

# **CONTENTS**

---

<b>Abbreviations .....</b>	xiii
----------------------------	------

## **Executive Summary**

Background.....	ES-1
Key Findings .....	ES-2
Seismicity and Seismic Hazards .....	ES-2
SPU's Water System Seismic Vulnerability .....	ES-2
Increasing the Seismic Resiliency of SPU's Water System .....	ES-2
Identification and Definition of Seismic Hazards.....	ES-3
Vertical Facility (Nonpipeline) Assessments.....	ES-5
Pipeline Assessments .....	ES-5
System Analysis.....	ES-7
Treated Water Storage.....	ES-9
Performance Goals, Mitigation Recommendations, and Cost Estimates .....	ES-9
Performance Goals .....	ES-9
Mitigation Strategies .....	ES-10
Seismic Design Standards for New Water System Assets .....	ES-11
Expected Response After Seismic Improvements.....	ES-12
Cost Estimates.....	ES-12

## **1. Introduction**

1.1 Background.....	1-1
1.2 Study Objectives .....	1-1
1.3 Seismic Study Team Members .....	1-2
1.4 Study Approach .....	1-2
1.5 Report Structure .....	1-4

## **2. Regional Seismicity, Earthquake Scenarios, and Seismic Hazards**

2.1 Seismicity of the Puget Sound Region .....	2-1
2.1.1 Cascadia Subduction Zone Interplate Earthquakes .....	2-1
2.1.2 Cascadia Subduction Zone Intraplate Earthquakes .....	2-2
2.1.3 Crustal/Shallow Earthquakes .....	2-3

## **CONTENTS**

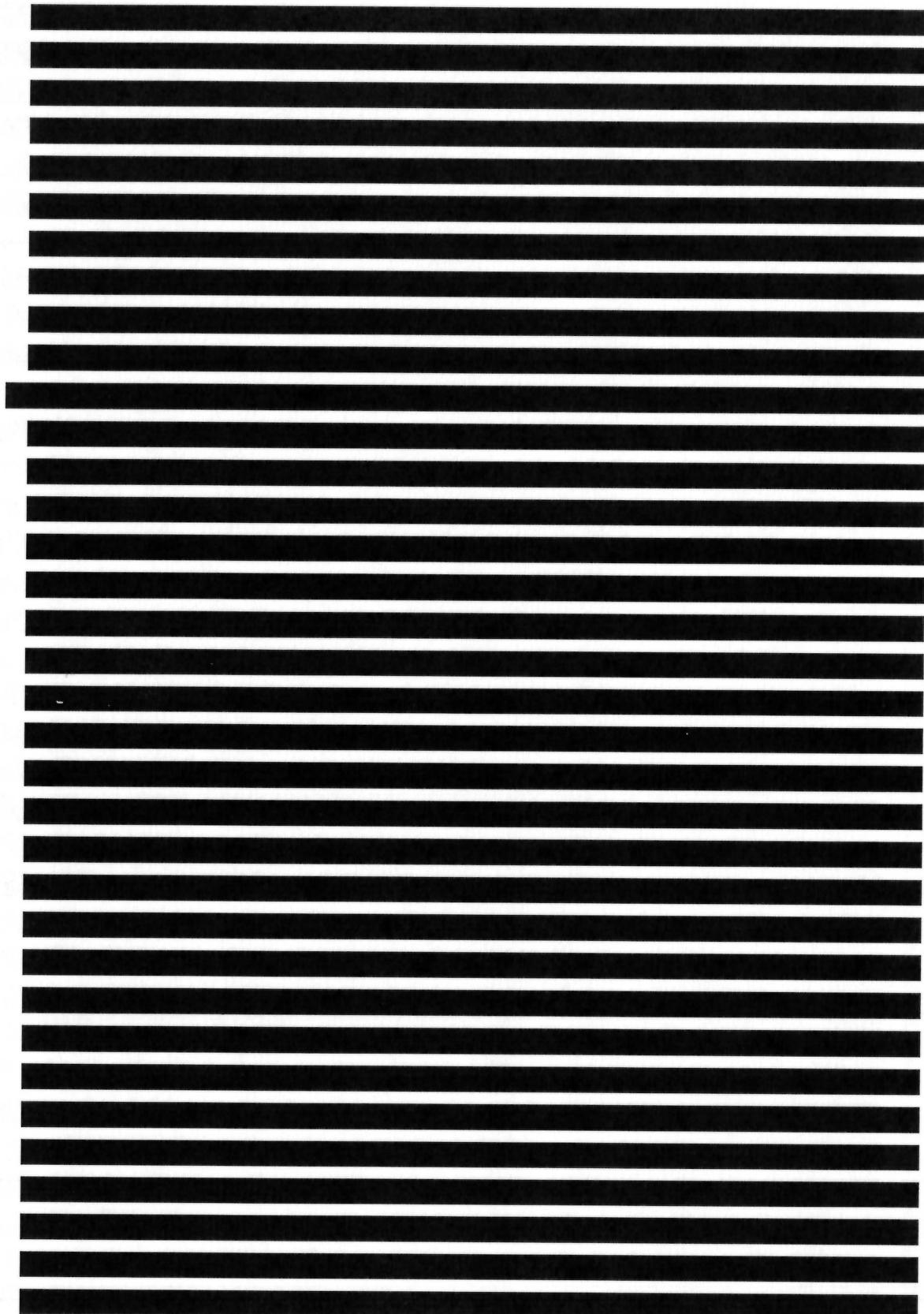
---

2.1.4	Evolution of the Seismological Understanding in the Pacific Northwest.....	2-3
2.2	Earthquake Scenarios.....	2-5
2.3	Ground-Shaking Intensity.....	2-6
2.4	Permanent Ground Displacement Hazards .....	2-7
2.4.1	Liquefaction .....	2-11
2.4.2	Landslides .....	2-13
2.4.3	Fault Rupture and Subsidence/Uplift.....	2-13
2.4.4	Tsunami and Seiche .....	2-19



## CONTENTS

---



## CONTENTS

The image features a repeating pattern of horizontal black bars of different widths against a white background. The bars are arranged in a grid-like fashion, with some bars being significantly wider than others, creating a visual effect similar to a barcode or a stylized striped fabric pattern. The widths of the bars decrease as they move from left to right across the frame.

## **CONTENTS**

---

The image features a repeating pattern of horizontal bars. Each bar is composed of two distinct horizontal segments: a solid black segment at the top and a solid white segment at the bottom. The bars are arranged in a regular, vertical grid. The overall effect is a clean, minimalist, and abstract visual texture.

## CONTENTS

A dark gray horizontal bar with three thin white horizontal lines above it.

## **5. Water System Post Earthquake Performance and Restoration**

5.1	System Response Model .....	5-1
5.1.1	Model Choice and Format.....	5-1
5.1.2	Model Inputs and Assumptions .....	5-1
5.2	Direct Service Area Model Results.....	5-9
5.3	Water Service Restoration to the Direct Service Area .....	5-15
5.4	Wholesale Turnout Water Availability .....	5-19
5.4.1	General Vulnerability of Transmission Pipelines that Serve Wholesale Customers .....	5-19
5.4.2	Transmission System Hydraulic Modeling Results .....	5-20
5.5	Distribution System Storage Analysis.....	5-20
5.5.1	Storage Comparisons .....	5-23
5.5.2	Hydraulic Analysis .....	5-24
5.5.3	Baseline Analysis.....	5-24
5.5.4	20-Year and 50-Year Analysis .....	5-25
5.5.5	Other Factors.....	5-25
5.5.6	Recommendation.....	5-26

## **6. Seismic Mitigation Recommendations and Cost Estimates**

6.1	Proposed Post-earthquake Performance Goals .....	6-1
6.1.1	SPU Water System Performance Goals for 2045.....	6-2
6.1.2	SPU Water System Performance Goals for 2075.....	6-2
6.1.3	Water Supply at Wholesale Meters .....	6-6
6.1.4	Fire Suppression Water—Water to Within 2,500 Feet of Any Point Within the City Via Seismic-Resistant Pipelines .....	6-6
6.1.5	Water Supply for Critical Retail Customers .....	6-6
6.1.6	Water Supply to the Direct Service Area.....	6-6
6.1.7	Emergency Water Supply .....	6-7
6.1.8	Water Potability .....	6-7
6.1.9	Life Safety and Property Damage .....	6-7

## **CONTENTS**

---

6.2 Seismic Mitigation and Improvement Strategies.....	6-7
6.2.1 Transmission System Upgrades .....	6-8
6.2.2 Isolation and Control.....	6-12
6.2.3 Seismic Design Standards .....	6-14
6.2.4 Critical Vertical Facility Upgrades.....	6-14
6.3 Seismic Resiliency Improvement Program, Proposed Schedule, and Planning Level Cost Estimates .....	6-15

### **7. Emergency Preparedness and Response Planning**

7.1 Post-earthquake Repair Resources .....	7-1
7.2 Earthquake-Specific Emergency Preparedness and Response Planning.....	7-7
7.3 Emergency Drinking Water .....	7-8

### **8. Seismic Design Standards for New Facilities and Pipelines**

8.1 New Nonpipeline Facilities .....	8-1
8.2 Occupancy Category for Nonpipeline Facilities .....	8-1
8.3 Existing Facilities .....	8-2
8.4 Seismic Design Standards for New Buried Pipelines .....	8-2
8.4.1 Pipeline Classifications .....	8-2
8.4.2 Pipeline Standards Background .....	8-4
8.4.3 Proposed Standards for Incorporation Into SPU's Design Standards and Guidelines.....	8-5

### **Appendix A – Facilities Evaluated by Reid Middleton**

### **Appendix B – Hydraulic Modeling Results**

### **Appendix C – Representative Water Utility Performance Goals**

### **Appendix D – Draft SPU Seismic Standards for New Pipe**

### **References**

## **CONTENTS**

---

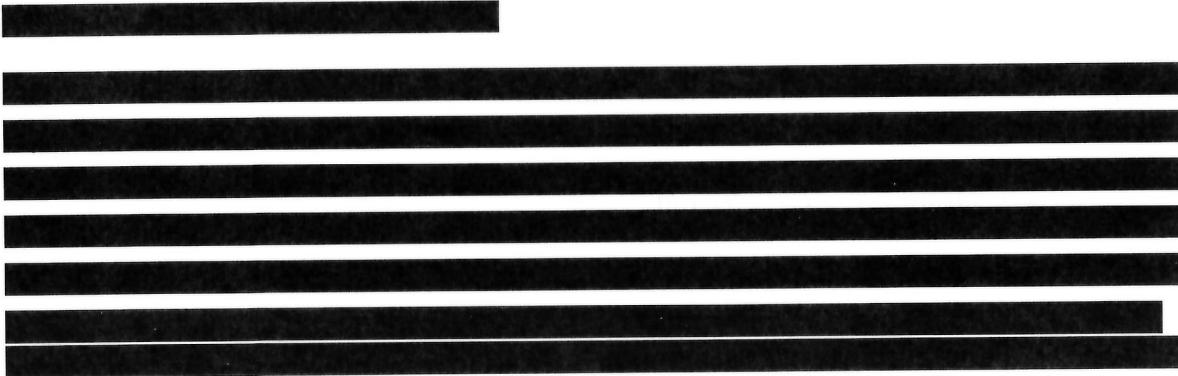
### **Figures**

#### **Executive Summary**

Figure ES-1. Potential earthquake sources in the Pacific Northwest (USGS 2001) .....	ES-4
Figure ES-2. SPU water system earthquake hazards map.....	ES-6
Figure ES-3. Retail service area restoration estimates after catastrophic earthquakes .....	ES-8

#### **2. Regional Seismicity, Earthquake Scenarios, and Seismic Hazards**

Figure 2-1. Western Washington earthquake hazards (USGS 2001) .....	2-2
Figure 2-2. Tectonic plate block movement (Wells et al. 2000) .....	2-4
Figure 2-3. M7.0 SFZ peak ground accelerations.....	2-8
Figure 2-4. M9.0 CSZ peak ground accelerations .....	2-9
Figure 2-5. 2014 USGS probabilistic peak ground accelerations.....	2-10
Figure 2-6. SPU distribution and transmission area seismic hazards .....	2-12
Figure 2-7. M7.0 SFZ distribution pipelines liquefaction displacement estimates .....	2-14
Figure 2-8. M9.0 CSZ distribution pipelines liquefaction displacement estimates .....	2-15
Figure 2-9. M7.0 SFZ liquefaction probability of occurrence estimates.....	2-16
Figure 2-10. M9.0 CSZ liquefaction probability of occurrence estimates .....	2-17
Figure 2-11. Seattle Fault Zone (Map by Lettis Consultants International 2016a).....	2-18
Figure 2-12. Tsunami inundation map for Seattle from a Seattle Fault event (Walsh et al. 2003)	2-20



#### **5. Water System Post Earthquake Performance and Restoration**

Figure 5-1. SSRA model schematic .....	5-2
Figure 5-2. Water loss (gpm) at 60 psi for M7.0 SFZ scenario (north service area).....	5-4

## **CONTENTS**

---

Figure 5-3. Water loss (gpm) at 60 psi for M7.0 SFZ scenario (north central direct service area)	5-5
Figure 5-4. Water loss (gpm) at 60 psi for M7.0 SFZ scenario (south central direct service area)	5-6
Figure 5-5. Water loss (gpm) at 60 psi for M7.0 SFZ scenario (southern direct service area)..	5-7
Figure 5-6. Fraction of direct service area (vertical axis) with water pressure versus time (horizontal axis) for M7.0 SFZ and M9.0 CSZ base cases .....	5-10
Figure 5-7. Fraction of direct service area with water pressure (vertical axis) versus time (horizontal axis) if the Cedar River transmission system could supply water to the direct service area .....	5-13
Figure 5-8. Fraction of direct service area with water pressure (vertical axis) versus time (horizontal axis) if the Tolt River transmission system could supply water to the direct service area .....	5-14
Figure 5-9. System restoration estimation curves for current SPU water system.....	5-18
Figure 5-10. Post-earthquake water availability after the M7.0 SFZ earthquake scenario (gray circles indicate zero water pressure at wholesale turnouts/nodes east of Seattle).....	5-22
Figure 5-11. Baseline hydraulic analysis (percentage of direct service area with water pressure on the vertical versus hours after the event).....	5-24
Figure 5-12. 20-year hydraulic model analysis (fraction of direct service area with water pressure on the vertical versus hours after the event) .....	5-25
Figure 5-13. 50-year hydraulic model analysis (fraction of direct service area with water pressure on the vertical versus hours after the event) .....	5-26

## **6. Seismic Mitigation Recommendations and Cost Estimates**

Figure 6-1. Current estimated transmission pipeline seismic vulnerability for M7.0 SFZ and M9.0 CSZ and restoration time .....	6-9
Figure 6-2. Estimated transmission pipeline seismic vulnerability for M7.0 SFZ and M9.0 CSZ and restoration time in 2045 .....	6-11
Figure 6-3. Estimated transmission pipeline seismic vulnerability for M7.0 SFZ and M9.0 CSZ and restoration time in 2075 .....	6-13

## **8. Seismic Design Standards for New Facilities and Pipelines**

Figure 8-1. SPU critical pipeline map .....	8-3
---	-----

## **CONTENTS**

---

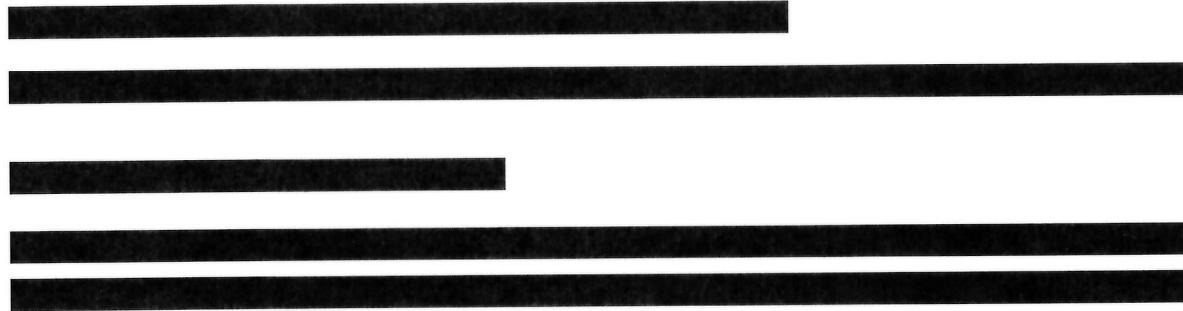
### **Tables**

#### **Executive Summary**

Table ES-1. Recommended mitigation plan summary and order of magnitude cost estimates .....	ES-13
---	-------

#### **1. Introduction**

Table 1-1. Facilities not included in SPU's seismic study .....	1-5
---	-----



#### **5. Water System Post Earthquake Performance and Restoration**

Table 5-1. Hydraulic modeling cases .....	5-11
---	------

Table 5-2. Transmission pipeline repair time estimates.....	5-17
---	------

Table 5-3. SPU Major Distribution Reservoirs .....	5-21
--	------

Table 5-4. Storage comparison with other West Coast utilities .....	5-23
---	------

#### **6. Seismic Mitigation Recommendations and Cost Estimates**

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.....	6-3
---	-----

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.....	6-4
---	-----

Table 6-3. Preliminary mitigation schedule and planning level (order of magnitude) cost estimates .....	6-5
---	-----

#### **7. Emergency Preparedness and Response Planning**

Table 7-1. Recommended transmission pipeline repair pipe .....	7-3
--	-----

Table 7-2. Recommended distribution pipeline repair pipe .....	7-5
--	-----