are prone to severe flooding. Only a few floods in the area have affected Seattle directly. The most significant have been on the Cedar River. The river flooded many times with major incidents occurring in 1975, 1990, 1995 and 1996. This flooding led to turbidity that impacted the city's ability to divert water due to the lack of filtration. These floods occurred in the winter when demand for water is low, minimizing impact. Filtration was added to the Tolt system in 2001, so the impact of floods on water supply is no longer a serious concern for that portion of the system.

Likelihood of Future Occurrence

Seattle will experience flooding in the future. The principal unknown is the severity of future events. Seattle Public Utilities has examined the amount of rainfall collected in its gages between 1978 and 2007. It discovered a small but statistically significant trend towards short-duration, high-intensity events. Cliff Mass analyzed rainfall intensity data and discovered that events like the one on December 14, 2006, have a 1% to 2% chance of occurring each year. These observations are supported by the Washington Climate Change Impacts Assessment whose simulations "generally predict increases in extreme high precipitation over the next half-century, particularly around Puget Sound." (p2). Seattle Public Utilities is already upgrading the city's drainage system in critical areas.

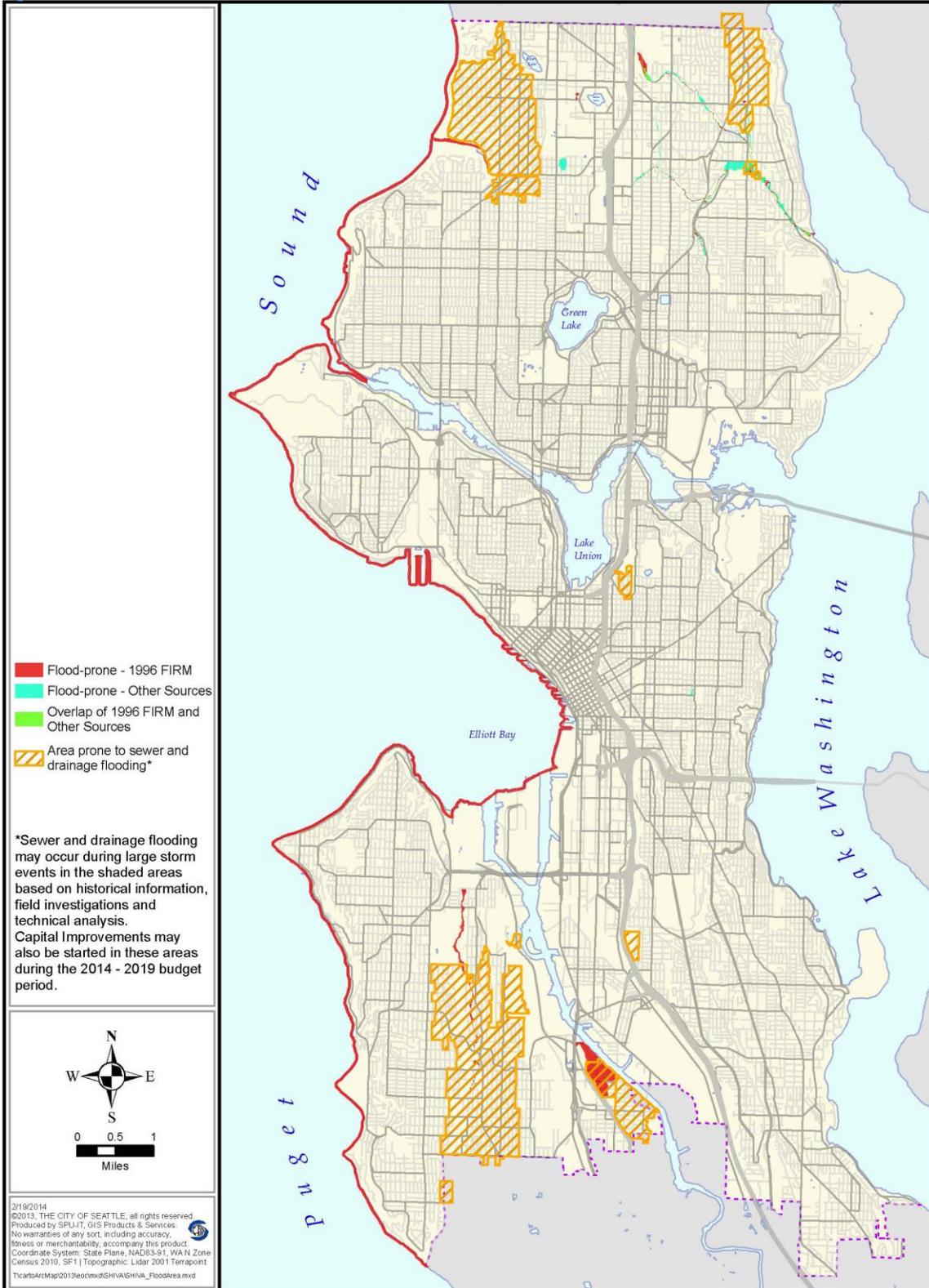
Vulnerability

The National Flood Insurance Rate Maps and U.S. Army Corps of Engineers inundation maps indicate areas prone to flooding in Seattle. The latter shows the area affected by a potential break of the Howard Hanson Dam. The Flood Insurance maps are being updated as of late 2009. These maps show that the locations prone to flooding are quite limited. These areas are most vulnerable during the winter when the city receives most of its rain. The city has adopted a variety of structural controls to prevent flooding. It placed a diversion on Thornton Creek and a stormwater detention basin on Longfellow Creek. However, each has its limits. The Thornton Creek diversion is effective up to the 100-year flood; the Longfellow basin was only partially effective during the January 1986 floodⁱⁱ.



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Figure 1. Flood Prone Areas



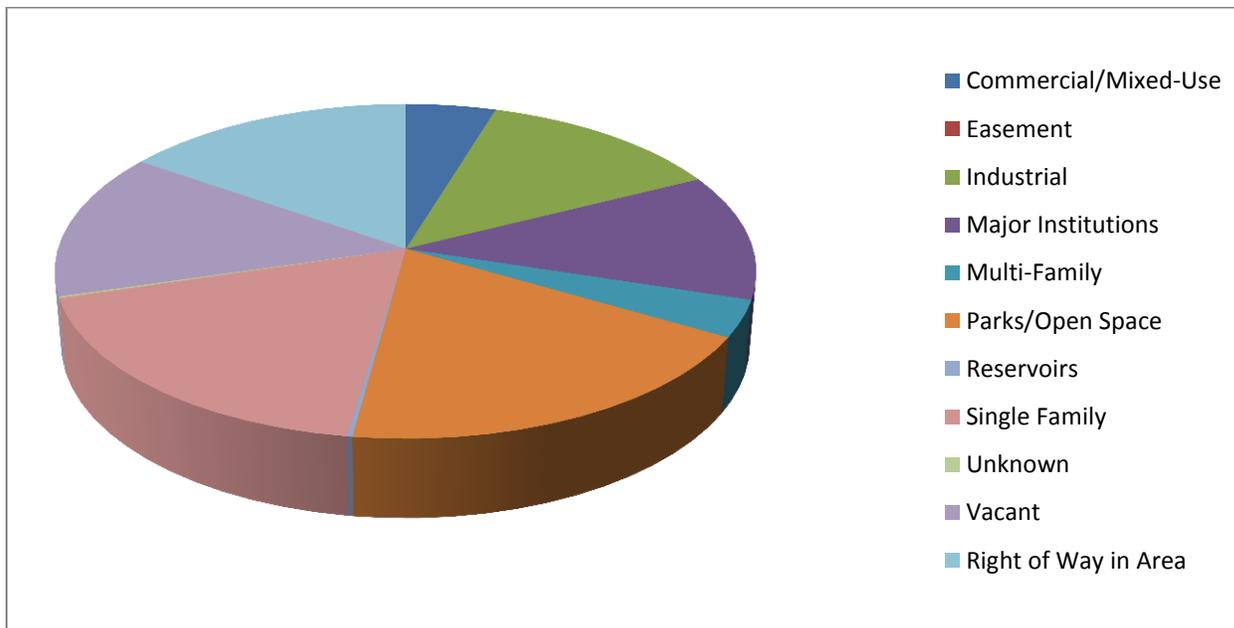


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Table 1. Land Use in Flood Prone Areas

	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Flood Area (1996 FIRM & other)	388.39	0.73%	100.00%
Property in area	328.81	0.62%	84.66%
<i>Commercial/Mixed-Use</i>	18.35	0.03%	4.72%
<i>Easement</i>	0.00	0.00%	0.00%
<i>Industrial</i>	50.06	0.09%	12.89%
<i>Major Institutions</i>	47.45	0.09%	12.22%
<i>Multi-Family</i>	13.82	0.03%	3.56%
<i>Parks/Open Space</i>	72.77	0.14%	18.74%
<i>Reservoirs</i>	0.81	0.00%	0.21%
<i>Single Family</i>	69.90	0.13%	18.00%
<i>Unknown</i>	0.62	0.00%	0.16%
<i>Vacant</i>	55.03	0.10%	14.17%
Right of Way in Area	59.58	0.11%	15.34%

Figure 2. Summary of Land Use in Flood Prone Areas





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Table 2. Estimated Population, Buildings and Assessed Value in Property Touching on Flood Prone Areas.

Number of Buildings	1,722*	Est. Pop
Number of Single Family Units	1,182	2435
Number of Multi-Family Units	2,038	4198
Gross Sq Footage	9,596,454	
Residential Gross Sq Footage	5,139,396	
Commercial Gross Sq Footage	3,802,382	
Total Assessed Value	\$ 3,569,721,500	
Estimated Residential Population		6633

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

Table 3. Critical Facilities in Flood Prone Areas

Medical and Health Services	0
Government Function	0
Protective Function	0
Schools	1
Hazardous Materials Storage Sites	0
Bridges	14
Major Tunnels	0
Water	1
Waste Water	0
Communications	0
Energy	0
Human Service Support	1
High Population	0
Total	17

Table 4. Facilities with Concentrated Vulnerable Populations in Flood Prone Areas.

Adult Family Homes	0
Boarding House	0
Child Care Centers	0
Nursing Home	0
Intermediate Care Facility	0
Total	0



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Table 5. Zoning in Flood Prone Area.

	Acres	% of Seattle	% Area
Seattle	53178.37	100%	
Flood Area (1996 FIRM & other)	388.39	0.73%	100.00%
Zoning	328.81	0.62%	84.66%
<i>Unzoned</i>	0.01	0.00%	0.00%
<i>Commercial - C1</i>	11.36	0.02%	2.92%
<i>Commercial - C2</i>	4.85	0.01%	1.25%
<i>Downtown Harborfront - DH1</i>	4.18	0.01%	1.08%
<i>Downtown Harborfront - DH2</i>	0.00	0.00%	0.00%
<i>Downtown Mixed Commercial - DMC</i>	0.00	0.00%	0.00%
<i>Downtown Mixed Residential/Commercial - DMR</i>	0.00	0.00%	0.00%
<i>Industrial Buffer - IB</i>	2.91	0.01%	0.75%
<i>Industrial Commercial - IC</i>	2.90	0.01%	0.75%
<i>Downtown, International District Mixed - IDM</i>	0.00	0.00%	0.00%
<i>Downtown, International District Residential - IDR</i>	0.00	0.00%	0.00%
<i>General Industrial - IG1</i>	34.64	0.07%	8.92%
<i>General Industrial - IG2</i>	48.22	0.09%	12.41%
<i>Lowrise - LR1</i>	7.89	0.01%	2.03%
<i>Lowrise - LR2</i>	8.55	0.02%	2.20%
<i>Lowrise - LR3</i>	4.62	0.01%	1.19%
<i>Major Institution - MIO</i>	149.01	0.28%	38.37%
<i>Multi-Family, Midrise - MR</i>	0.00	0.00%	0.00%
<i>Neighborhood Commercial - NC1</i>	11.72	0.02%	3.02%
<i>Neighborhood Commercial - NC2</i>	1.60	0.00%	0.41%
<i>Neighborhood Commercial - NC3</i>	1.46	0.00%	0.38%
<i>Downtown, Pike Place Market - PMM</i>	0.00	0.00%	0.00%
<i>Downtown, Pioneer Square - PSM</i>	0.00	0.00%	0.00%
<i>Single Family - SF 5000</i>	51.48	0.10%	13.25%
<i>Single Family - SF 7200</i>	93.45	0.18%	24.06%
<i>Single Family - SF 9600</i>	40.91	0.08%	10.53%
<i>Neighborhood Commercial, Seattle Mixed - SM</i>	0.00	0.00%	0.00%
<i>Neighborhood Commercial, Seattle Mixed - SMI</i>	0.00	0.00%	0.00%
<i>Neighborhood Commercial, Seattle Mixed Residential - SMR</i>	0.00	0.00%	0.00%
Right of Way	59.58	0.11%	15.34%



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Table 6. Growth Centers in Flood Prone Areas.

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Zone	% Center
Seattle	53178	100%		
<i>All Hub and Residential Urban Villages</i>	<i>5714.5</i>	<i>10.75%</i>		
<i>All Urban Centers</i>	<i>5715.5</i>	<i>6.98%</i>		
<i>All Manufacturing / Industrial Center</i>	<i>5716.5</i>	<i>11.10%</i>		
Flood Area (1996 FIRM & other)	388.39	0.73%	100.00%	
<i>Hub and Residential Urban Villages in Zone</i>	<i>11.52</i>	<i>0.02%</i>	<i>0.02%</i>	<i>0.20%</i>
<i>Urban Centers in Zone</i>	<i>7.71</i>	<i>0.01%</i>	<i>0.01%</i>	<i>0.21%</i>
<i>Manufacturing / Industrial Center in Zone</i>	<i>119.58</i>	<i>0.22%</i>	<i>0.22%</i>	<i>2.03%</i>

Table 7. Wildlife Area in Flood Prone Area.

	Acres	% Seattle
Seattle	53178	100%
Flood Area (1996 FIRM & other)	388.39	0.73%
Wildlife Habitat Areas	3749.89	7.05%
<i>Wildlife Habitat in Urban Flood Areas</i>	<i>56.77</i>	<i>0.11%</i>

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

In 2009, a void was discovered in the Howard Hanson Dam. Concerns about its strength have led to temporary repairs and a reduction in capacity of the reservoir. This means that more water would have to be released from the dam in a heavy storm. At the time, the Corps of Engineers, the dam’s operator, estimated a 1 in 33 chance of flooding due to releases. The dam was subsequently repaired successfully.

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

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

The Cedar system, which provides two-thirds of Seattle’s water supply, is also vulnerable to flooding. Because of the lack of filtration on the Cedar, diversions from the river are shut down when the water is turbid and water stored in Lake Youngs is used instead. Since flooding on the Cedar occurs in the fall or winter when demand for water is at lowest, water from Lake Youngs and the Tolt system can meet the full needs for water supply.

Table 8. Land Use in Urban Flood Area

Area	Acres	% Seattle	% Area
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Seattle	53178.37	100%	
Urban Flood Prone Areas	3312.57	6.23%	100.00%
Property in Area	2398.31	4.51%	72.40%
Commercial/Mixed-Use	157.00	0.30%	4.74%
Easement	0.00	0.00%	0.00%
Industrial	66.46	0.12%	2.01%
Major Institutions	189.86	0.36%	5.73%
Multi-Family	284.92	0.54%	8.60%
Parks/Open Space/Cemeteries	40.46	0.08%	1.22%
Reservoirs	0.00	0.00%	0.00%
Single Family	1410.64	2.65%	42.58%
Unknown	5.42	0.01%	0.16%
Vacant	243.55	0.46%	7.35%
Right of Way	914.26	1.72%	27.60%

Figure 3. Summary of Land Use in Urban Flood Prone Areas.

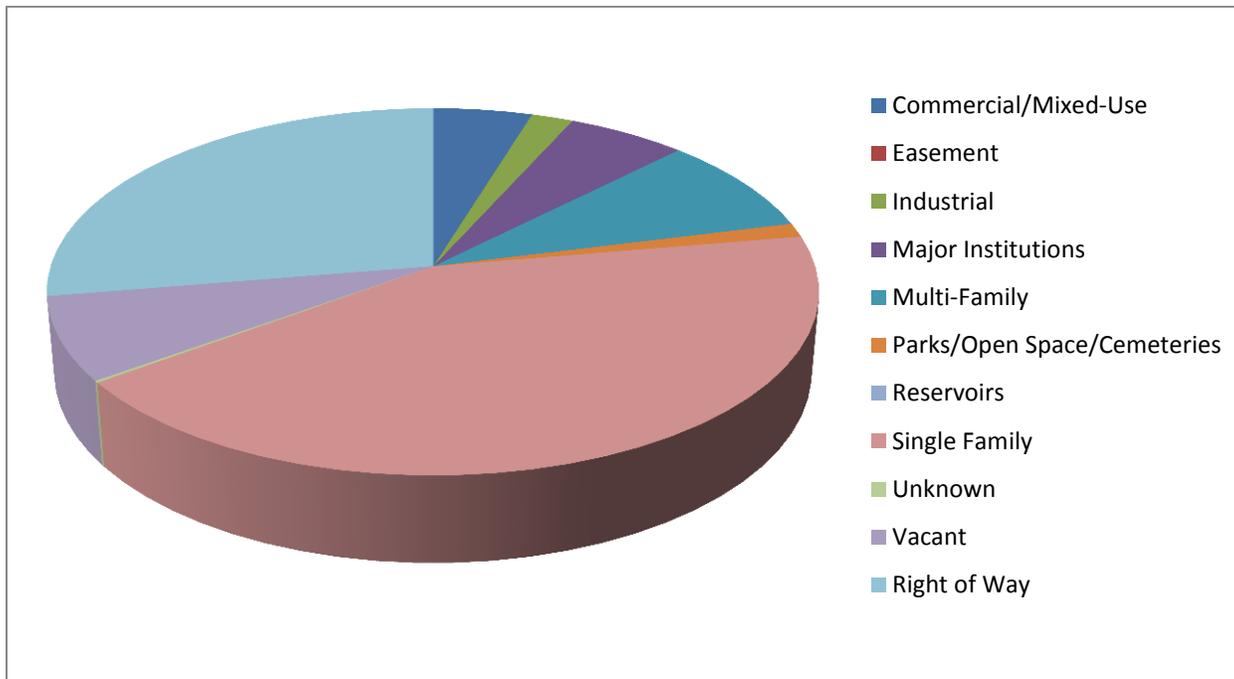


Table 9. Estimated Population, Buildings and Assessed Value in Urban Flood Area.

Number of Buildings	11,483	Est. Pop
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<i>Number of Single Family Units</i>	8,505	17,520
<i>Number of Multi-Family Units</i>	10,637	21,912
<i>Residential Gross Sq Footage</i>	27,796,973	
<i>Commercial Gross Sq Footage</i>	4,187,463	
<i>Total Assessed Value</i>	\$ 5,054,230,233	
Estimated Residential Population		39,433

Table 10. Critical Facilities in Urban Flood Areas.

Medical and Health Services	1
Government Function	0
Protective Function	3
Schools	9
Hazardous Materials Storage Sites	0
Bridges	3
Major Tunnels	0
Water	1
Waste Water	2
Communications	0
Energy	3
Human Services	7
High Population	0
Total	29

Table 11. Facilities with Concentrated Vulnerable Populations in Urban Flood Prone Areas.

Adult Family Homes	13
Boarding House	6
Child Care Centers	13
Nursing Home	4
Intermediate Care Facility	0
Total	36



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Table 12. Zoning in Urban Flood Prone Areas.

	Acres	% of Seattle	% Area
Seattle	53178.37	100%	
Urban Flood Prone Areas	3312.57	6%	100%
Parcel area in zone	2398.31	5%	72%
<i>Unzoned</i>	0.03	0.00%	0.00%
<i>Commercial - C1</i>	122.87	0.23%	3.71%
<i>Commercial - C2</i>	6.24	0.01%	0.19%
<i>Downtown Harborfront - DH1</i>	0.00	0.00%	0.00%
<i>Downtown Harborfront - DH2</i>	0.00	0.00%	0.00%
<i>Downtown Mixed Commercial - DMC</i>	0.00	0.00%	0.00%
<i>Downtown Mixed Residential/Commercial - DMR</i>	0.00	0.00%	0.00%
<i>Industrial Buffer - IB</i>	14.29	0.03%	0.43%
<i>Industrial Commercial - IC</i>	0.00	0.00%	0.00%
<i>Downtown, International District Mixed - IDM</i>	0.00	0.00%	0.00%
<i>Downtown, International District Residential - IDR</i>	0.00	0.00%	0.00%
<i>General Industrial - IG1</i>	11.93	0.02%	0.36%
<i>General Industrial - IG2</i>	55.19	0.10%	1.67%
<i>Lowrise - LR1</i>	102.94	0.19%	3.11%
<i>Lowrise - LR2</i>	97.21	0.18%	2.93%
<i>Lowrise - LR3</i>	167.23	0.31%	5.05%
<i>Major Institution - MIO</i>	82.89	0.16%	2.50%
<i>Multi-Family, Midrise - MR</i>	12.37	0.02%	0.37%
<i>Neighborhood Commercial - NC1</i>	2.96	0.01%	0.09%
<i>Neighborhood Commercial - NC2</i>	16.35	0.03%	0.49%
<i>Neighborhood Commercial - NC3</i>	25.08	0.05%	0.76%
<i>Downtown, Pike Place Market - PMM</i>	0.00	0.00%	0.00%
<i>Downtown, Pioneer Square - PSM</i>	0.00	0.00%	0.00%
<i>Single Family - SF 5000</i>	762.17	1.43%	23.01%
<i>Single Family - SF 7200</i>	744.13	1.40%	22.46%
<i>Single Family - SF 9600</i>	174.43	0.33%	5.27%
<i>Neighborhood Commercial, Seattle Mixed- SM</i>	0.00	0.00%	0.00%
<i>Neighborhood Commercial, Seattle Mixed - SMI</i>	0.00	0.00%	0.00%
<i>Neighborhood Commercial, Seattle Mixed Residential - SMR</i>	0.00	0.00%	0.00%
Right of Way	914.26	1.72%	27.60%



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Table 13. Growth Centers in Urban Flood Prone Areas.

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Zone	% Center
Seattle	53178	100%		
<i>All Hub and Residential Urban Villages</i>	<i>5714.5</i>	<i>10.75%</i>		
<i>All Urban Centers</i>	<i>5715.5</i>	<i>6.98%</i>		
<i>All Manufacturing / Industrial Center</i>	<i>5716.5</i>	<i>11.10%</i>		
Urban Flood Prone Areas	3312.57	6%	100.00%	
<i>Hub and Residential Urban Villages in Zone</i>	<i>476.88</i>	<i>0.90%</i>	<i>14.40%</i>	<i>8.35%</i>
<i>Urban Centers in Zone</i>	<i>16.32</i>	<i>0.03%</i>	<i>0.49%</i>	<i>0.44%</i>
<i>Manufacturing / Industrial Center in Zone</i>	<i>117.72</i>	<i>0.22%</i>	<i>3.55%</i>	<i>2.00%</i>

Table 14. Wildlife Areas in Urban Flood Prone Areas.

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

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

Much of Seattle’s coastline consists of bluffs with homes built at the top. Coastal storms can erode the toe of these sea cliffs and are a factor in landslides. In parts of West Seattle, Magnolia and along Lake Washington, homes are built along the shore. These properties are exposed to coastal storm damage.

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

Sea-level rise will make coast flooding worse. The estimate for the amount of rise in Puget Sound by 2050 range from 3” to 22,” increasing by 2100to between 6” and 50”ⁱⁱⁱ. In the worst case scenario, seawalls could be overtopped, if not replaced.

Lifeline Exposures:

- The sewer and drainage system is naturally exposed to flooding because it is part of the infrastructure to help control runoff. Sewer and drainage mains run along most of Thornton, Longfellow and Piper’s Creeks; along most of the coast of West Seattle; South Park; Interbay; portions of Magnolia’s coast and Myrtle Edwards Park
- About a ½ mile of City Light transmission lines run through the Longfellow Creek 100 year floodplain and the northern transmission lines cross the Thornton Creek floodplain.
- Seattle’s northern Water supply line crosses the Thornton Creek floodplain.

Transportation Exposures:



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- Seattle's Puget Sound facing marine terminals are exposed to coast flooding.
- The BNSF rail corridor runs along Puget Sound north of the Ship Canal are is exposed to flooding although landslides are a more common threat.
- Lake City Way and 35th Ave NE are bisected by Thornton Creek.
- Many residential streets in the South Park neighborhood are in the 100 year floodplain. West Marginal Way runs alongside it.
- Beach Drive SW in West Seattle runs along Puget Sound and is exposed to coastal flooding.

Consequences

Flooding in Seattle is a regular occurrence, but Seattle's flooding problem is not as severe as the rest of Western Washington. The situation may be changing, however, with urban flooding becoming a larger threat. Flooding is frequently part of a larger storm event.

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

With the exception of the South Park community, the Duwamish Valley is not likely to flood. Even in the event of a major release of water from the Howard Hanson dam, the river is likely to remain within its banks.

Areas near streams and in natural bowls will be at some risk of localized ponding. The main risk is to property, the majority of which is residential. This residential flooding has a much less pronounced effect on the local economy since the economic base remains unaffected. Nevertheless, a flood could make transportation difficult in the affected area. The low depth and water velocity of this type of flood mean it is mainly an economic rather than a safety risk.

Coastal flooding in Lake Washington or in Puget Sound could damage a large area. The most common land use near the shore is residential, but the Port of Seattle and the Burlington Northern Railway might also be affected because of their proximity to the water.

The Duwamish Valley is not likely to flood, but if it did occur the results would be severe. The dominant land use in the Duwamish Valley is industrial. A flood in this area would cause a severe disruption of the local economy, leading to a decline in tax revenue and a loss of jobs. If firms relocate following a flood, the city could lose some of this income permanently. The Duwamish Valley houses many hazardous materials, adding another dimension to the city's vulnerability.

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

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



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Most Likely Scenario

A powerful 'Pineapple Express' brings days of heavy rain to the area. Thornton and Longfellow creeks flood. The drainage system is overwhelmed in two spots. During the storm 8 major landslides occur. Property damage is extensive, but there are no fatalities. Several roads are undermined by sinkholes taking out water and sewer lines.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Winter storms are regularity in Seattle during the winter. One type of system is known as an atmospheric river. It occurs when moist warm air is pulled up into the Pacific Northwest by the jet stream. Such a storm is colloquially called 'Pineapple Express'
Geographic Scope	5	This is regional storm. All of Seattle and the surrounding areas are affected.
Duration	2	The storm lasts 4 days.
Health Effects, Deaths and Injuries	1	No one is killed or injured during the storm.
Displaced Households and Suffering	2	Urban flooding displaces 25 households. Mitigation in the Madison Valley and Thornton Creek areas lessens the impact of flooding.
Economy	2	Businesses in the Midvale, Southpark and Lake City have minor to moderate flooding.
Environment	2	The storm overwhelms the City's drainage system causing Seattle's combined sewer overflow (CSO) locations to release sewage into Puget Sound, Lake Union and Lake Washington.
Structures	2	No buildings are destroyed, but 9 buildings have to be evacuated because the basements and ground floors flood. Another 150 buildings have basement flooding only. These buildings can still be occupied.
Transportation	2	Aurora and the Mercer Street underpass and many residential streets fill with flood water.
Critical Services and Utilities	1	No critical services are degraded in the flood incident.
Confidence in Government	1	Local government is able to respond quickly to localized flooding. In areas with riverine flooding (Thornton and Longfellow creeks) the City organizes sandbagging. This effort and the success of detention ponds are credited to the City.
Cascading Effects	1	The release of raw sewage is a significant problem, but does not necessitate an immediate emergency response.

Maximum Credible Scenario

An atmospheric river remains pointed at Western Washington for nine days. The whole region is flooding. Periods of extremely heavy rain occur (1" per hour). A king tide occurs during this period. In Seattle creeks flood. South Park is flooded due to the King Tide and drainage problems. Urban flooding in 12 locations. 36 major landslides triggered due to increase in ground water. Levees on the Duwamish appear to be weakening.



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Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	This scenario is based on ARkStorm, a USGS project. The ARkStorm is estimated to be a 500 to 1000 year event. It is a more extreme form of atmospheric river than has been experienced in Seattle historically, but it has roots in a powerful storm that struck California in 1961-2. Furthermore climate data suggests that extreme precipitation <i>may</i> be increasing and a there <i>may</i> be a tendency of the jet stream to remain locked in one pattern for an extended time. It is prudent to plan for the two possibilities to combine. Such an event would be unprecedented but it is not unrealistic to expect.
Geographic Scope	5	This storm is a regional event. Surrounding jurisdictions would be suffering the same or worse. Area rivers would be at record flood stage. Seattle would not be able to count on assistance from within the region.
Duration	4	The rain lasts for nine days without a break of more than 24 hours.
Health Effects, Deaths and Injuries	2	4 people are killed in a landslide and 2 people drown in flood waters.
Displaced Households and Suffering	4	Seattle's creeks which normally only see ponding are actively flooding. King tides drive people along the shore and in Southpark from their homes. Areas in the interior of the city flood when the drainage system becomes overwhelmed. Altogether 850 people need to be sheltered. Many people with mobility impairments have difficulty going out to get food and make medical appointments.
Economy	3	Many businesses are flooded and cannot operate. Seattle's core industries: biotech, aerospace and software are able to continue operation with some difficulties. 800 structures suffer major uninsured losses.
Environment	2	Rain causes erosion and landslides that break 2 major sewer lines. 5 facilities housing large amounts of hazardous materials are flooded releasing chemicals into the water.
Structures	3	34 buildings suffer major damage from king tide flooding and must be red tagged, but the more significant problem is 100s of flooded homes. Most are able to be salvaged when the incident is over but require major work to repair.
Transportation	4	Many residential streets are flooded. Smaller neighborhoods are cut off. I-5 is cut off at Chehalis and I-90 is periodically threatened by rockslides. Rail service north of the ship canal is halted many times due to landslides. Major corridors remain open as do the airport and marine terminals.
Critical Services and Utilities	3	Public safety vehicles unable to reach smaller neighborhoods cut off by flooding. Food distribution becomes difficult due to I-5 flooding and I-90 rockslides.
Confidence in Government	3	As the flooding continues the public becomes tired of the inconvenience and wonders why more isn't being done to fix problems and obtain more aid from the federal government.
Cascading Effects	3	The storms have caused landslides and hazardous materials releases.



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Conclusions

Flood control is an old activity in King County, including Seattle. Changes in the landscape, like the dredging and filling along the Duwamish, have reduced most of the immediate threat. The Howard Hanson Dam maintains further structural protection, and smaller controls work on Longfellow and Thornton Creeks. These structural solutions are backed up by the city's membership in the National Flood Insurance Program that requires buildings within the floodplain to have flood insurance. All of these factors make flooding one of the most well-studied and funded mitigation efforts in the city. Nevertheless, recent urban flooding incident point to a hazard that is shifting and exposing new vulnerabilities.

ⁱ FEMA, 1994

ⁱⁱ FEMA, 1994

ⁱⁱⁱ University of Washington Climate Impacts Group and the Washington Department of Ecology, 2008