EXECUTIVE SUMMARY

Background

Seismic risk assessment continues to evolve in the Puget Sound region, as well as in other parts of the world. Utilities like Seattle Public Utilities (SPU) are working to better understand these risks, and making the investments needed to address them, while continuing to deliver drinking water and other essential water provision services to their customers.

In 1990, the Seattle Water Department, which merged with other city departments in 1997 to form SPU, commissioned a seismic study of its water system. The work was initiated in response to growing concern about seismic risk. Cygna Energy Services (Cygna) conducted this comprehensive seismic vulnerability assessment.

For the past 28 years, SPU has been addressing the issues identified in the Cygna assessment, as well as planning for and incorporating modern seismic standards into new projects as mandated by federal and state regulations. Many vulnerable facilities have already been upgraded to the seismic standards developed by Cygna, and over $60 million has been spent on making seismic upgrades to existing infrastructure. New facilities, such as SPU's buried terminal reservoirs, were designed and constructed to remain functional if subjected to the ground-shaking levels stipulated by the Seattle Building Code.

Since 1990, scientific knowledge about the impact of earthquakes on water systems has increased dramatically, and understanding of the seismicity of the Puget Sound region—in particular the Seattle Fault Zone and the Cascadia Subduction Zone—has also advanced substantially. Growing understanding of these risks led SPU to conduct another seismic study in 2016 and 2017. This report summarizes the findings of SPU's current seismic vulnerability assessment of its water system, and updates and expands the seismic vulnerability assessment completed by Cygna.

The overall goal of this new study was to incorporate the current understanding of seismic risk into long-term planning for SPU's water system. The SPU water system was evaluated for a M7.0 (magnitude 7.0) Seattle Fault Zone (M7.0 SFZ) earthquake and a M9.0 Cascadia Subduction Zone (M9.0 CSZ) earthquake scenario. Each facility was also evaluated for ground shaking levels approximately equal to the current Seattle Building Code ground shaking levels. Performance- and goal-based approaches were used to establish a cost-effective set of short-term and long-term strategies that will help to ensure service to SPU's customers after a seismic event.

This study incorporates the strategy that planning for seismic risk needs to be an ongoing part of a utility's business model and includes a prudent funding strategy and progressive investments over time. It recommends targeting shorter-term investments for the higher-risk areas of the system, while planning for longer-term investments in upgrades.

This study fits into SPU's broader resiliency framework, which aims to ensure that infrastructure will remain functional in a natural disaster and service levels will be restored as soon as possible, as well as cope with climate changes and other events.

Key Findings

Seismicity and Seismic Hazards

The chance of a major, catastrophic earthquake similar to the 2011 Tohoku (east Japan) earthquake, or 2011 Christchurch (New Zealand) earthquake striking Seattle in the next 50 years is approximately 15% to 20% (based on a 5% chance of a M6.5 or larger Seattle Fault Zone earthquake and a 14% chance of a M9.0 Cascadia Subduction Zone earthquake (Steele 2013)). Less catastrophic, but more frequently occurring earthquakes, such as the 2001 Nisqually earthquake, are also concerns. There is an approximately 84% chance there will be another earthquake similar to the M6.8 Nisqually earthquake in Seattle in the next 50 years (Steele 2013).

In addition to intense ground-shaking, many of SPU's transmission and direct service areas are subject to liquefaction, landslides, settlement, and fault-rupture hazards that could result in permanent ground displacement ranging from a few inches to over 10 feet during a major, catastrophic earthquake. Even in a Nisqually-type earthquake, ground-shaking could be intense in the epicentral region and could result in significant permanent ground displacements, although the areas of intense ground shaking and permanent ground displacements would not be as widespread as in a catastrophic earthquake.

SPU's Water System Seismic Vulnerability

Similar to many other water utilities in the United States, SPU's water system would likely suffer significant damage and disruption during a catastrophic earthquake like the 1995 and 2011 earthquakes in Japan, or the 2011 New Zealand earthquake. Computer modeling suggests that water pressure could be lost throughout SPU's water system within 16 to 24 hours for the M7.0 SFZ or M9.0 CSZ earthquake scenarios considered in this study. It could take about a month until water service would be restored to 70% of SPU's direct service customers, and two months or more until water service would be restored to all direct service customers. Much like Los Angeles Department of Water and Power after the 1994 Northridge earthquake, to restore pre-earthquake reliability and service levels to SPU's water system would likely take years after a major earthquake.

Although system response to a Nisqually-type earthquake was not evaluated during this study, there was no significant disruption to SPU's water system during the 2001 earthquake or similar earthquakes in 1949 and 1965. It is possible that a slightly larger Nisqually-like earthquake located closer to Seattle could cause more significant damage to SPU's water system, but it would be considerably less than the impacts from the earthquake scenarios used in this study.

Increasing the Seismic Resiliency of SPU's Water System

There are proven technologies and strategies that water utilities in the United States, Japan and New Zealand are implementing to mitigate and/or prevent water system damage. They include installing earthquake-resistant pipe, upgrading existing facilities to meet current seismic requirements, ensuring there is adequate water storage to provide emergency water after a major earthquake and stockpiling repair materials. Implementing these technologies is expensive and could take decades.

There are less costly short-term measures, such as improving emergency preparedness and response planning, and adopting isolation and control strategies, that can be used to mitigate the effects of seismic damage until expensive long-term infrastructure improvements can be made. The cost of these short-term measures is on the order of $40 to $50 million over the next 15 to 20 years. Long-term infrastructure improvements will cost over $800 million over approximately the next 50 years, followed by further investment for decades.

Over the next 20 years, the recommended strategy is to

1. Improve earthquake-emergency preparedness and response planning, and develop post-earthquake isolation and control strategies;
2. Begin upgrading critical transmission pipelines in discrete areas with the highest hazards;
3. Continue upgrading key vertical facilities (such as buildings and water storage facilities);
4. Construct new facilities in accordance with modern, performance-based seismic codes;
5. Use pipeline systems that can resist the expected seismic hazards along the alignment. When new pipelines are installed or existing pipelines replaced, use pipeline systems that can resist the expected seismic hazards along the pipeline alignment.

After the first 20 years, continue to focus on remaining critical facility upgrades and upgrading transmission pipelines in the remaining hazard areas, including the zones susceptible to liquefaction, landslide, and fault offset.

Identification and Definition of Seismic Hazards

The tectonic setting for the Pacific Northwest is shown on Figure ES-1. It is characterized by subduction of the Juan de Fuca tectonic plate beneath the North American Plate, as well as north-south compression caused by the Oregon block of the North American Plate pushing the Washington block into the stationary Canadian block.

Three potential earthquake scenarios threaten the Puget Sound region:

1. Interplate subduction earthquake:

   This occurs when stresses/forces created as the Juan de Fuca Plate attempts to slide underneath the North American Plate exceed the forces locking the two plates together at their boundary. This fault is capable of rupturing off the coast from Northern California to southern British Columbia and could produce magnitude 9.0 (M9.0) or greater earthquakes. Although the ground motions from a large subduction earthquake would be attenuated somewhat by the time they reached Seattle, strong ground-shaking could last for three or four minutes.
2. Deep intraplate earthquake

   This would occur in the upper portion of the Juan de Fuca Plate directly below Puget Sound. Although these earthquakes may reach M7.0 to 7.5, due to their typical depths of 40 to 60 kilometers, the ground-motions would be somewhat attenuated by the time they reached the surface and would not be as large as ground motions from a similarly sized shallow earthquake.

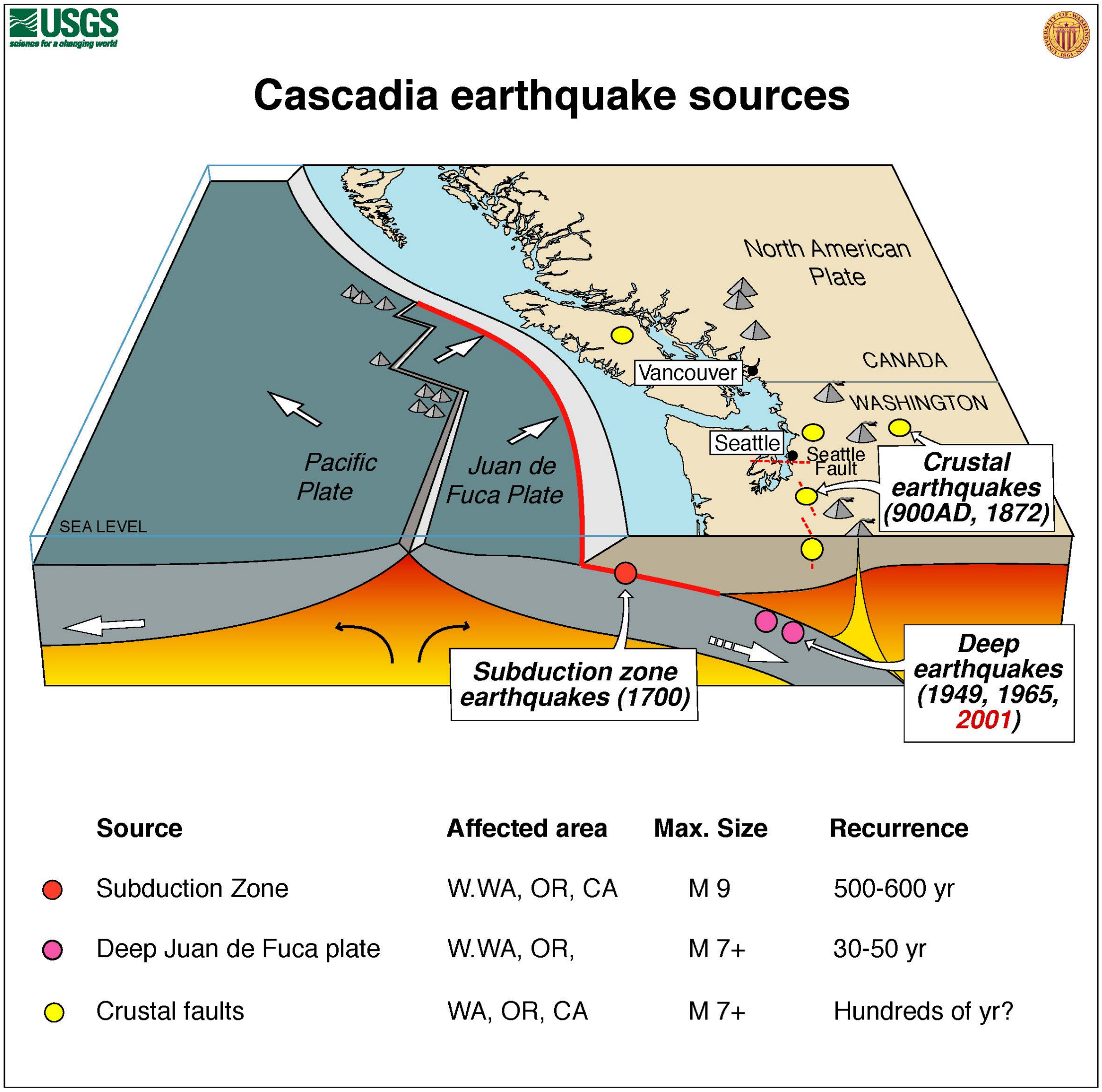

Figure ES-1. Potential earthquake sources in the Pacific Northwest (United States Geological Survey 2001)

3. Shallow crustal earthquake

   These earthquakes are caused by compression of the Washington block of the North American Plate and may reach M7.0 to 7.5. Because these shallow earthquakes may occur within a few miles of the earth's surface, ground-shaking intensity in Seattle will be more than twice as strong as the intensity for the interplate event, and more than five or six times as strong as the ground-shaking intensity that occurred in Seattle during the 2001 Nisqually earthquake.

In addition to ground-shaking, earthquakes can cause unstable soils to liquefy (in other words, lose shear and bearing strength and behave like a liquid), slide, and settle. Earthquakes also trigger landslides. A crustal earthquake could produce surface fault offsets of three to five meters in the Seattle area. Permanent ground displacements are the primary cause of the buried pipeline damage that has plagued water utilities (and other systems with buried pipelines) in past earthquakes.

Figure ES-2 shows the areas where permanent ground displacements are most likely to occur. There are also likely to be isolated, unidentified areas where permanent ground displacements could also occur, but they would probably not be as widespread.

Earthquake ground motions, such as peak ground acceleration, were estimated using current ground motion attenuation models for the M7.0 SFZ and M9.0 CSZ scenarios. The 2014 United States Geological Survey (USGS) 0.02 probability (2% chance) of exceedance in 50 years (2,475-year average-return interval) peak ground accelerations (2014 USGS Ground Motions) were also incorporated in this work. Regional seismic hazard mapping and models were used to estimate permanent ground displacements for the two earthquake scenarios. Section 2 summarizes the hazard analyses.

Vertical Facility (Nonpipeline) Assessments

SPU's water system facilities were evaluated for the two earthquake scenarios and the 2014 USGS Ground Motions. Facility assessments included office and maintenance buildings, pump stations, gatehouses, reservoirs, elevated tanks, and standpipes. The estimated likelihood of each facility remaining functional for each scenario was cross-referenced against the facility's criticality. Pseudostatic methodologies (as opposed to complex dynamic analyses) were used to estimate vertical facility response.

SPU's newer (and generally largest) treated water storage reservoirs are expected to perform well in significant earthquakes. Recommended action includes further seismic analyses and upgrades to some of the older storage reservoirs, older buildings, and some smaller elevated tanks and standpipes. Section 3 contains a detailed description of the facility assessments, along with a summary table of the results.

Pipeline Assessments

SPU classifies its pipelines into two categories: transmission and distribution. In general, transmission pipelines are the larger diameter pipelines that carry water from the mountain reservoirs into SPU's direct service area and to wholesale customers. Distribution pipelines are the smaller diameter pipelines that convey water to customers within the direct service area.

Different seismic analysis methods were used for the two pipeline classes. Transmission pipelines were evaluated using a high-level approach. Regional seismic hazard maps were used to identify locations where the transmission pipelines pass through permanent ground displacement areas. Those areas judged to have the most significant hazards were visited by members of the project team. Based on the pipe construction materials and engineering judgment regarding the permanent ground displacement potential, expert opinion was used to predict the likelihood that the pipe would remain functional for each earthquake scenario.

Significant findings include the need for seismic upgrades and/or emergency response plans at several discrete locations, including

- Cedar River Pipelines 1, 2, 3 at Renton;
- Cedar River Pipelines 1, 2, 3 at the Martin Luther King Way slide area;
- Cedar Eastside Supply Line at the Cedar River Crossing;
- Tolt Pipelines at Norway Hill;
- West Seattle Pipeline at the Duwamish River Crossing;
- Cedar River Pipeline 4 at the Green River Crossing.

Additionally, there are other areas that warrant further investigation along these transmission pipeline routes, particularly in areas of potential liquefaction, landslide, settlement, and fault rupture. These will be the focus of follow-up studies.

Distribution pipelines were assessed using the American Lifelines Alliance (ALA) watermain vulnerability equations. The equations use peak ground velocity, permanent ground displacement, and pipeline characteristics to estimate the number of pipe failures. Approximately 2,000 distribution pipeline failures (repairs) were estimated for the M7.0 SFZ scenario, and approximately 1,400 were estimated for the M9.0 CSZ scenario. Areas susceptible to permanent ground displacement (liquefaction, landslide, settlement, and fault rupture) are the highest concern. The pipeline damage would result in water losses that could drain the water system after an earthquake.

These pipeline failure estimates are generally consistent with the performance of water utility pipeline systems in previous earthquakes. It is important to note that due to the many assumptions and approximations that went into these estimates, the actual number of pipe repairs in these scenarios could vary by as much as plus or minus 50%. Section 4 contains a detailed description of the pipeline assessments and a summary table of the results.

System Analysis

The facility and pipeline assessments were combined with computer hydraulic model analysis to estimate the water system response to, and recovery from, catastrophic earthquakes, such as the M7.0 SFZ and M9.0 CSZ scenarios. The USGS Ground Motions would not occur simultaneously throughout the SPU system, since they are derived from different earthquake sources, so a system analysis was not performed for these ground motions.

The results suggest that in either the M7.0 SFZ or M9.0 CSZ scenarios, the best estimate is that SPU’s direct service area would completely lose pressure within 16 to 24 hours. Typically, as

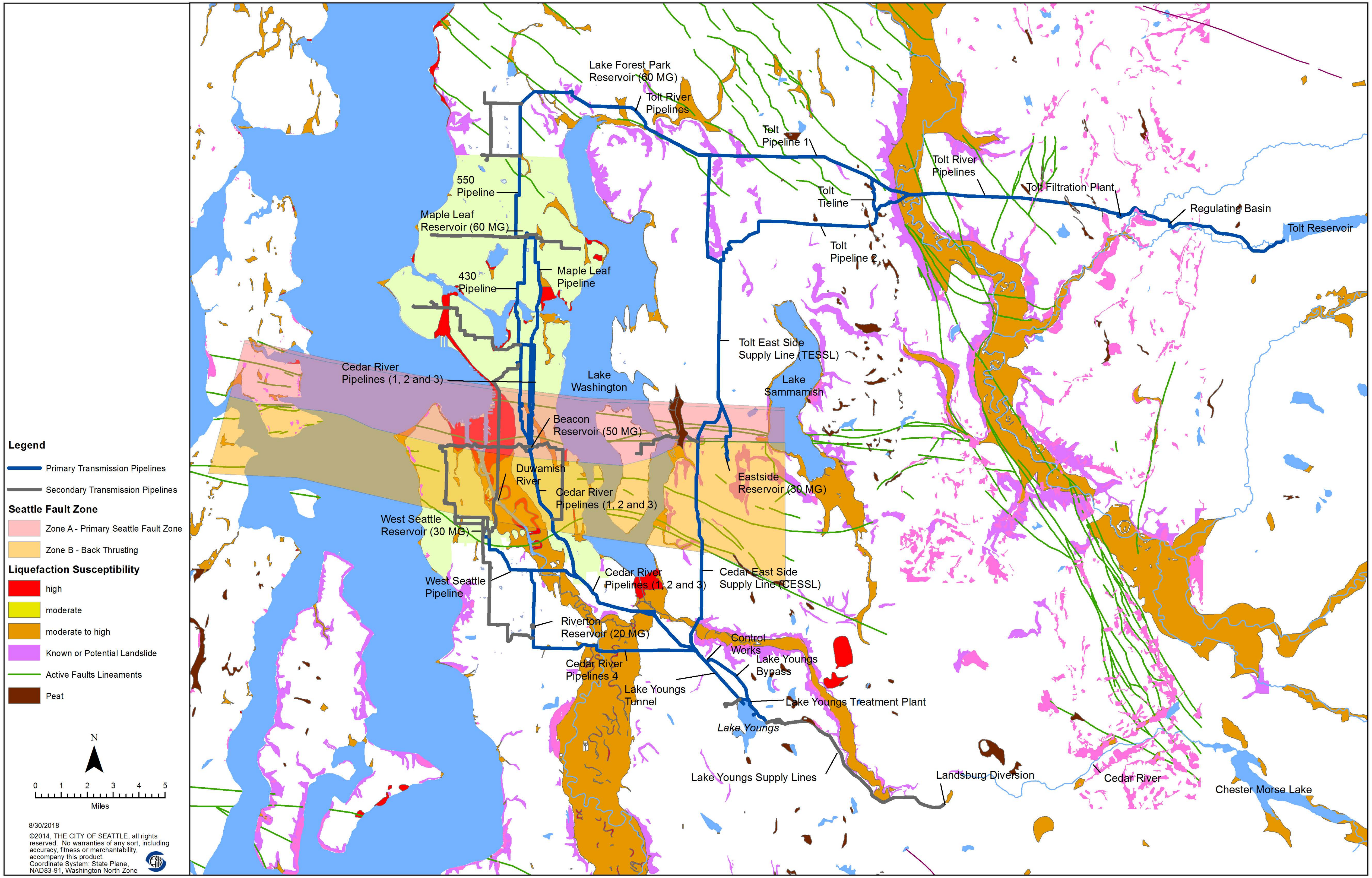

Figure ES-2. SPU water system earthquake hazards map (note: Seattle Fault Zone is believed to extend east of the shaded area that is shown out to the Cascade Mountain foothills)

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reservoirs and tanks drain due to water pipe leaks and breaks, the pressure would be lost in higher elevation pressure zones first.

Loss of water pressure within 16 to 24 hours is consistent with what has happened to other water utilities in catastrophic earthquakes. However, uncertainty remains regarding actual ground motions, permanent ground displacements, facility and pipeline responses, operating conditions at the time of the earthquake, and operational response. It is possible that the system could drain more rapidly or slowly than the best estimate suggests.

It is likely that both earthquake scenarios would have a significant impact on the major transmission pipelines. Although distribution pipeline repairs would start almost immediately after an earthquake, it could take up to six to eight weeks to make even temporary repairs to transmission pipelines in areas such as underground river crossings or steep slopes. Estimates of water service restoration times are shown on Figure ES-3.

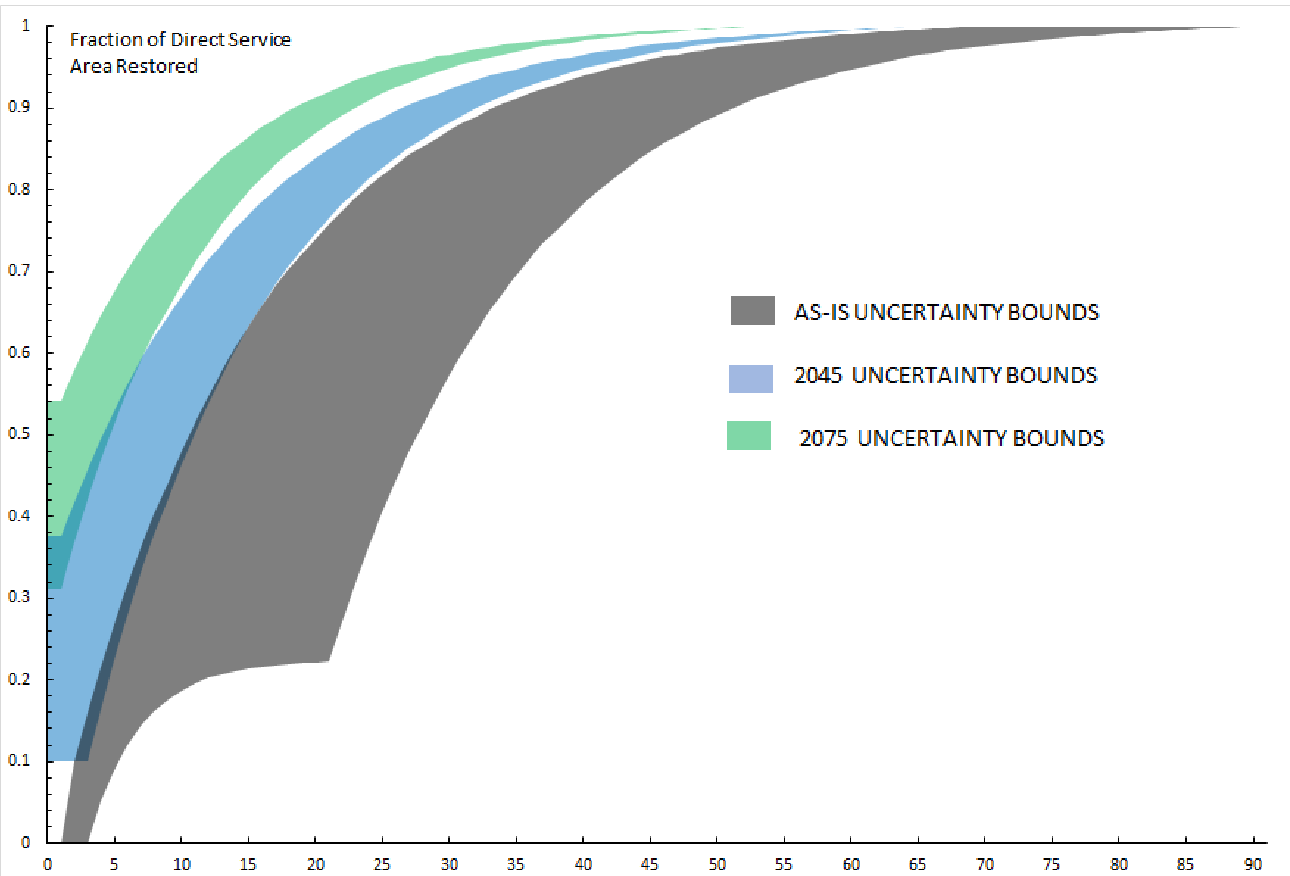

Figure ES-3. Retail service area restoration estimates after catastrophic earthquakes: current condition, after 20+ years of seismic upgrades, and after 50+ years of seismic upgrades

The 1949, 1965, and 2001 Puget Sound area intraplate earthquakes show that the effects from future intraplate earthquakes on SPU's water system would be much less than the impacts from the two scenario earthquakes modeled by this study. It is possible that a future intraplate earthquake could be slightly larger (e.g., M7.5) than recent intraplate earthquakes, and occur directly below SPU's direct service area, and result in more significant impacts. These impacts would still be significantly less than the impacts estimated for this study's earthquake scenarios.

Treated Water Storage

The current study also analyzed the effect and importance of treated water storage for response and recovery after catastrophic earthquakes. A previous system reliability analysis, which was based on less severe water outage assumptions, had recommended downsizing some treated water reservoirs, and decommissioning two of them (Roosevelt Reservoir and Volunteer Reservoir) to provide more cost-effective water service for ratepayers. In this study, the role of storage in post-earthquake recovery was reassessed, since the study also identified the potential for more significant water outages than had previously been identified.

The role of treated water storage was analyzed in three ways:

1. Comparing storage relative to water demands against the storage available at other West Coast water utilities, especially those having completed (or currently undergoing) seismic planning analyses
2. Using computer hydraulic model analyses to estimate the impact of storage on postseismic response and recovery
3. Examining other factors, such as operational flexibility and resiliency

Based on the analysis, additional storage is needed. Roosevelt and Volunteer Reservoirs should remain part of SPU's drinking water system. Since they are not covered reservoirs, recent regulations have determined that the water is nonpotable, which has resulted in both reservoirs being disconnected from the drinking water system. However, for emergency response purposes, the two reservoirs could be configured to provide emergency water. In the future, they may be upgraded to potable water reservoir standards.

Section 5 discusses water system post-earthquake performance and restoration.

Performance Goals, Mitigation Recommendations, and Cost Estimates

The replacement value for SPU's distribution system watermains is approximately $19 billion (SPU 2018b). It is not economically feasible to replace all of the seismically vulnerable assets over a short period of time. Water system performance goals are needed so customers know what seismic mitigation funds would provide in terms of overall system performance and help prioritize facilities for mitigation. Performance goals will also help stakeholders know what to expect after a major earthquake.

Performance Goals

SPU drafted performance goals that were modeled after the Oregon Resilience Plan (Oregon Seismic Safety Policy Advisory Commission 2013), using the following metrics:

- Providing fire suppression water immediately after an earthquake
- Providing water to essential facilities, such as hospitals and other emergency response centers
- Providing water to SPU's direct service area and customers
- Providing water to SPU's wholesale customer turnouts
- Providing emergency drinking water supply

And there are two sets of performance goals:

- 2045 Goals, which are based on a 20-year plan for seismic upgrades
- 2075 Goals, which are based on an additional 30 years of seismic upgrades

Inherent in the performance goals and system improvements is that life-safety risks, such as occupied-building collapse, are not acceptable.

A detailed description of performance goals and system improvements is presented in Section 6.

Mitigation Strategies

To increase the seismic resiliency of SPU's water system and meet the performance goals, five general strategies were developed. These strategies are intended to complement one another. They were designed to cost-effectively mitigate facility damage that is currently expected under the earthquake scenarios until long-term infrastructure seismic improvements can be made.

The five strategies are:

1. Isolation and control
    a. Add isolation systems to appropriate reservoirs so that reservoirs do not completely drain out if there is excessive pipeline damage. Note that newer reservoirs, representing more than half of SPU's direct service area system storage, already have seismic isolation valves installed.
    b. Evaluate the feasibility of isolating those areas within the distribution system where large amounts of pipeline damage and water leaks would drain reservoirs.

2. Transmission pipelines
    a. In the next 20 years, reduce the expected transmission pipeline restoration times by:
        i. Seismically upgrading those critical locations, such as slide areas and river crossings, which could take weeks to months to repair after a catastrophic earthquake;
        ii. Evaluating the need for, and installing as applicable, line valves and manifolds in selective locations to decrease restoration times;
        iii. Developing a response plan and the repair resources so that those transmission pipeline failures that occur can be repaired within 7 to 10 days.

   b. After 20 years, continue to improve the seismic reliability of critical transmission lines through seismic upgrades in the remaining high seismic risk areas. This includes sections of the Cedar River Pipelines, Tolt Pipelines, Cedar and Tolt Eastside Supply Pipelines, and West Seattle Pipeline. Areas of focus include fault zones, liquefaction zones, and landslide-prone areas.

3. Seismic-resistant design for new water system assets
   a. Require the use of earthquake-resistant pipe per new seismic design standards described in Section 8:
      i. When new pipelines are installed or replaced in areas that are susceptible to permanent ground displacements;
      ii. For watermains that are essential for firefighting (mains needed to provide water within 2,500 feet of anywhere within the direct service area);
      iii. For watermains that serve essential facilities, such as hospitals and emergency response centers.
   b. Require site-specific seismic design when transmission pipelines are replaced or rehabilitated.
   c. Require that new vertical facilities be designed to remain functional for the American Society of Civil Engineers (ASCE) 7 seismic design ground motions (which are typically adopted by the Seattle Building Code).

4. Seismic upgrade projects for vertical facilities
   a. Seismically retrofit the most critical water system facilities, including office and maintenance buildings, pump stations, gatehouses, reservoirs, elevated tanks, and standpipes.

5. Emergency preparedness and response planning
   a. Identify additional repair materials and resources needed, either to stockpile in strategic locations, or to obtain after a seismic event.
   b. Place particular emphasis on resources and materials needed for large diameter pipeline repair with the goal of reducing outage times.
   c. Augment existing strategies and resources needed to provide emergency drinking water after an earthquake.
   d. Develop a hazard-specific response plan for earthquakes that fits within the SPU emergency management approach

The mitigation approach is presented in more detail in Section 6. Recommended improvements to emergency preparedness and response planning are described in Section 7.

Seismic Design Standards for New Water System Assets

One of the most cost-effective mitigation strategies that SPU can implement is to make sure that all new facilities meet modern/current seismic code requirements. Most vertical facilities, such as buildings and tanks, are covered by these requirements. Those facilities needed to operate the water system or respond in the event of an earthquake should be designed as essential facilities.

Currently, there are not any water utility industry seismic design requirements for buried pipelines. There are, however, several types of pipelines that have proven to be earthquake-resistant. Some of these systems, such as earthquake-resistant ductile-iron pipe, are becoming available in the United States. In Japan, there have been almost no failures in earthquake-resistant pipe. Because SPU and other West Coast water utilities are on the forefront of using earthquake-resistant ductile-iron pipe in the United States, there have been some initial challenges. But by switching to these systems when older pipelines are retired, water utilities can greatly reduce the potential for earthquake damage to their systems.

As part of this seismic assessment, SPU has developed new seismic design standards for its buried pipelines. SPU plans to incorporate these newly developed seismic design standards for buried pipe into its Design Standards and Guidelines, following a formal review and acceptance process. The new proposed standards are discussed in Section 8 and included in Appendix D.

Expected Response After Seismic Improvements

Based on these mitigation recommendations, estimated water restoration time to the direct service area is shown on Figure ES-3 for current conditions, after 20 or more years of seismic upgrades, and after 50 years of seismic upgrades. The figure shows a range of response times for each case. Best and worst case assumptions, discussed in Section 5, were used to as an indicator of the uncertainty inherent in the analysis. The worst case “as-is” restoration curve assumes that only water from the Seattle Wells is initially available and that it takes three weeks to begin to restore the Cedar and/or Tolt system. The best case “as-is,” year 2045 and year 2075 cases assume enough water is being conveyed to the direct service area (distribution system) to supply those parts of the distribution area that remain or have been restored to service. It should be noted that response and recovery efforts would be focused on critical customers, most notably emergency care centers at major hospitals.

Cost Estimates

The recommended long-term mitigation plan is shown in Table ES-1. The recommendations span five decades and beyond. With each project that is initiated, an engineering options analysis would be prepared with detailed recommendations. Detailed scopes, cost estimates, and schedules reflecting a greater level of site-specific analysis will be needed for each project. Estimated costs are likely to change over time.

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Mitigation Element	Approximate Time Frame (values in 2018 dollars) 2018 – 2022	2023 - 2027	2028 - 2032	2033 - 2037	2038 - 2042	2043 - 2047	2048 - 2052	2053 - 2057	2058 - 2062	2063 - 2067	2068 - 2072	Total	Notes
Isolation and Control													
Analysis	$50,000												
Reservoir and Tank Seismic Valves		$5,000,000	$5,000,000									$10,000,000	
Distribution System Isolation Valves		$5,000,000	$5,000,000									$10,000,000	
Transmission System Isolation Valves		$5,000,000	$5,000,000									$10,000,000	
Transmission Pipelines - Discrete Locations													
Analysis/Design	$500,000												
CRPLs in Renton		$35,000,000	$40,000,000									$75,000,000	
CRPLs in MLK Slide Area				$20,000,000	$20,000,000							$40,000,000	
CESSL in Cedar R. Liquefact & Slide Area				$10,000,000	$10,000,000							$20,000,000	
TPLs in Norway Hill				$15,000,000	$15,000,000							$30,000,000	
WSPL Duwamish River Crossing						$10,000,000	$10,000,000					$20,000,000	
Other point location upgrades, including TPLs in Bent/Pile Support Crossings		$1,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$19,000,000	
CRPL No. 4 in Green River Crossing										$6,500,000	$6,500,000	$13,000,000	
Transmission Pipelines - Other Areas Along Pipeline Routes	*These numbers assume total replacement of remaining pipe segments in liquefiable, landslide, or fault zones. This approach reflects a most conservative approach, and there may be more cost-effective strategies, including waiting until the pipe sections are replaced due to end of life, and blending emergency response and targeted upgrades.*												
Seismic Resistant CRPL (1 CRPL)						$20,000,000	$20,000,000	$20,000,000	$20,000,000	$20,000,000	$20,000,000	$120,000,000	Total cost $244M - half in years 20-50, half after that
Seismic Resistant TPL (focus on area of only one TPL, assumes total slipline)						$12,000,000	$12,000,000	$12,000,000	$12,000,000	$12,000,000	$12,000,000	$72,000,000	Total cost $144M - half in years 20-50, half after that
Seismic Resistant TESSL/CESSL						$15,000,000	$15,000,000	$15,000,000	$15,000,000	$15,000,000	$15,000,000	$90,000,000	Total cost $186M - half in years 20-50, half after that
WSPL Duwamish River Valley								$10,000,000	$10,000,000	$10,000,000	$10,000,000	$40,000,000	Total cost $80M - half in years 20-50, half after that
EQ-Resistant Critical Pipelines (Distribution Watermain Focused)	*These numbers are on top of separate annual costs for replacing/rehabilitating distribution pipes. They reflect the additional costs to make upgrades seismically resistant where needed.*												
EQ Resistant Pipe in PGD Areas	$2,500,000	$5,000,000	$7,500,000	$10,000,000	$12,500,000	$15,000,000	$17,500,000	$20,000,000	$20,000,000	$20,000,000	$20,000,000	$150,000,000	
Vertical Facilities	*These numbers reflect relatively conservative assumptions for full functionality after the design earthquake. Other approaches, such as performance-based criteria, will be considered.*												
Analysis/Design	$400,000											$400,000	trans. pipelines, trenton tanks, control works bldg., occ wh and tolt chl. bldg
Storage													
Myrtle Elevated Tank No. 2 Pipe Clearance		$100,000										$100,000	
Riverton Heights Reservoir		$10,000,000										$10,000,000	
Eastside Reservoir		$12,000,000										$12,000,000	
Beverly Park Elevated			$12,000,000									$12,000,000	
Control Works Surge Tanks				$5,000,000								$5,000,000	
Cascades Dam				$5,000,000	$5,000,000							$10,000,000	Placeholder - options analysis beginning 2018. Eval. indep. of seismic study
Volunteer Standpipe				$12,000,000								$12,000,000	
Magnolia Reservoir					$2,000,000							$2,000,000	Assumes roof-to-wall connection upgrade only
Magnolia Elevated Tank					$7,500,000							$7,500,000	
Richmond Highlands #2						$5,000,000						$5,000,000	
View Ridge Reservoir							$5,000,000					$5,000,000	
Foy Standpipe							$4,000,000					$4,000,000	Only if determined to be life safety concern and standpipe is needed
Charleston Standpipe								$4,000,000				$4,000,000	
Staffed Buildings													
North Operations Center		$4,000,000											Ongoing study about staff buildings
OCC Warehouse					$1,500,000							$1,500,000	Ongoing study about staff buildings
OCC Admin Building					$100,000							$100,000	Ongoing study about staff buildings
OCC Meter Shop					$1,000,000							$1,000,000	Ongoing study about staff buildings
OCC Pipe Carpentry Shop					$1,000,000							$1,000,000	Ongoing study about staff buildings
Lake Youngs Office Building					$300,000							$300,000	
OCC Vehicle Maintenance Building						$4,000,000						$4,000,000	Ongoing study about staff buildings
Other Buildings													
Nonstructural Upgrades		$400,000	$400,000	$400,000	$400,000							$1,600,000	
Tolt Reservoir Bridge Connection		$100,000										$100,000	
Maple Leaf Gate House		$2,000,000										$2,000,000	
Roosevelt Gate House		$2,500,000										$2,500,000	
Lincoln Gatehouse/Pump Station			$4,000,000									$4,000,000	
Broadway Pump Station			$1,000,000									$1,000,000	
Boulevard Pk and Riverton Well Emerg. Power			$500,000									$500,000	
Landsburg Tunnel Gatehouse				$1,000,000								$1,000,000	
Lake Youngs Pump Station (old)				$500,000								$500,000	
West Seattle Pump Station					$1,000,000							$1,000,000	
Trenton Pump Station						$2,000,000						$2,000,000	
Fairwood Pump Station							$1,000,000					$1,000,000	
Lake Forest Park Chlorination							$1,000,000					$1,000,000	
Emergency Preparedness & Response Planning													
Repair Mat'l & Resource Acquisition	$6,000,000											$6,000,000	
Post-EQ Response Plan Augmentation		$1,000,000	$1,000,000									$2,000,000	
Post-EQ Emerg Drinking Wtr Supply Stations		$1,000,000	$1,000,000									$2,000,000	
Subtotals													
Isolation and Control	$50,000	$15,000,000	$15,000,000	$0	$0	$0	$0	$0	$0	$0	$0	$30,050,000	
Transmission - Discrete Locations	$500,000	$36,000,000	$42,000,000	$47,000,000	$47,000,000	$12,000,000	$12,000,000	$2,000,000	$2,000,000	$8,500,000	$8,500,000	$217,500,000	
Transmission - Other Areas Along Pipeline Routes	$0	$0	$0	$0	$0	$47,000,000	$47,000,000	$57,000,000	$57,000,000	$57,000,000	$57,000,000	$322,000,000	
Distribution Pipes	$2,500,000	$5,000,000	$7,500,000	$10,000,000	$12,500,000	$15,000,000	$17,500,000	$20,000,000	$20,000,000	$20,000,000	$20,000,000	$150,000,000	
Facilities	$400,000	$31,100,000	$17,900,000	$23,900,000	$19,800,000	$11,000,000	$11,000,000	$4,000,000	$0	$0	$0	$119,100,000	
Emergency Preparedness	$6,000,000	$2,000,000	$2,000,000	$0	$0	$0	$0	$0	$0	$0	$0	$10,000,000	
Total (5-yr increments)													
Total per 5-year increment	**$9,450,000**	**$89,100,000**	**$84,400,000**	**$80,900,000**	**$79,300,000**	**$85,000,000**	**$87,500,000**	**$83,000,000**	**$79,000,000**	**$85,500,000**	**$85,500,000**	**$848,650,000**	
Total per year	*$1,890,000*	*$17,820,000*	*$16,880,000*	*$16,180,000*	*$15,860,000*	*$17,000,000*	*$17,500,000*	*$16,600,000*	*$15,800,000*	*$17,100,000*	*$17,100,000*		

Table ES-1. Recommended mitigation plan summary and order of magnitude cost estimates

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