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TECHNICAL MEMORANDUM

Water Distribution System Seismic Hazard Analysis
County of Mendocino: Redwood Valley County Water District

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Redwood Complex Fire Recovery Effort in Redwood Valley, California

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1.0 INTRODUCTION

This memorandum presents the results of a seismic hazard analysis (SHA) for the Redwood Valley County Water District (RVCWD) water distribution system (WDS). Two earthquake scenarios were evaluated to support the cost-benefit calculations associated with replacing the WDS. Earthquake characteristics for each scenario are described in Table 1.

Table 1. Design Earthquake Characteristics and Results

Design Earthquake Characteristic	Scenario 1	Scenario 2
Fault	Maacama – Garberville	San Andreas North
Magnitude (Richter scale)	7.3	6.7
Distance from RVCWD WDS (miles)	2.8	31
Peak Ground Acceleration (g*)	1.12	1.06
Recurrence Interval (years)	475	120

* g = the acceleration of gravity (32.147 feet per second squared)

Scenario 1 utilizes a design earthquake model using the USGS web application (USGS, 2018) and is based on guidelines from *Seismic Guidelines for Water Pipelines* by American Lifeline Alliance (ALA, 2005); a public-private partnership between the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). Scenario 2 is based on a historic earthquake event on the North San Andreas Fault. Pipeline damage was estimated using the methodology presented by Isoyama and others (2000).

Pipeline materials were assumed to consist of 4-inch ductile cast-iron pipe (DIP) and/or 4-inch polyvinyl chloride pipe (PVC).

2.0 METHODS AND RESULTS

Damage to the water distribution system was estimated using modeled peak ground accelerations (PGAs) and factors based on pipe material, pipe diameter, and subsurface conditions.

Pipeline damage for both scenarios was estimated using Equation 1 (modified from Isoyama and others, 2000):

$$R = C_p C_d C_g [1.698 \times 10^{-16} \alpha^{6.06}] \left[\frac{1 \text{ mile}}{0.62137 \text{ kilometers}}\right] \quad \text{(Equation 1)}$$

where R = damage rate (failures per mile)
C_p = weight based on pipe material
C_d = weight based on pipe diameter
C_g = weight based on topography
α = peak ground acceleration (centimeters per second)

Equation 1 is based on multivariate regression analysis correlating damage rate to PGA, pipe material, pipe length, and topography (Isoyama, 2000). The multivariate regression analysis utilized data from the 1971 San Fernando Earthquake (California), the 1923 Kanto Earthquake (Japan), the 1978 Tokyo Earthquake (Japan), and the 1995 Hyogoken-nanbu Earthquake (Japan). C_g values for terrace and alluvial topography of 1.5 and 1, respectively, were used to develop a confidence interval for the RVCWD WDS because the region includes both terrace and alluvial topography (LACO, 2017). Coefficients used in the analysis are provided in Table 2.

Table 2. Pipeline Damage Estimation Coefficients

Coefficient / Pipe Material:	DIP	PVC
C_p	0.5	1
C_d	1	1
$C_{g\_alluvium}$	1	1
$C_{g\_terrace}$	1.5	1.5

2.1 Scenario 1 – Maacama – Garberville Design Earthquake

Scenario 1 utilizes a design earthquake based on a 7.3-magnitude Maacama – Garberville fault event with an epicenter 2.8 miles from the RVCWD WDS. An earthquake hazard return period of 475 years (10 percent probability of exceedance in 50 years) for Pipe Function Class II (normal and ordinary pipeline use, common pipelines in most water systems) was selected based on the guidelines from the *Seismic Guidelines for Water Pipelines* document (ALA, 2005). The *Seismic Guidelines for Water Pipelines* document prescribes the use of a USGS web-based Probabilistic Seismic Hazard Analysis (PSHA) tool to develop design earthquake characteristics. PGAs were modeled using the USGS web-based PSHA tool and assuming a Site Soil Class of B to C (USGS, 2018).

Earthquake data inputs included:

- Seismic Earthquake Database Edition: Dynamic Conterminous U.S. 2008 (v3.3.1);
- Time horizon of 475 years;
- Site Class of B/C Boundary: 760 m/s shear wave velocity in upper 100 feet. This assumption is based on our understanding of subsurface conditions that primarily consist of cemented alluvial deposits (known as the Continental Basin Deposits) (LACO, 2017); and
- Latitude and Longitude: 39.265185° N, 123.20412° W.

Hazard curves and uniform hazard response spectrum results from the USGS web-based PSHA tool are provided in Exhibit 1.

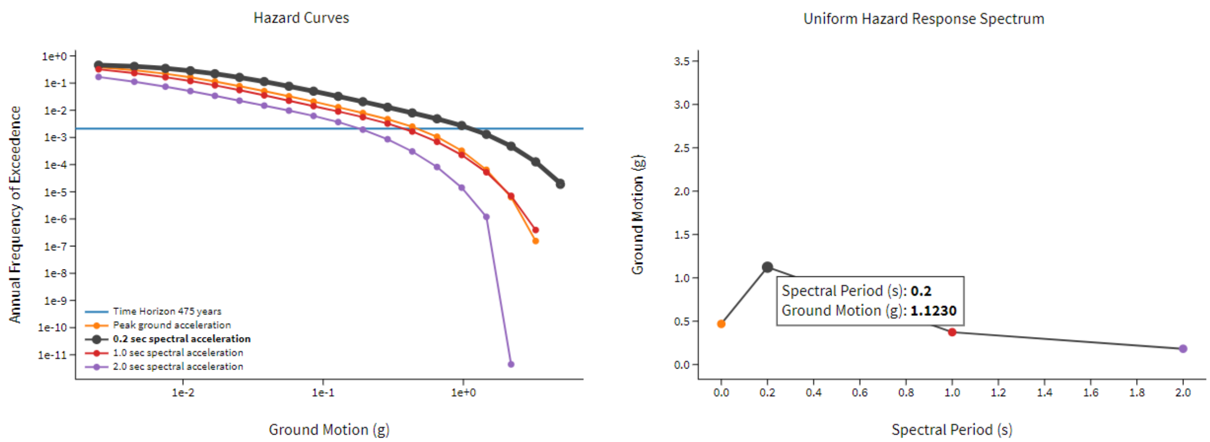

Exhibit 1. RVCWD WDS Hazard Curves and Uniform Hazard Response Spectrum

The USGS deaggregation tool (a subcomponent of the PSHA tool) was used to define a design earthquake with a peak ground acceleration of 1.12 times the acceleration of gravity at 0.2 seconds and a characteristic magnitude of 7.3 at a modal hypocentral distance of 2.8 miles from the center of the RVCWD WDS. The Maacama – Garberville fault was the primary contributor at location 38.864° N, 123.001° W. Table 3 describes the results of the analysis with respect to pipe damage and interval.

Table 3. Pipe Damage Results from Analysis

Pipe Characteristics	Pipe Damage (breaks per mile)	Pipe Damage Frequency (feet)
DIP Pipe in Terrace Topography	549	10
DIP Pipe in Alluvial Topography	366	14
PVC Pipe in Terrace Topography	1,098	5
PVC Pipe in Alluvial Topography	732	7

Based on the results of Scenario 1, the RVCWD WDS pipeline will break every 5 to 14 feet of lineal pipe length during a seismic event with a recurrence interval of 10 percent in 50 years. This is considered a complete failure of the RVCWD WDS. Changing the Site Class from the B/C boundary to Site Class D generated a decrease in PGA of 7 percent. This decrease in PGA generated pipe damage interval results ranging from 7 to 22 feet.

2.2 Scenario 2 – Historical San Andreas North Design Earthquake

Scenario 2 utilizes a design earthquake based on the 6.7-magnitude 1989 San Andreas North earthquake with an epicenter 31 miles from the RVCWD WDS (USGS, 2002). The peak ground acceleration from the Scenario 2 earthquake at the RVCWD WDS was estimated to be 1.06 times the acceleration of gravity based on the Attenuation Law (Equation 1) (Trombetti et al., 2004). Table 4 describes the results of the analysis with respect to pipe damage and interval.

$$\log A = -1.845 + 0.636MS - \log(R^2 + 5^2)^{1/2} + 0.195s \qquad \text{(Equation 1)}$$

where A = the peak ground acceleration expressed in the acceleration of gravity
MS = seismic event magnitude in Richter scale
R = the distance of the site from the seismic event epicenter (kilometers)
s = a deterministic coefficient equal to 0 for bedrock and 1 for soft soil

Table 4. Pipe Damage Results from Analysis

Pipe Characteristics	Pipe Damage (breaks per mile)	Pipe Damage Frequency (feet)
DIP Pipe in Terrace Topography	393	13
DIP Pipe in Alluvial Topography	262	20
PVC Pipe in Terrace Topography	786	7
PVC Pipe in Alluvial Topography	524	10

Based on the results of Scenario 2, the RVCWD WDS pipeline will incur damage every 7 to 20 feet of lineal pipe length during a seismic event with a recurrence interval of 120 years. Changing the Site Class from the B/C boundary to Site Class D generated a decrease in PGA of 7 percent. This decrease in PGA generated pipe damage interval results ranging from 10 to 31 feet. Similarly to Scenario 1, this situation is considered to be a total WDS failure.

3.0 CONCLUSIONS

The results of the SHA analysis indicate that:

- Total WDS failure will occur during an earthquake with a recurrence interval of 120 years;
- Failures will occur every 7 to 20 feet of lineal pipeline for an earthquake with a recurrence interval of 120 years;
- Failures will occur every 5 to 14 feet of lineal pipeline for an earthquake with a recurrence interval of 475 years;
- The RVCWD WDS should be replaced with a new pipeline that is retrofitted for seismic hazards; and
- Seismic retrofitting in addition to larger pipe diameter and robust pipe material should be considered during future design.

4.0 REFERENCES

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