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Joint Water Commission

Seismic Hazard Mitigation Study

TECHNICAL MEMORANDUM NO. 8
PIPELINE PROBABLE MAXIMUM LOSSES

FINAL

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PIPELINE PROBABLE MAXIMUM LOSSES

1.0 INTRODUCTION

This technical memorandum (TM) addresses probable maximum losses in the Joint Water Commission transmission pipelines expected to occur in an earthquake with a return interval of 475 years, or 10% probability of occurrence in 50 years. The purpose of this document is to provide information to the JWC that can be used in estimating probable maximum losses for insurance purposes.

This memorandum is part of a project that evaluates the seismic vulnerability of the JWC Water Treatment Plant (WTP). This document focuses on the expected earthquake performance of the transmission pipelines that transmit water from the WTP to the JWC member retail distribution systems.

The methodology used in this analysis is more fully documented in the *American Lifelines Alliance* (ALA) *Seismic Fragility Formulations for Water Systems* (ALA, 2001). The liquefaction hazard mapping used in this evaluation is available from the Oregon Department of Geology and Mineral Industries (DOGAMI).

2.0 JWC TRANSMISSION SYSTEM

The JWC transmission system consists of approximately 120,000 linear feet (LF) of large diameter concrete cylinder pipe, 30,000 lf of welded steel pipe and approximately 4,000 lf of ductile iron pipe. Pipe diameters range from 18-inch to 72-inch. Refer to Table 1 for greater detail. The pipelines begin at the WTP and move water northward and eastward to the retailer systems, as shown in Figure 1.

Table 1	JWC Transmission Pipelines - Material and Length per Liquefaction Zone Seismic Hazard Mitigation Study Joint Water Commission				
Pipeline Reference	**Material (1)**	**Total Length (LF)**	**Length Zone 3 (LF)**	**Length Zone 2 (LF)**	**Length Zone 0 & 1 (LF)**
South Transmission Pipe					
WTLI	CCP	43,471	10,868	10,868	21,736
WTL3	CCP	26,949	6,447	17,749	2,754
Subtotal		70,421	17,314	28,617	24,490
Forest Grove-Hillsboro Line					
WTL2	CCP	8,027	8,027	0	0
North-South Intertie					
WTL4	WSP	18,300	3,275	2,697	12,328
North Transmission Pipe					
WTL5	WSP	25,327	10,253	14,500	575
WTR57	WSP	1,587		0	1,587
WTL6	WSP	15,995	722	4,162	11,111
WTL7	WSP	16,800	11,154	4,636	1,010
WTL7 DIP	DIP	3,767	3,767	0	0
Subtotal		63,475	25,896	23,298	14,282
Total		**160,223**	**54,512**	**54,612**	**51,100**

Notes:
(1) CCP - Concrete Cylinder Pipe; WSP - Welded Steel Pipe; DIP - Duchle Iron Pipe; WTC - Water Transmission Line.

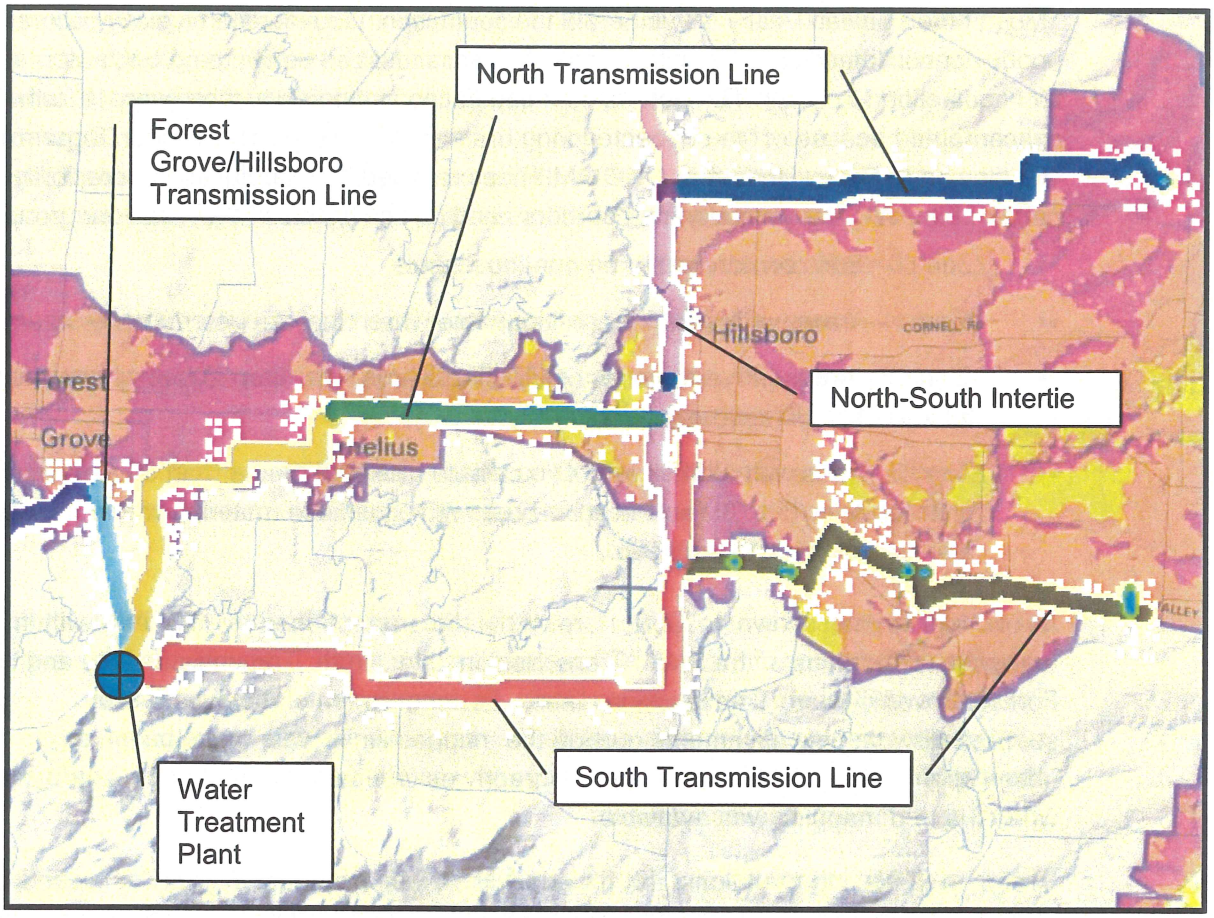

Figure 1 **JWC Transmission System Overlaid on DOGAMI Liquefaction Hazard Map**

3.0 EARTHQUAKE HAZARD

The Probable Maximum Loss in the JWC transmission pipeline system is estimated for an earthquake with an expected return period of 475 years. The most likely earthquake with the 475 yr return interval is a Cascadia Subduction Earthquake. This type of earthquake would occur at the interface between the North American and Juan de Fuca tectonic plates off the Oregon Coast. The expected rock ground motions from this event are estimated to be 19 percent times gravity, and amplified as they propagate to the ground surface (refer to TM 1). This is a measure of both wave propagation and shaking intensity that would have an impact on the pipe. This analysis uses the parameter Peak Ground Velocity (PGV) as a measure of earthquake intensity. Considering the rock ground motion and the overlying soils, a PGV of approximately 15 inches/second is expected for the 475-year return earthquake. Ground shaking from this event is expected to last for several minutes.

Much of the Tualatin Valley is vulnerable to liquefaction. Liquefaction typically occurs in poorly consolidated sands or silty sands. The soils must be below the groundwater table for liquefaction to occur. The potential for liquefaction in the subduction event is further exacerbated because of the expected long duration of shaking. The Oregon Department of Geology and Mineral Industries (DOGAMI) has mapped the liquefaction susceptibility of parts of the JWC transmission line corridors and has categorized them into four groups:

- Zone 0 - Soils considered to be non- liquefiable;
- Zone 1 - Areas with soils that are liquefiable when they are intermittently saturated;
- Zone 2 - Areas with a thickness of liquefiable soils less than 20 feet where the water table is 15 to 30 feet deep; and
- Zone 3 - Areas with a thickness of liquefiable material greater than 30 feet where the water table is 15 to 30 feet deep or areas with liquefiable material where the water table is less than 15 feet deep.

All of the pipe lines shown in Table 1 are within the area mapped by DOGAMI with the exception for portions of the South Transmission Line, North Transmission Line and the Forest Grove/Hillsboro Transmission Lines. An assessment of the liquefaction susceptibility of these alignments outside the mapped limits was made based on observation and interpretation of the topography as compared to that of the nearby area where hazard mapping was available.

Based on these interpretations, for this analysis, it was assumed the WTP is located in an area similar to Zone 3. Using information developed for the JWC WTP site, it is assumed that approximately 12 inches of settlement may occur in Zone 3 (see TM 1). The 12 inches of settlement is a maximum calculated number. The fragilities have been developed assuming a maximum settlement/displacement, with differential displacements occurring within the area. As Zone 2 has a significantly thinner layer of liquefiable material, 6 inches of settlement is assumed. No settlement is assumed for Zone 1. Minimal lateral spreading is expected in the soils along the pipeline corridors due to its high silt content.

4.0 PIPELINE LOSS ESTIMATION

The methodology documented in the ALA *Formulations for Water Systems* (ALA, 2001) is used for this analysis. The expected number of repairs per 1,000 LF of pipe are calculated as described below. Expected damage to pipelines due to seismic forces is attributed to either wave propagation or permanent ground deformation (PGD). The expected damage is estimated differently for each. The methodology used to estimate pipeline damage due to wave propagation is applied to areas not subject to liquefaction (Zones 0 and 1). The methodology to estimate pipeline damage due to PGD due to liquefaction is applied to pipe in Liquefaction Zones 2 and 3.

4.1 Wave Propagation (applied to pipe in Zones 0 and 1)

The ALA equation to calculate estimated repair rate for wave propagation is:

Repair Rate = K1 x 0.00187 x PGV

Where:

Repair Rate = estimated repairs required per 1,000 LF of pipe

K1 = correction factor taking into account the type of pipe.

- Concrete cylinder Pipe (CCP) - 0.8
- Welded Steel Pipe with Welded Joints (WSP) - 0.15
- Ductile Iron Pipe (DIP) – 0.014

PGV (inches/sec) = Peak Ground Velocity, 15 in/sec for the 475-year return earthquake.

The resulting repair rates per 1,000 LF of pipe are:

- CCP – 0.022
- WSP – 0.004
- DIP - 0 0.014

4.2 Permanent Ground Deformation (applied to pipe in Zones 2 and 3)

The ALA equation to calculate estimated repair rate for PGD is:

Repair Rate = K2 x 1.06 x $PGD^{0.319}$

Where:

Repair Rate = repairs required per 1,000 feet of pipe

K2 = correction factor taking into account the type of pipe.

- For CCP K2 = 0.7
- DIP = 0.5

PGD (inches) = Permanent ground deformation. The PGD is taken as the amount of expected settlement for each zone.

- Zone 3 - PGD = 12 inches
- Zone 2 - PGD = 6 inches

The resulting repair rates for Zones 3 and 2 for CCP and DIP are shown in Table 2.

Table 2	Repairs Rates/1,000 feet of Pipe for PGD Seismic Hazard Mitigation Study Joint Water Commission	
Pipe Material	**12-inch Settlement**	**6-inch Settlement**
CCP	1.64	1.31
WSP	0.35	0.28
DIP	1.17	0.94

5.0 FINDINGS

Using the ALA methodology and the hazard parameters for the 475-year return event, an estimated 100 repairs are expected to be required in the JWC transmission system. This amounts to approximately 3.3 repairs per mile of pipe. Of the 100 expected repairs, 99 are due to liquefaction-induced PGD and only one repair is due to wave propagation. The 100 repairs are expected to be an upper bound. ALA discusses the extent of failure suggesting that for failures resulting from PGD, approximately 80 percent will be breaks, and 20 percent will be leaks. A break is defined as a loss of hydraulic continuity. In other words, the pipe may still be functional with a leak, but would not be functional following a break. A summary of the findings is provided in Table 3.

Table 3	JWC Transmission Pipelines - Probable Maximum Pipeline Repairs Seismic Hazard Mitigation Study Joint Water Commission				
Pipeline Reference	**Material**	**Zone 3 Repairs PGD)**	**Zone 2 Repairs (PGD)**	**Zones 0 & 1 Repairs (Wave Propagation)**	**Total Repairs**
South Transmission Pipe					
WTLI	CCP	17.82	14.28	0.49	32.59
WTL3	CCP	10.57	23.32	0.06	33.95
Subtotal		28	38	0.55	66.54
Forest Grove-Hillsboro Line					
WTL2	CCP	13.16	0.00	0.00	13.16
North-South Intertie					
WTL4	WSP	1.15	0.76	0.05	1.95
North Transmission Pipe					
WTL5	WSP	3.59	4.06	0.00	7.65
WTR57	WSP	0.00	0	0.01	0.01
WTL6	WSP	0.25	1.17	0.05	1.47
WTL7	WSP	3.90	1.31	0.00	5.21
WTL7 DIP	DIP	4.41	0.00	0.00	4.41
Subtotal		12	7	**0.06**	**18.75**
Total		**55**	**45**	**0.66**	**100.41**

Notes:
(1) CCP - Concrete Cylinder Pipe; WSP - Welded Steel Pipe; DIP - Duchle Iron Pipe; WTC - Water Transmission Line.

However, fewer repairs will probably be realized than the upper bound estimate of 100 for three reasons. First, the GIS analysis assumes that the entire Zone is going to undergo settlement. Even though extensive liquefaction is expected in a subduction earthquake due to the long duration of strong ground shaking (2 - 3 minutes), there is some variation in the underlying soils. As a result, settlement is not expected to occur everywhere, and not all of the pipe in any given zone would be exposed to liquefaction-induced settlement.

Second, the ALA empirical database used for developing the pipeline damage relationships includes data primarily for damage due to lateral spreading, and not just settlement. Pipeline failures in liquefiable soils are primarily caused by movement of large blocks of ground moving laterally. Cracks occur between these blocks resulting in extensive damage to the pipe. In the JWC system, the PGD should be limited to settlement, with minimal lateral spreading due to the high fines content in the soils. This assumption is based on the assessment of the soils at the JWC WTP site. Vertical shear cracking is expected to have less of an impact on the pipe than the shear cracking that occurs when lateral spreading takes place. As a result, as few as half as many repairs are expected in the JWC system than are estimated using the ALA methodology.

Third, the distribution ratio of breaks to leaks would be expected to be closer to 50% breaks to 50% leaks, rather than the 80% breaks to 20% leaks suggested by the ALA methodology. This is due to the less severe PGD environment as described in the previous paragraph.

Therefore, the expected result is an estimated need for 50 pipeline repairs, of which 25 would be breaks and 25 would be leaks.

6.0 RESTORATION

In discussions with JWC personnel, it was estimated that it would take 4 days to repair one break, and that 4 repair crews would be available following the earthquake selected for this analysis. There would be an initial 7-day lag at the beginning of the period to inventory damage and to manufacture and transport the first set of repair materials to the site. Using these data, it is expected that breaks on the western half of the system would be repaired within 21 days, and the remaining breaks repaired in an additional 11 days. After these repairs restore hydraulic continuity in the system, it is assumed repair of leaks would follow.

7.0 COST OF REPAIR

It is estimated that it will cost approximately $20,000 to repair a pipeline break considering 4 crews days and repair materials. Leaks would be expected to cost approximately half as much, or $10,000. These estimates are based on the cost of repairing a 42-inch diameter pipe. The total cost of repair 25 breaks and 25 leaks is estimated to be $750,000, including direct and overhead costs.

8.0 CONCLUSIONS & RECOMENDATIONS

The findings indicate it would take an estimated 32 days to repair all pipeline breaks in the JWC transmission system. It is assumed that initially, no water could be moved from the

WTP to the JWC member systems, and that as repairs progressed, service would be restored pipe segment by pipe segment over that 32-day period.

The JWC is considering actions to improve the level of service of the WTP following an earthquake. The levels of service being considered for the WTP require the system to be operable much more quickly than the 32 days of transmission system outage estimated herein. To meet the proposed level of service goals, the transmission system will have to be improved.

This analysis was performed to provide an estimate of probable maximum losses for assessing insurance coverage, and was not performed at the same level of detail as was provided for the WTP evaluation. A similar estimate could be developed for other earthquakes, and in greater depth, to gain an understanding of which pipelines are the most vulnerable, and where, and to develop mitigation methods to speed restoration.

To reduce the number of pipeline repairs and the time associated to restore service following an earthquake a number of actions could be taken. First, the most vulnerable pipeline segments could be improved by improving soil conditions or strengthening the pipe. System redundancy could be improved by installing new pipelines In addition, disaster recovery times could be reduced through emergency planning and/or stockpiling repair materials.

8.1 Transmission System and LOS Goals

To analyze the JWC transmission system to the same level of detail as the WTP, an analysis, would be required for each pipeline and the pipeline corridor including the geotechnical parameters. This level of analysis would allow LOS for the transmission system to be determined. The type of information that would be needed includes:

Pipeline

- Diameter
- Pipe material parameters – WSP, CCP
- Wall thickness (for steel)
- Can and reinforcing detail (CCP)
- Joint type – gasketed, welded, welded joint design
- Bend design and locations
- Appurtenance design and locations
- Hard points – interaction with other structures
- Condition

Geotechnical

- Topography
- Soil column parameters
- Water table depth
- Liquefaction susceptibility of each layer
- Susceptibility to lateral spreading, and estimated extent

This information could then be analyzed to identify locations where joint separation would likely occur (gasketed bell & spigot joints), or pipe stresses would likely exceed the capacity of the pipe (welded joint, continuous pipe). Once these deficiencies are identified, mitigation measures can be undertaken to improve pipe performance such as:

- Geotechnically stabilize the pipeline alignment
- Line the pipe with a more flexible material (e.g. polyethylene)
- Modify the pipe by strengthening it or adding flexibility
- Replace the pipe

8.2 System Redundancy

System redundancy could be improved by paralleling existing lines and/or otherwise enhancing the ability of the system to move water around existing vulnerable pipelines. Construction of new pipelines is expensive, so pursuit of this approach would likely be done in conjunction with projects designed to increase system capacity.

8.3 Disaster Recovery

Outage time of the transmission system could be enhanced by developing a restoration plan, making modifications to the transmission system that may enhance recovery, and by stock piling materials that are not expected to be immediately available following an event.

A restoration plan would be developed by studying several scenarios to understand recovery requirements and limitations that impede restoration. Once these elements are identified, the JWC could then move to mitigate the problems through planning.

Hardware improvements that may enhance recovery include evaluation and possible installation of additional valves to improve JWC capabilities to isolate segments of line. Related to this would be the addition of facilities to allow quick draining of lines. If there are any highly vulnerable segments of line, it may be appropriate to install hard connections on either side to allow for quick installation of bypasses using large diameter hoses.

It is likely that repair sections of large diameter pipe will be difficult to acquire following a major earthquake event. Developing a stockpile of pipe and repair clamps for the larger diameter pipe may allow for quicker restoration.