An Investigation of the Seismic Performance of Portland Water Bureau's Water System in an M 9.0 Earthquake

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ABSTRACT

The Oregon Resilience Plan (ORP) was developed in 2013 by the State of Oregon to reduce risk and improve recovery during and following a Magnitude (M) 9.0 earthquake and tsunami. The Portland Water Bureau (PWB) hired InfraTerra, Inc. to help them prepare a Water System Seismic Study (WSSS) of the PWB water system. PWB and InfraTerra determined the seismic performance of PWB's water system in an M 9.0 earthquake and developed mitigation actions to meet the target states of recovery (TSoR) provided in the ORP. The study findings highlighted the need to invest in mitigation projects and water system improvements. The study also identified resources needed for post-earthquake repair and areas where additional planning and policy change were needed.

INTRODUCTION

Background

The Oregon Resilience Plan (ORP) was developed by the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) upon passage of House Resolution 3 by the Oregon House of Representatives. The purpose of the ORP is to reduce risk and improve recovery during and following a Magnitude (M) 9.0 Cascadia Subduction Zone earthquake and tsunami. The ORP addressed a number of concerns by developing Task Groups that looked at Business and Workforce Continuity, Critical and Essential Buildings, Transportation, Energy, Information and Communications, and Water and Wastewater. The ORP was finalized in 2013.

In 2016, the Portland Water Bureau (PWB) hired InfraTerra, Inc. to help prepare a Water System Seismic Study (WSSS) of the PWB water system. The performance goals developed by the OSSPAC Water and Wastewater Task Group of the ORP formed the basis for the WSSS. A key recommendation of the Task Group was to identify and strengthen a backbone water system that can provide water for critical needs following a M9 Cascadia Subduction Zone (CSZ) earthquake while damage to the remainder of the system is being repaired within a period of 6 months to a year. Table I shows ORP's target states of recovery (TSoR) for its water system.

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TABLE I. OREGON RESILIENCE PLAN WATER SYSTEM TARGET STATES OF RECOVERY

Event Occurs

Domestic Water Supply	0-24 hours	1-3 days	3-7 days	1-2 weeks	2 weeks - 1 month	1-3 months	3-6 months	6-months - 1 year	1-3 years	3+ years
Potable water available at supply source (WTP, wells, impoundment)	20%-30% operational	50%-60% operational		80%-90% operational			90% operational (current state)			
Main transmission facilities, pipes, pump stations, and reservoirs (backbone operational)	80%-90% operational					90% operational (current state)				
Water supply to critical facilities available	50%-60% operational	80%-90% operational				90% operational (current state)				
Water for fire suppression - at key supply points	80%-90% operational		90% operational (current state)							
Water for fire suppression - at fire hydrants			20%-30% operational	50%-60% operational	80%-90% operational			90% operational (current state)		
Water available at community distribution centers/points		50%-60% operational	80%-90% operational	90% operational (current state)						
Distribution system operational		20%-30% operational	50%-60% operational	80%-90% operational				90% operational (current state)		

Figure 1 shows the location of the CSZ in relation to PWB.

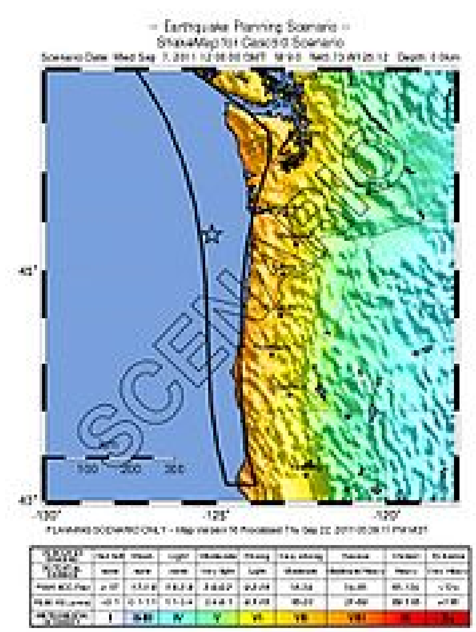

Figure 1. PWB seismic hazard from the Cascadia Subduction Zone

The WSSS scope included the following main tasks:

- Develop hazard maps for earthquake-induced liquefaction, lateral spreading, and landslides in the Portland area;
- Identify and assess the backbone system
- Assess the water distribution system;
- Develop mitigation measures to meet ORP's TSoR;
- Evaluate emergency preparedness for response and recovery.

Water System Description

The PWB water system is the largest water system in Oregon and serves a population of over 935,000, almost one-quarter of the state's population. Its service area covers approximately 225 square miles, including portions of Multnomah, Washington and Clackamas counties. PWB provides water to both wholesale and retail customers with the retail service area accounting for 64 percent (143.3 square miles) of PWB's service area. The Average Day Demand (ADD) for the water system is 86.9 million gallons per day (mgd) and the Winter or Minimal Day Demand (MinDD) is 76.4 mgd (approximately 88 percent of the ADD). The MinDD was chosen as the level of service (LOS) goal for the WSSS.

The Bull Run watershed is the primary source of water for the PWB system, and can supply up to 205 mgd. Water from the Bull Run Headworks comes into town via three large diameter supply pipelines (Conduit 2, Conduit 3 and Conduit 4), constructed in 1911, 1925, and 1952, respectively. Although the conduits are separated within the Bull Run watershed, transfer of water between the conduits is possible at the Larson's and Hudson Intertie facilities. In addition to the Bull Run supply, the Columbia South Shore Wellfield (CSSWF), with 27 production wells, serves as a secondary source of water supply for PWB and can provide up to 114 mgd of water supply.

The PWB distribution system consists of over 2,000 miles of pipelines that service 165 pressure zones. The distribution pipelines consist predominantly of concrete cylinder, cast iron, ductile iron, and steel. The cast iron pipelines are known to have high seismic vulnerability, and constitute more than 60 percent of the pipelines within the backbone and distribution system. Ductile iron is the other main pipeline type and constitutes more than 30 percent of the distribution system pipelines. The distribution system also includes 59 distribution system tanks, 5 terminal reservoirs, and 36 pump stations.

The WSSS project team, including key PWB stakeholders, InfraTerra staff, and PWB's outside expert, Don Ballantyne, participated in a workshop to identify critical components of the PWB's system that can serve as a backbone system. The identified backbone included terminal reservoirs, critical pump stations and 120 miles of major pipelines that can transport water across PWB's service area. The backbone also includes PWB's Bull Run and CSSWF supplies.

Seismic History

PWB has been upgrading its system to meet seismic requirements over the last twenty years. This work has included upgrades to several assets at PWB's Bull Run Headworks facility, new and improved interties between supply conduits, bridge and trestle improvements, and two tunnel projects. PWB also constructed three new terminal reservoirs, completed a pilot study using earthquake-resistant pipe, and has made improvements to several of its distribution storage tanks and pump stations.

IMPACTS FROM AN M9 CSZ EARTHQUAKE

Hazard Maps

The main seismic hazards to PWB's water system are soil liquefaction, seismically triggered landslides, and slope instability. The WSSS invested a great deal of resources into quantifying the liquefaction and landslide hazards by developing permanent ground deformation (PGD) maps for the study earthquake. Four maps were developed: liquefaction susceptibility, liquefaction-induced PGD (lateral spread), liquefaction-induced PGD (settlement) and earthquake triggered landslides. These GIS based maps will help PWB in future analyses and emergency response as well as providing key information for the WSSS hazard assessment.

Hazard Assessment

The seismic vulnerability assessment of PWB infrastructure included site reconnaissance and seismic analysis. The seismic analysis incorporated the potential for direct damage to the water system infrastructure from earthquake effects such as ground shaking, wave propagation, and permanent ground deformation. The assessment did not include potential collateral damage to the system resulting from failure of other infrastructure such as buildings and bridges.

Site reconnaissance of all storage and pumping facilities, groundwater production wells and groundwater pump station facilities was performed. The Bull Run 1 and Bull Run 2 dams, Headworks facilities, the Larson's and Hudson interties and the conduit bridge crossings were also reviewed. Geologic field reconnaissance included documentation of observed ground conditions and evidence of ground movement. Structural reconnaissance focused on as-built conditions and documentation of any visible signs of structural distress.

Seismic analysis ranged from simplified calculations to complex non-linear finite element analysis for critical pipelines. Probability of failures were developed using empirical as well as analytical methods and included Monte Carlo analyses to incorporate uncertainties in hazard quantification, structural response and structural capacities for pipelines, conduits, river crossings, tanks and pump stations.

The results of PWB's hazard assessment indicated that the backbone distribution system and wellfield pipelines would be most impacted by lateral spreading and that the supply conduits would be impacted by liquefaction-related lateral spreading and landslides.

Water System Performance

Seismic assessment of the PWB water system showed significant vulnerabilities in the current supply, the backbone, distribution, storage, and pumping systems. Hydraulic analysis of the backbone system showed that the existing system is unable to meet the MinDD or minimum level of service goal of 76.4 mgd following a M9 CSZ earthquake, and that the system could potentially drain within minutes following the earthquake due to the large number of predicted leaks and breaks. In addition, if it is assumed that a complete loss of pressure in the distribution system cannot be prevented (i.e. majority of system is allowed to drain, as a result of widespread damage), the time required to restore the system by post-earthquake repairs is significantly greater than the TSoRs identified in ORP.

Median estimates of the time required to perform necessary post-earthquake pipeline repairs showed that even with the most optimistic estimates of repair crew availability, the ORP's TSoRs for the restoration of backbone and distribution cannot currently be met. For example, PWB estimates that it would take a minimum of 5 days to complete backbone repairs, assuming 40 crews (which would require outside assistance such as mutual aid agreements) working one 12-hour shift or 20 crews working two 12-hour shifts per day. This restoration timeline is higher than ORP's TSoR for restoration, which is 80 to 90 percent of the backbone within 24 hours, as shown in Table I. Similarly, it would take a little over 5 weeks to complete the median estimates of repairs for the distribution system (assuming that the backbone and wellfield pipeline repairs would be performed first), whereas the ORP's TSoR for the restoration for 80 to 90 percent of the distribution system is 1 to 2 weeks. Furthermore, these estimates do not account for other demands on the repair crews, such as damage to the supply system, electrical/mechanical components in the pump stations, road clearing operations, and structural damage to the pump stations, tanks, and the production wells in the wellfield.

Consequently, it was determined that it is not possible to reliably meet the ORP goals for the backbone and distribution system without the implementation of improvement projects to reduce the number of post-earthquake repairs.

EFFORTS TO ASSESS AND MITGATE IMPACTS

Water System Mitigation

A comprehensive list of mitigation projects with planning-level costs was developed. These projects included replacement of sections of the supply conduits, significant upgrades to the Columbia South Shore Wellfield, tank and pump station retrofits, improvements to the backbone system, and additional studies that need to be completed. Projects were given an initial priority, and a plan to fund and phase these projects over the next 5 or 10 years (short-term) and over the next 50 years (long-term) is currently underway.

Emergency Response Improvements

The WSSS consultants reviewed several existing PWB emergency plans and provided recommendations for improving them. As part of the work, they provided insight into improving our pipe repair protocols, firefighting response, and emergency potable water strategies. This insight will help PWB strengthen their emergency planning and response efforts.

CONCLUSION

The Portland Water Bureau has completed its Water System Seismic Study and now has a list of improvements that will create a roadmap to reach the goals of the Oregon Resilience Plan over the next 50 years. Funding and prioritization of recommended water system improvements are now taking place. The Portland Water Bureau also has additional insight that will strengthen their emergency planning and response activities.

REFERENCES

City of Portland Water Bureau ((2017). *Statistical Report FY 2015-16*

InfraTerra, Inc. (2017). *City of Portland Water System Seismic Study*

OSSPAC (2013). *Oregon Resilience Plan*