6. SEISMIC MITIGATION RECOMMENDATIONS AND COST ESTIMATES

Sections 4 and 5 demonstrated that damage to SPU's transmission and distribution systems from a major earthquake in the Puget Sound region could be extensive. Even under a best-case scenario, the time to restore limited water supplies to all customers would be measured in months, rather than days and weeks. To address the need to improve seismic resiliency, this section details proposed post-earthquake water system performance goals and the seismic upgrades that would be needed to achieve those goals. Planning level cost estimates for these seismic upgrades are also presented in this section.

6.1 Proposed Post-earthquake Performance Goals

Most SPU water system facilities were constructed before the current understanding of the seismology and associated seismic hazards in the Puget Sound was developed. Historically, water systems have consistently performed poorly in major earthquakes. Water has been unavailable for firefighting immediately after earthquakes, and restoration of even minimal service to all customers has sometimes exceeded two months. For example, the Los Angeles Department of Water and Power (Davis 2015) estimated that it took over five years to bring the LADWP water system close to the same level of service and reliability that existed prior to the 1994 Northridge earthquake. Under a M7.8 San Andreas Fault earthquake scenario, it would likely take three weeks to restore minimal water service to all LADWP customers. Water use restrictions would likely be in place for 15 months (Davis 2015).

The replacement value of SPU's water system assets is measured in the billions of dollars. The replacement cost for only SPU's distribution pipelines (which does not include the transmission pipelines or other assets, such as tanks, pump stations, buildings, etc.) is approximately $19 billion (SPU 2018b). It is not economically feasible to replace all seismically vulnerable assets over a short period of time. Water system post-earthquake performance goals are needed to let ratepayers know what seismic improvements would accomplish and what preparations would still be necessary. These performance goals will also help identify mitigation needs and let stakeholders know what to expect after a major earthquake.

Several water utilities have established post-earthquake performance goals (Eidinger and Davis 2012). Examples of these goals are shown in Appendix C. The Oregon Seismic Safety Policy Advisory Commission (OSSPAC) also developed model performance goals (OSSPAC 2013). The OSSPAC goals were influenced by the desire to restore water service in a timely manner to minimize the impact on the regional economy. The performance goals have been adopted by some Oregon water utilities and are included in Appendix C.

SPU's draft performance goals are modeled after the Oregon Resilience Plan goals. Although *Resilient Washington State* (Washington State Seismic Safety Committee Emergency Management Council 2012) listed some generic goals, the Oregon Resilience Plan was further developed and included more stakeholder involvement and input.

The categories addressed by the SPU draft performance goals are:

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

The performance goals previously developed by other utilities, the Oregon Resilience Plan, and the current estimated performance of the SPU water system under the M7.0 SFZ scenario were used as the basis for SPU's proposed post-earthquake system performance goals. Because it is not practical or cost-effective to fully implement a water system seismic mitigation program over a short period of time, two sets of goals were developed for two successive timelines that end in 2045 and 2075.

The 2045 and 2075 proposed performance goals are listed in Tables 6-1 and 6-2, respectively. The intent is for these goals to be reviewed by SPU's stakeholders, including SPU's ratepayers, wholesale customers, the Seattle Fire Department, SPU management, and the City of Seattle leadership, before they are finalized.

SPU performance goals have been developed in concert with water system improvements, which are to be accomplished over two successive timeframes for which the second set of improvements is an integrated extension of the first set.

6.1.1 SPU Water System Performance Goals for 2045

Achievement of the 2045 goals (by 2045) assumes that full funding is available from 2024 through 2045 and the following mitigation projects outlined in Table 6-3 are completed per the Table 6-3 schedule:

- Critical vertical facility and transmission pipeline improvements
- Isolation and control strategies to mitigate water distribution pipeline breakage
- Ninety miles of distribution watermains have been replaced in accordance with the proposed pipeline standards presented in Section 8 and Appendix D
- Emergency preparedness and response procedure enhancements, in combination with transmission pipeline upgrades, to allow minimal (low winter demand) transmission pipeline water conveyance to most areas in seven to 10 days

6.1.2 SPU Water System Performance Goals for 2075

Achievement of the 2075 goals (by 2075) assumes that full funding is available from 2045 through 2075 and the mitigation projects outlined in Table 6-3 are completed per the Table 6-3 schedule:

- Critical vertical facility and transmission pipeline improvements
- Isolation and control strategies to mitigate water distribution pipeline breakage

		Immediately After	3 Days	7 Days	14 Days	1 Month	2 Months
Water Supply at Wholesale Meters	Minimum Water Volume	Winter Demand	Winter demand	Winter demand	Winter Demand	Winter Demand	Normal
	Water Quality	Nonpotable	Nonpotable	Nonpotable	Nonpotable	Potable	Potable
	Water Availability	25% of Meters	25% of Meters	50% of Meters	75% of Meters	100% of Meters	100% of Meters
Fire Suppression Water–Water to Within 2,500 Feet of Any Point Within the City Via Seismic-Resistant Pipelines	Minimum Water Volume	3,000 gpm for 3 hours	3,000 gpm for 3 hours	3,000 gpm for 3 hours	3,000 gpm for 3 hours	3,000 gpm for 3 hours	5,000 gpm for 4 hours
	Water Availability	25% of City Covered	33% of City Covered	50% of City Covered	75% of City Covered	90% of City Covered	100% of City Covered
Water Supply for Critical Retail Customers (e.g., hospitals)	Water Quality	Nonpotable	Nonpotable	Nonpotable	Nonpotable	Potable	Potable
	Water Availability	25% of critical customers	50% of critical customers	100% of critical customers	100% of critical customers	100% of critical customers	100% of critical customers
Water Supply to Direct Service Area	Water Quality	Nonpotable	Nonpotable	Nonpotable	Nonpotable	Nonpotable	Potable
	Water Availability	25% of direct service customers	33% of direct service customers	50% of direct service customers	75% of direct service customers	90% of direct service customers	100% of direct service customer
Water Supply at Retail Customer Emergency Supply Points	Water Quality	Potable	Potable	Potable			
	Water Availability	0%	50%	100%			

Table 6-1. Proposed post-earthquake water system level of service goals for 2045 after M7.0 Seattle Fault Zone or M9.0 Cascadia Subduction Zone earthquake scenarios

		Immediately After	3 Days	7 Days	14 Days	1 Month	45 Days
Water Supply at Wholesale Meters	Minimum Water Volume	Winter demand	Winter demand	Winter demand	Winter demand	Normal	
	Water Quality	Nonpotable	Nonpotable	Nonpotable	Potable	Potable	
	Water Availability	50% of Meters	50% of Meters	90% of Meters	100% of Meters	100% of Meters	
Fire Suppression Water–Water to Within 2,500 Feet of Any Point Within the City Via Seismic-Resistant Pipelines	Minimum Water Volume	3,000 gpm for 3 hours	3,000 gpm for 3 hours	3,000 gpm for 3 hours	3,000 gpm for 3 hours	5,000 gpm for 4 hours	
	Water Availability	50% of City Covered	67% of City Covered	90% of City Covered	100% of City Covered	100% of City Covered	
Water Supply for Critical Retail Customers (e.g., hospitals)	Water Quality	Nonpotable	Nonpotable	Nonpotable	Potable		
	Water Availability	50% of critical customers	90% of critical customers	100% of critical customers	100% of critical customers		
Water Supply to Direct Service Area	Water Quality	Nonpotable	Nonpotable	Nonpotable	Potable	Potable	Potable
	Water Availability	50% of direct service customers	67% of direct service customers	75% of direct service customers	90% of direct service customers	95% of direct service customers	100% of direct service customers
Water Supply at Retail Customer Emergency Supply Points	Water Quality	Potable	Potable				
	Water Availability	90%	100%				

Table 6-2. Proposed post-earthquake water system level of service goals for 2075 after M7.0 Seattle Fault Zone or M9.0 Cascadia Subduction Zone earthquake scenarios

6. SEISMIC MITIGATION RECOMMENDATIONS AND COST ESTIMATES

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 6-3. Preliminary mitigation schedule and planning level (order of magnitude) cost estimates

- In accordance with the proposed pipeline standards presented in Section 8 and Appendix D, 330 miles of distribution watermains have been replaced
- Emergency preparedness and response procedure enhancement, in combination with transmission pipeline upgrades, to allow minimal (low winter demand) transmission pipeline water conveyance to be restored in seven to 10 days

6.1.3 Water Supply at Wholesale Meters

In addition to SPU's direct service area, SPU also supplies water to 19 municipalities and special purpose districts, and the Cascade Water Alliance. Currently, the M7.0 SFZ and M9.0 CSZ scenarios would likely cut off supply to most or all wholesale customers. It might take more than one month to restore supply to many wholesale customers. This metric is used as an indicator of SPU's ability to supply its wholesale customers.

6.1.4 Fire Suppression Water–Water to Within 2,500 Feet of Any Point Within the City Via Seismic-Resistant Pipelines

Until SPU's vulnerable transmission and distribution system pipelines can be replaced with earthquake-resistant pipelines there will be areas within the direct service area that will lose pressure after a catastrophic earthquake. Except for the most critical pipelines, the intent is to wait until pipeline condition requires replacement to seismically upgrade pipelines. Some SPU pipelines have over 100 years of remaining useful life left so it will take that long to complete the installation of seismic resistant pipe throughout SPU's system. To provide firefighting water throughout the direct service area, a grid of watermains that will convey water to within approximately 2,500 feet of any point within the direct service area has been defined. With hoses and other means, firefighting water can then be conveyed to all locations within the direct service area.

6.1.5 Water Supply for Critical Retail Customers

This performance category is analogous to the fire-suppression water performance category except that the pipeline grid that is defined will supply water directly to SPU's critical facility customers. Critical customers include those facilities, such as hospitals and emergency response centers that must remain operational after a major earthquake.

6.1.6 Water Supply to the Direct Service Area

This performance category relates to SPU's retail customers with piped water supply. The metric used to define adequate water supply is the low winter demand. The supply should be adequate for basic health and sanitation needs and provide business and industry with the water they need to operate. However, there would likely be water restrictions to limit nonessential uses, such as irrigation for landscaping.

6.1.7 Emergency Water Supply

Because drinking water will be initially unavailable in many parts of the direct service area, this performance category will define the time needed to provide emergency drinking water supplies, such as bottled water, or water blivets (portable water bladders), that can fill small water containers throughout the direct service area.

6.1.8 Water Potability

Water potability is not specifically addressed in these performance goals. Although the treatment plants are expected to suffer only relatively minor damage and remain largely functional, or be quickly returned to functionality, there will be a "disinfect before drinking" order because of significant pipeline damage. The length of time for this order will depend on how long it takes to ensure that potential contaminants are not entering the drinking water system in areas where the pressure boundary is not intact. As more earthquake-resistant pipe is installed in the SPU water system, the number of breaks and leaks after a major earthquake is expected to decrease and the time needed to lift a "disinfect before drinking" order is also expected to decrease. Because electricity and/or gas may not be available, and stoves or other heat sources could ignite gas that has escaped from broken gas lines, chemical treatment is preferred over boiling water.

6.1.9 Life Safety and Property Damage

Life safety and property damage are also not specifically addressed in the performance goals. Implicit in the goals is the prevention of any damage that could cause death, injury, or significant amounts of property damage.

6.2 Seismic Mitigation and Improvement Strategies

To increase seismic resiliency of SPU's water system, SPU has developed five strategies. These strategies are interconnected and intended to complement one another. They have been designed to cost effectively mitigate the effects of facility damage that are currently expected from an earthquake in the near future, and greatly reduce the amount of damage over the long term. The strategies are:

1. Transmission pipelines
    a. Seismically upgrade one of the CRPLs from Lake Youngs to Maple Leaf Reservoir so that it would likely survive a major earthquake and provide at least minimal water (i.e., water to fight fires and supply basic needs, but not enough for landscaping or other noncritical uses). The Cedar River system was chosen over the Tolt system because it is easier to supply water from the Cedar River system throughout the SPU service area. The CRPLs are also older than the Tolt pipelines and many sections may need replacement or rehabilitation over the next 50 years regardless of seismic concerns. Because Lake Youngs stores enough water to supply water for approximately one month, upgrade of Cedar system pipelines upstream of Lake Youngs is not considered as critical. This

seismic-resistant transmission pipeline will be constructed over a 50- to 75-year time frame.
   b. Upgrade the transmission pipeline sites with the highest vulnerability and longest estimated repair times (longest potential out-of-service time). Currently, there are some vulnerable river crossings and pipelines in landslide areas that may take several weeks or even months to repair. If damage is limited to more accessible areas, restoration times can be greatly reduced.
   c. When transmission pipelines are replaced, pipeline systems will be used that are likely to withstand the expected seismic hazards at each location.

2. Isolation and control
   a. Add isolation systems to appropriate reservoirs so that reservoirs do not completely drain out if there is excessive pipeline damage.
   b. Evaluate the feasibility of isolating those areas within the distribution system where significant distribution pipeline damage would drain reservoirs. Design and implement the isolation system. This strategy will be implemented over a 10-year time frame and is intended to mitigate distribution pipe breakage effects.

3. Require seismic resistant design for new facilities
   a. Require the use of earthquake-resistant pipe
      i. When new pipelines are installed or replaced in areas that are susceptible to PGDs or subject to intense ground-shaking;
      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 ASCE 7 seismic design ground motions.

4. Seismically retrofit the most critical facilities (tanks, pump stations, etc.). Less critical facilities will not be seismically upgraded, particularly those facilities with shorter remaining useful lives. The probability of the occurrence of a major earthquake before these facilities are replaced is relatively small and it is more cost-effective to use limited resources to address the seismic vulnerability of more critical facilities that have a bigger impact on system performance. These upgrades will be done over a 20- to 50-year time frame.
5. Improve emergency preparedness and response planning. Needed repair materials and resources, and methods to obtain them, will be identified. Particular emphasis will be placed on resources and materials needed for large diameter pipeline repair, with the goal of reducing outage times. Strategies and resources needed to provide emergency drinking water after an earthquake will be augmented. An earthquake-specific emergency action plan will be developed. These plans, procedures, and storage of repair materials will be implemented over a 10-year time frame.

6.2.1 Transmission System Upgrades

The vulnerability of selective transmission pipeline locations is summarized on Figure 4-4. Figure 6-1 shows the current vulnerability of the transmission pipeline alignments and the

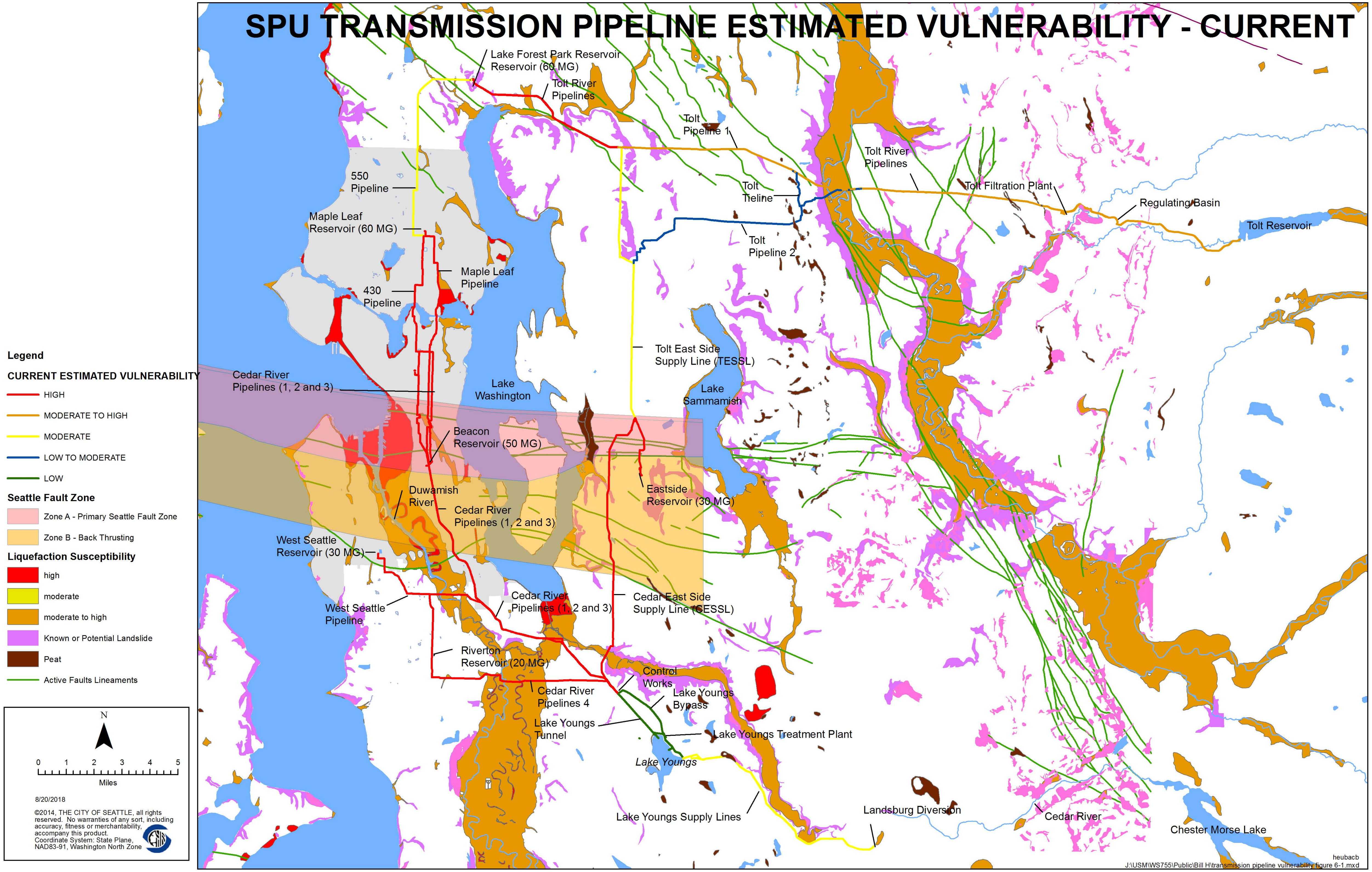

Figure 6-1. Current estimated transmission pipeline seismic vulnerability for M7.0 SFZ and M9.0 CSZ and restoration time

estimated minimum repair times. In an emergency, it may take up to 21 days to restore enough transmission pipeline capacity to provide minimal service (enough flow to supply low winter demand) to SPU's direct service area and wholesale customers in the M7.0 SFZ and M9.0 CSZ scenarios.

In addition to liquefaction- and landslide-induced permanent ground displacements, surface faulting across the CRPLs or CESSL could further complicate and delay restoration to some areas in M7.0 SFZ scenario. SPU Field Operations estimates that it could take six to eight weeks to restore water conveyance across significant surface fault ruptures. Even after minimal water conveyance is restored, it would still take significantly longer to restore the transmission pipelines to their pre-earthquake service levels. As an example, in the M7.8 San Andreas Fault Scenario, estimates by LADWP personnel show that it could take over one year to restore all of the aqueducts that provide water to Los Angeles (Davis 2015).

A SWIF scenario was not assessed as part of this study. Although SPU's direct service area would likely fare much better in a SWIF scenario, much more intense ground-shaking would be expected for the Tolt transmission system. Additionally, there could be surface fault ruptures across the Tolt Pipeline alignments. In a SWIF scenario, even minimal restoration of the Tolt system may take 21 or more days. Depending on the size and location of a SWIF event, the Cedar system could also take upwards of 21 days before even minimal flows could be restored.

As Figure 4-6 and Table 4-2 show, there are dozens of potentially vulnerable locations along the transmission pipeline alignments that need further analysis. The transmission system upgrade strategy is to first upgrade those vulnerable locations subject to liquefaction- or landslide-induced permanent ground displacements that would require complex and time-consuming repairs so that even if the transmission system went down, minimal service could be restored in seven to 10 days. These “critical” locations are typically river crossings and steep sloped areas. The time frame for these upgrades is over the 20-year period ending in 2045. Figure 6-2 projects transmission system vulnerability in 2045.

Over the next 50 to 75 years, targeted upgrades and replacement of aging transmission lines would be used to create a seismic-resistant transmission pipeline network that would be more likely (but not guaranteed) to maintain at least minimal service to SPU's direct service area and SPU's wholesale customers after a major earthquake. The transmission pipelines will be designed to accommodate PGDs that may occur in liquefaction-, landslide-, and settlement-susceptible areas. Upgrade will likely include a combination of rehabilitation of existing lines with techniques such as sliplining, and replacement of existing lines with new pipe. As much as possible, the upgrades would be coordinated with condition-related replacement and rehabilitation to optimize the seismic improvement costs. In stable soil areas that already have pipe that is able to accommodate the expected seismic hazards, the existing pipe would not be replaced or rehabilitated.

A different approach is recommended for mitigating possible damage from surface faulting. There is much uncertainty about the surface displacements that may occur in the Seattle Fault or SWIF zones. Depending on the size and location of the earthquake, there may not be any surface expression of faulting, or there may be up to one to three meters (three to 10 feet) of

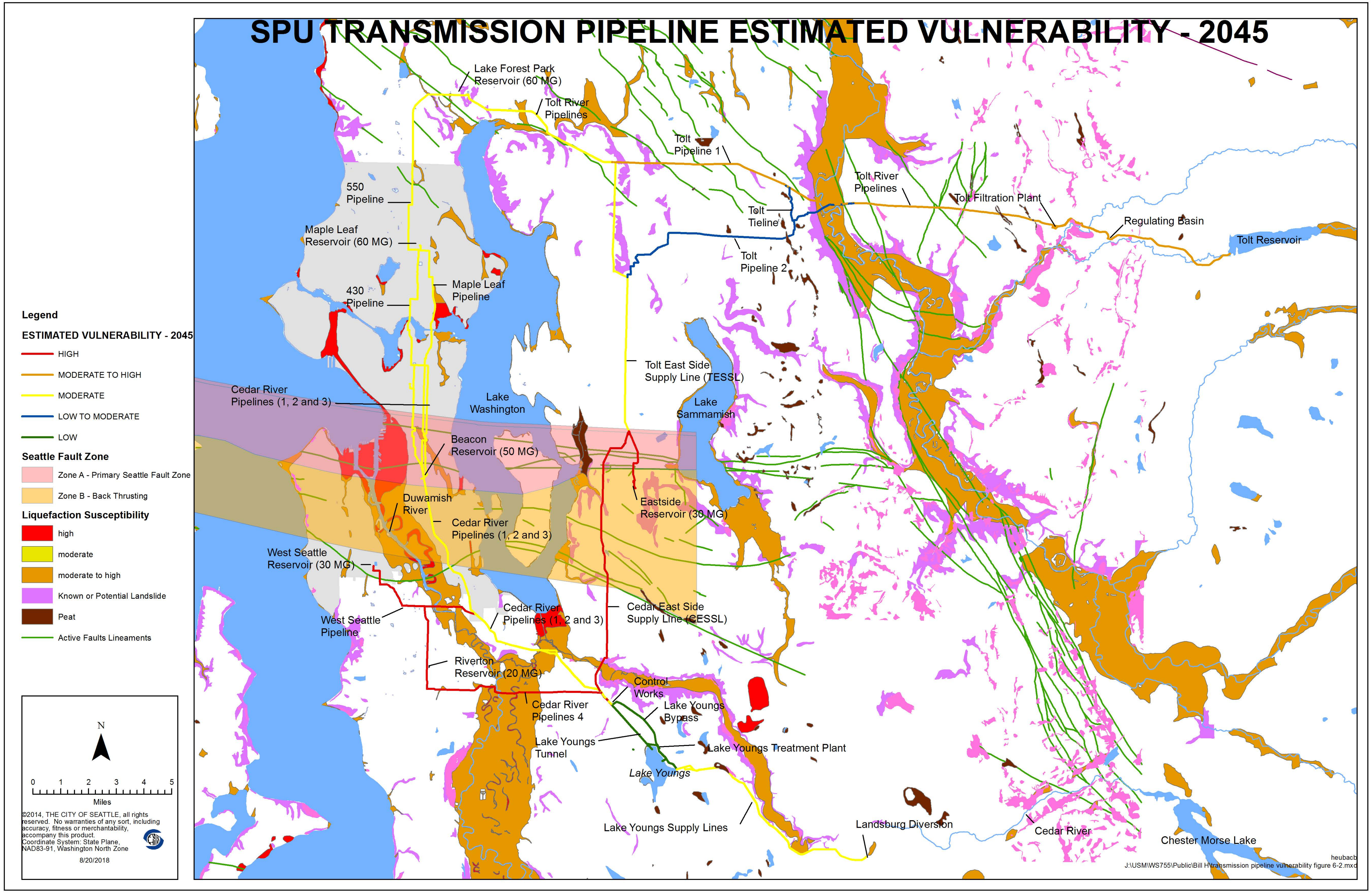

Figure 6-2. Estimated transmission pipeline seismic vulnerability for M7.0 SFZ and M9.0 CSZ and restoration time in 2045

displacement that could occur abruptly along a discrete plane, or there could be up to six meters (20 feet) of uplift distributed over 100 to 200 meters (330 to 660 feet) in the Seattle Fault Zone (Lettis Consultants International 2016a). Specific locations where these displacements may occur is not known. Even less is currently known about the SWIF zone.

The USGS suggests there is an approximately 0.05 probability (5% chance) of a M6.5 or higher shallow fault earthquake in the Puget Sound region in the next 50 years (Steele 2013). The likelihood of surface rupture across one of SPU’s transmission pipelines during the next 50 years, or even before condition-related issues require pipeline replacement, is much less. The cost to “immediately” (do not wait until pipeline condition requires replacement) replace all of the transmission pipelines throughout the Seattle Fault and SWIF zones with pipelines designed to resist fault movements would likely be in at least the $500 million to $1 billion range.

The recommended strategy for the transmission pipeline alignments in fault zones is to wait to replace these mains with earthquake-resistant pipe when they are closer to the time when condition-related replacement is required. In the meantime, the strategy is to identify the materials that would be needed to repair key pipelines impaired by fault movement and stockpile these materials so that in the unlikely event of critical pipeline rupture, minimal water conveyance past the break could be restored within seven to 10 days. Consideration will also be given to identifying locations where manifolds could be installed to allow bypassing of broken transmission pipeline sections. The installation of additional line valves and interties so that damaged areas can be bypassed will also be evaluated.

The 50- to 75-year upgrades would not reduce the vulnerability to a low level for all transmission pipelines but would make it likely that minimal water could be supplied to SPU’s direct service area and most wholesale customers within seven days of the event. After 100 years or more, as the transmission pipelines are replaced due to aging effects, the entire transmission system would be constructed with pipe that has the appropriate earthquake resistance.

Because there are still uncertainties with the transmission pipeline system vulnerability, further investigation is needed to assess those areas that could not be evaluated more rigorously during this study. Additional tasks would include estimating the inventories of repair materials that should be kept and determining if manifolds to connect bypass piping and more line valves are needed.

Figure 6-3 shows the projected transmission system vulnerability after 50 years. After 100 plus years, when most transmission mains have been replaced for condition-related reasons, there would be a high likelihood that at least minimal water could be supplied to SPU’s direct service area and SPU’s wholesale customers following a major earthquake.

6.2.2 Isolation and Control

Isolation and control are intended to mitigate the effects of the current seismic vulnerability of the SPU water system and enable quicker recovery if a major earthquake occurs before the water system can be seismically upgraded. There are two components to the isolation and control mitigation strategy. The first component considers isolating reservoirs before water loss

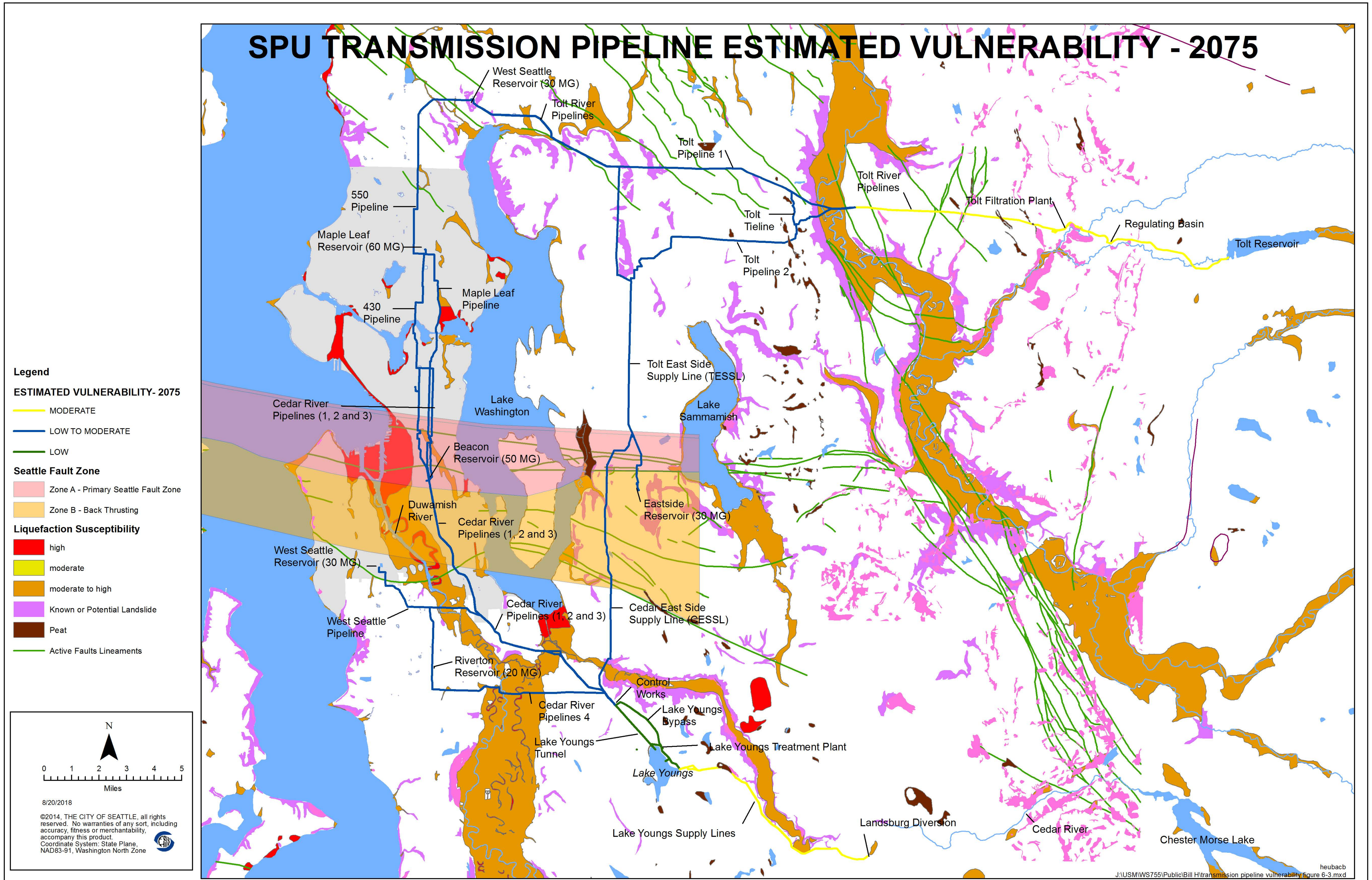

Figure 6-3. Estimated transmission pipeline seismic vulnerability for M7.0 SFZ and M9.0 CSZ and restoration time in 2075

caused by pipe breakage allows the reservoirs to drain. The second component considers isolating areas of the distribution system where severe pipe damage is expected.

The hydraulic modeling results and the experience of other utilities show that the extensive distribution pipeline damage expected after the M7.0 SFZ and M9 CSZ scenarios could completely drain SPU's direct service reservoirs within 24 hours. Isolation systems have already been installed on Beacon, Maple Leaf, Myrtle, and West Seattle Reservoirs. These systems allow each reservoir to drain until the reservoirs are half full. The remaining water could continue to be released uncontrolled to the system or it could be stored in the reservoir so it could be used for firefighting or drinking water.

Another measure that should be investigated is using valves to isolate areas after severe pipeline damage has occurred. Hydraulic modeling runs indicate that if these areas of expected damage are isolated, water system performance is greatly enhanced in other areas because less water is able to drain from the system, thereby preserving water supply for a longer time.

There are many issues that need to be resolved before distribution pipeline seismic isolation could be installed. For example:

- The optimal area(s) to be isolated would need to be identified
- A decision would have to be made as to whether it is acceptable to cut off areas from their water supply
- Should the system be automatic, and, if so, what should be used as the triggering mechanism? Manual and remote control override would be necessary.
- If the system controls were manual, would operators have time to operate them appropriately in emergency conditions?
- The installation and operation of an isolation system would need to be coordinated with the Seattle Fire Department
- Will the benefits be worth the installation and ongoing maintenance costs?
- Appropriate hardware and software will need to be identified.

6.2.3 Seismic Design Standards

Proposed seismic design standards for new SPU water system facilities are described in Section 8 and presented in Appendix D. These standards mainly address new watermains. Buildings, tanks, and other types of structures are already covered by existing codes and standards. However, it is important to note that all new SPU facilities that directly relate to water supply or emergency response are designed as essential facilities that must remain functional after the design-level earthquake. The goal of these standards is to ensure that as SPU water system facilities age, they will be replaced with seismic-resistant facilities so the entire system becomes seismic-resistant.

6.2.4 Critical Vertical Facility Upgrades

Because there is currently a high likelihood that SPU's direct service area may lose the Cedar and Tolt River sources after a major earthquake, maintaining storage within the direct service area is essential. This goal will be accomplished by upgrading the largest vulnerable reservoirs and using isolation and control strategies to prevent distribution pipeline damage from depleting storage. Because the Eastside Reservoir is a crucial storage facility for SPU's wholesale customers, it also has a high priority for upgrade. Additionally, those tanks that could endanger life safety if they failed will also have high priority for upgrade.

Basic procedures were used to evaluate all of the reservoirs and tanks. Soil structure interaction (SSI) was not considered in the evaluations. Because SSI can reduce seismic demands on buried structures, SSI analysis should be used to verify that those buried reservoirs and tanks identified for upgrade actually need to be retrofitted and to establish the degree of retrofitting that is actually needed.

Although Roosevelt and Volunteer Park Reservoirs have been temporarily removed from service, hydraulic modeling results have shown that these two reservoirs would maintain water pressure in the areas they serve for as long as an additional 16 hours if they were connected to the system after an earthquake. Another benefit of Roosevelt and Volunteer Park Reservoirs is that if they are kept disconnected from the system until needed, the water they store could be directed to the areas where it is needed for firefighting after an earthquake. In-town storage is crucial given the currently vulnerability of SPU's water transmission system.

Several critical gatehouses and pump stations are seismically vulnerable. Gatehouses and pump stations that are needed to achieve SPU's post-earthquake performance goals should also be upgraded. Other buildings and facilities, including those vulnerable nonstructural components that could endanger building occupants or affect building functionality needed for emergency response, should also be upgraded.

6.3 Seismic Resiliency Improvement Program, Proposed Schedule, and Planning Level Cost Estimates

The recommended schedule and planning level cost estimates for the mitigation measures is presented in Table 6-3. This table is intended as a starting point and will likely be modified as SPU's water system seismic mitigation program matures.