1. INTRODUCTION

This report summarizes the findings of Seattle Public Utilities' (SPU) water system seismic vulnerability assessment. This assessment occurred in 2016 and 2017 and updates the 1990 seismic vulnerability assessment completed by Cygna Energy Services (Cygna).

1.1 Background

In 1990, the Seattle Water Department, which later merged with other city departments to form SPU, commissioned a seismic study of its water system. The study was initiated in response to growing concern about seismic risk in the Pacific Northwest region. Cygna conducted this comprehensive seismic vulnerability assessment of the Seattle Water Department's facilities (Cygna 1990).

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 been upgraded to the seismic standards developed by Cygna, and 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.

However, scientific and engineering knowledge about the impact of earthquakes on water systems has increased dramatically since 1990 and understanding of the seismicity of the Pacific Northwest region—in particular the Seattle Fault Zone (SFZ) and Cascadia Subduction Zone (CSZ)—has also advanced substantially. As a result, SPU conducted another comprehensive seismic study in 2016 and 2017. This recent study evaluated facilities in accordance with current seismic code design ground motions, which are discussed in Section 2, and considered overall water system response to two earthquake scenarios.

1.2 Study Objectives

Study objectives were to update the Cygna assessment and

- Perform preliminary seismic vulnerability assessments with an emphasis on critical facilities and pipelines for
  - Two earthquake scenarios;
  - American Society of Civil Engineers/Structural Engineering Institute 7-10 (ASCE/SEI 7-10) code assessment ground motions.
- Estimate overall post-earthquake water system performance;
- Establish post-earthquake water system performance goals;
- Develop planning level mitigation measures, cost estimates, and a time frame to meet post-earthquake performance goals;
- Define seismic design standards for new SPU infrastructure with an emphasis on water transmission and distribution pipelines.

1.3 Seismic Study Team Members

The seismic study team consisted of SPU, two teams of consultants, and a project review panel. Consultants who worked on the project are:

G&E Engineering Systems Inc. (G&E) Team
- New Albion Geotechnical Inc.
- McMillen Jacobs Associates
- Lettis Consultants International Inc. (LCI)
- Leong Holston Associates

Reid Middleton Team
- Arcadis Inc.
- Doug Honegger Consulting
- John Stanton

Project Review Panel
- Tom O'Rourke
- Steve Kramer
- Don Ballantyne

The G&E team evaluated geotechnical hazards, used engineering judgment to estimate the seismic vulnerability of SPU's water system facilities, and made site visits to SPU facilities and some of the critical pipeline locations. The Reid Middleton team performed further evaluations (using American Concrete Institute (ACI), ASCE 41-13 Tier 1, and American Water Works Association (AWWA) procedures) for buildings, tanks, and reservoirs believed to be most critical, and addressed questions regarding previous assessments. SPU assessed distribution pipeline vulnerability, developed recommendations to improve SPU's earthquake emergency preparedness and response planning and prepared this summary report. A review panel of seismic experts comprised of Tom O'Rourke, Don Ballantyne, Doug Honegger, Reid Middleton, and SPU staff evaluated transmission pipeline vulnerability. Arcadis Inc., a subconsultant to Reid Middleton, performed hydraulic modeling to estimate the overall system response. Tom O'Rourke, Steve Kramer, and Don Ballantyne reviewed the seismic study's direction and methodologies.

1.4 Study Approach

The study team looked at both the response of SPU's individual water system facilities and the overall water system response during two earthquake scenarios. The first earthquake scenario was a magnitude 7.0 SFZ (M7.0 SFZ) event with an epicenter in Seattle, and the second was a magnitude 9.0 CSZ (M9.0 CSZ) event that would occur off the Pacific Northwest coast. A M9.0 CSZ earthquake or an approximately M6.5 or higher SFZ earthquake are the earthquake scenarios that would likely have the most significant impact on SPU's water system.

A South Whidbey Island Fault (SWIF) scenario and an earthquake scenario deep within the Juan de Fuca Plate were not modeled in this study. Although a SWIF scenario could significantly affect SPU's Tolt transmission facilities, and potentially its Cedar transmission facilities, available resources were used to assess the higher probability and likely more damaging SFZ and CSZ scenarios.

Deep Juan de Fuca intraplate earthquakes similar to the 1949, 1965 and 2001 Puget Sound earthquakes occur much more frequently than the two scenarios used in this study. These intraplate earthquakes occur at large depths below the ground surface and have not significantly affected the SPU water system. It is possible that a deep Juan de Fuca intraplate earthquake could occur that is somewhat stronger and/or closer to Seattle than previously documented intraplate earthquakes, but such an intraplate event is not expected to have nearly as much impact on SPU's system operation as the SFZ or CSZ scenarios. Mitigation measures recommended in this report were thus developed for more severe conditions than those that would generally be expected from an intraplate earthquake scenario.

Ground-shaking-attenuation models were used to estimate the ground-shaking intensity at facility locations under each scenario. SPU water system facilities were also evaluated using the 0.02 probability (2% chance) of exceedance in 50 years (2,475-year average-return period) ground motions, which are approximately equal to the design ground motions used in the Seattle Building Code. Estimates of the typical permanent ground displacements (PGDs) that may occur were estimated with regional earthquake PGD susceptibility maps and models that consider soil properties, ground-shaking intensity, and ground-shaking duration.

Most of SPU's water system facilities and pipelines were evaluated. Notable exceptions include major dams, such as the Masonry and Landsburg Dams on the Cedar River, and the Tolt River Dam. These dams are constantly monitored and evaluated by others, including SPU's dam safety group and Seattle City Light. Facilities that were not included in SPU's seismic study are listed in Table 1-1.

For less critical SPU facilities, or recently constructed facilities that meet current seismic standards, engineering judgment was used to estimate seismic vulnerability. Pseudo static and visual techniques described in ASCE, AWWA, and ACI standards were used for more critical facilities.

Regional distribution pipeline breakage for the two earthquake scenarios was estimated using American Lifelines Alliance (ALA) watermain fragility models. These models estimate damage as a function of pipeline characteristics, peak ground velocity, and permanent ground displacement. Transmission pipeline vulnerability was based on transmission pipeline characteristics and earthquake hazards along each pipeline alignment.

An iterative process was used to develop post-earthquake performance goals that balance system performance with limited resources. A hydraulic model was used to estimate overall system response to the two earthquake scenarios and to evaluate seismic improvement concepts. These improvement concepts included infrastructure upgrades, emergency preparedness, response planning enhancement, and consideration of isolation and control strategies.

1.5 Report Structure

This report includes an executive summary, eight sections, a list of abbreviations, four appendices, and references. Section 1 presents the study background, approach, and report structure. In Section 2, permanent ground displacement and ground-shaking intensity parameter development are summarized for each earthquake scenario. Pump stations, tanks, and other vertical facility assessment findings are presented in Section 3. Pipeline assessment findings are presented in Section 4. Taking into account the results presented in Sections 3 and 4, Section 5 describes the overall system response to each earthquake scenario. Suggested post-earthquake performance goals and mitigation recommendations and costs needed to achieve those performance goals are discussed in Section 6. Recommendations to improve SPU's earthquake emergency preparedness and response planning are outlined in Section 7. The background for the proposed seismic standards for SPU facilities is presented in Section 8. References and a list of abbreviations follow Section 8. The four appendices contain a list of the critical facilities that were re-evaluated by the Reid Middleton team, the hydraulic modeling results, representative water utility post-earthquake performance goals, and proposed seismic standards for SPU watermains.

Facility	Comments
Cedar Falls Education Center	This facility is not necessary for water system operation.
Tolt Bridges	Tolt Bridge No. 1 (North Fork Tolt River crossing) has been seismically upgraded.
Landsburg Dam	Landsburg Dam would not likely lose functionality, but detailed analysis may be needed.
Masonry Dam	Masonry Dam is a Seattle City Light facility; follows FERC regulations.
Tolt Dam	Tolt Dam is FERC compliant.
SW Spokane Street Pump Station	This pump station is currently being rehabilitated and seismically upgraded.
Seattle Municipal Tower	This facility falls under the purview of Finance and Administrative Services.
Water Quality Lab	
Cedar River Pipelines No. 1, 2, and 3 Isolation Vaults in Renton	G&E noted these vaults are seismically rugged.
Lake Youngs Corrosion Building	This facility is no longer in use.
Beacon Reservoir	These four reservoirs were recently seismically upgraded. The probability of any of these reservoirs losing functionality because of structural failure is considered to be low. A nonstructural assessment is needed to verify that there are no significant nonstructural issues.
Maple Leaf Reservoir	
Myrtle Reservoir	
West Seattle Reservoir	
Barton Standpipe	These four facilities have been removed from service. It is unlikely that they will be returned to service.
Woodland Park Standpipe	
Maple Leaf Elevated Tank	
Myrtle Elevated Tank No.1	
Roosevelt Reservoir	This reservoir is not currently in service. The geotechnical investigation and assessment needed to assess the seismic vulnerability of Roosevelt Reservoir was not performed as part of this study. Previous seismic assessments suggest that the embankments at Roosevelt Reservoir may start to experience significant deformations at seismic accelerations of 0.39g (see Section 2) or possibly lower. The last significant assessment appears to have been performed in 1985. If Roosevelt Reservoir is returned to service, a more comprehensive assessment that incorporates the current understanding of seismic hazards and geotechnical response should be performed.
Volunteer Park Reservoir	This reservoir is not currently in service. The geotechnical investigation and assessment needed to assess the seismic vulnerability of Volunteer Park Reservoir was not performed as part of this study. If Volunteer Park Reservoir is returned to service, a comprehensive assessment that incorporates the current understanding of the seismic hazards and geotechnical response should be performed.

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