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GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

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August 5, 2014

Mr. David Kraska, PE
Carollo Engineers, Inc.
720 SW Washington Street, Suite 550
Portland, Oregon 97205

**RE: DRAFT SEISMIC HAZARD ASSESSMENT FOR CRITICAL
INFRASTRUCTURE
TUALATIN VALLEY WATER DISTRICT WATER MASTER PLAN AND
WATER MANAGEMENT AND CONSERVATION PLAN UPDATE
WASHINGTON COUNTY, OREGON**

Dear Mr. Kraska:

This letter report presents the results of our geotechnical seismic hazard assessment of the Tualatin Valley Water District (TVWD) service area for use in assessing the vulnerability of TVWD's for critical infrastructure in Washington County, Oregon. The location of the TVWD service district is shown on Figure 1, Vicinity Map, and the infrastructure within the service area is shown on Figure 2, TVWD Service Area Map. The assessment was performed utilizing Geographic Information System (GIS) data and is based on the magnitude 9.0 Cascadia Subduction Zone (CSZ) scenario defined in the Oregon Resilience Plan (OSSPAC, 2013). Our services are being performed under Task Order No. 1 and an Agreement for Professional Services between Carollo Engineers, Inc., and Shannon & Wilson, Inc. (S&W), dated June 27, 2014.

SCOPE OF SERVICES

The purposes of the Carollo team's seismic hazard assessment are to assess the existing system with respect to the levels of service stated in the Oregon Resilience Plan and develop recommended mitigation measures to address deficiencies. Shannon & Wilson's task is to prepare and provide GIS maps of peak ground velocity, probability of liquefaction, probability of earthquake-induced landslides, and liquefaction- and landslide-induced permanent ground displacements. To achieve these purposes, our scope of services included:

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24-1-03887-001

- Review of Existing Geologic Information
- Perform Limited Field Reconnaissance
- Develop Seismic Ground Motion and Permanent Ground Deformation Hazard Maps in GIS format
- Summarize the Maps for the Seismic Hazard Assessment in a Technical Memorandum

EXISTING INFORMATION REVIEW

Regional Seismological Setting

Earthquakes in the Pacific Northwest occur largely as a result of the subduction of the Juan de Fuca plate beneath the North American plate along the Cascadia Subduction Zone (CSZ). The CSZ is located approximately parallel to the coastline from northern California to southern British Columbia. The compressional forces that exist between these two colliding plates cause the oceanic Juan de Fuca plate to descend, or subduct, beneath the continental plate at a rate of about 1.5 inches per year. This process leads to volcanism in the North American plate and stresses and faulting in both plates throughout much of the western regions of southern British Columbia, Washington, Oregon, and northern California. Stress between the colliding plates is periodically relieved through great or giant earthquakes at the CSZ plate interface.

Within the regional tectonic framework and historical seismicity, three broad earthquake sources are identified.

- **Subduction Zone Interface Earthquakes** originate along the CSZ, which is located 25 miles beneath the coastline. Paleoseismic evidence and historic tsunami records from Japan indicate that the most recent subduction zone interface event was in the 1700 AD and was an approximately magnitude 9 earthquake that likely ruptured the full length of the CSZ.
- **Deep-Focus, Intraplate Earthquakes** originate from within the subducting Juan de Fuca oceanic plate as a result of the downward bending and tension in the subducted plate. These earthquakes typically occur 28 to 38 miles beneath the surface. Such events could be as large as Magnitude 7.5. Historic earthquake include the 1949 magnitude 7.1 Olympia earthquake, the 1965 magnitude 6.5 earthquake between Tacoma and Seattle, and the magnitude 6.8 2001 Nisqually earthquake. The highest rates of CSZ intraslab activity is beneath the Puget Sound area with much lower rates observed beneath western Oregon.

- **Shallow-Focus Crustal Earthquakes** are typically located within the upper 12 miles of the earth's surface. The relative plate movements along the CSZ causes not only east-west compressive strain but dextral shear, clockwise rotation, and north-south compression of the leading edge of the North American Plate (Wells and others, 1998), which is the cause of much of the shallow crustal seismicity of engineering significance in region. The largest known crustal earthquake in the Pacific Northwest is the 1872 North Cascades earthquake with an estimated magnitude of about 7. Other examples include the 1993 magnitude 5.6 Scotts Mill earthquake and magnitude 6 Klamath Falls earthquake.

Oregon Resilience Plan

The Oregon Resilience Plan is a result of Oregon House Resolution 3, adopted in April, 2011. The House Resolution directed the Oregon Seismic Safety Policy Advisory Commission “to lead and coordinate preparation of an Oregon Resilience Plan that reviews policy options, summarizes relevant reports and studies by state agencies, and makes recommendations on policy direction to protect lives and keep commerce flowing during and after a Cascadia earthquake and tsunami” (OSSPAC, 2013). A task group then developed a Cascadia Earthquake Scenario for use by other work groups as a basis for assessing the effects of the scenario on various sectors of society or parts of the built environment.

This assessment is for a magnitude 9.0 CSZ earthquake, as defined in the Oregon Resilience Plan. Other magnitudes of CSZ events and earthquakes from other sources are not considered.

Regional Geology

The Tualatin Valley is an approximately 25-mile-long by 13-mile-wide, northwest trending elliptical plain. It is a sub-basin adjoining the northwest end of the much larger Willamette Valley physiographic province (Orr and Orr, 1992). Like the Willamette Valley, the Tualatin Valley is a structural depression created by complex folding and faulting of the basement rocks (Schlicker and Deacon, 1967). The basement, or floor, of the basin is made up of a sequence of lava flows known as the Columbia River Basalt Group (CRBG) which flowed into the area in the middle Miocene epoch, between about 17 and 6 million years ago.

The Tualatin Valley has been partially filled with sedimentary deposits consisting of clay, silt, sand, and gravel. Pre-Quaternary sediments, deposited in the basin more than 1.8 million years ago, were mapped by Trimble (1963) as “Troutdale Formation and Sandy River Mudstone

Equivalent.” Schlicker and Deacon (1967) differentiated some of the lowermost basin fill units as the Helvetia Formation. Madin (1990) felt that these fine-grained deposits had more characteristics in common with the Sandy River Mudstone than with the Troutdale Formation and therefore retained the term Sandy River Mudstone Equivalent.

Between about 1.5 million and 125 thousand years ago, dozens of volcanoes erupted around the Portland area, each for relatively brief periods of time. They are collectively named the Boring volcanic field, after the town of Boring, Oregon. The volcanoes issued cinder cones as well as basalt and basaltic andesite lava flows, which are commonly referred to as Boring Lavas (Ma and others, 2012). Since their origin, the Boring Lavas have deeply weathered within the upper 15 feet and along joints and fractures (Schlicker and Deacon, 1967). At elevations above about 400 feet, the Boring Lavas are often mantled by variable thicknesses of loess, or wind-blown sediment. The loess was likely deposited by easterly winds late in the Pleistocene epoch (about 18 to 10 thousand years ago).

During the late stages of the last great ice age, between about 18,000 and 15,000 years ago, a lobe of the continental ice sheet repeatedly blocked and dammed the Clark Fork River in western Montana, which then formed an immense glacial lake called Lake Missoula. The lake grew until its depth was sufficient to buoyantly lift and rupture the ice dam, which allowed the entire massive lake to empty catastrophically. Once the lake had emptied, the ice sheet again gradually dammed the Clark Fork Valley and the lake refilled, leading to 40 or more repetitive outburst floods at intervals of decades (Allen and others, 2009). These repeated floods are collectively referred to as the Missoula Floods. During each short-lived Missoula Flood episode, floodwaters washed across the Idaho panhandle, through eastern Washington’s scablands, and through the Columbia River Gorge. When the floodwater emerged from the western end of the gorge, it spread out over the Portland Basin and pooled to elevations of about 400 feet, depositing a tremendous load of sediment. Boulders, cobbles, and gravel were deposited nearest the mouth of the gorge and along the main channel of the Columbia River. Cobble-gravel bars reached westward across the basin, grading to thick blankets of micaceous sand and silt (Allen and others, 2009). Ma and others (2012) divided the Missoula Flood Deposits into four groups:

- Silt Colluvium consisting of sand and silt colluvium, generally along stream channels
- Fine-Grained Deposits consisting of sand and silt
- Coarse-Grained Deposits consisting mostly of gravel with cobbles and boulders
- Channel Deposits consisting of interlayered and variable silt, sand, and gravel

Available Mapping

The Oregon Department of Geology and Mineral Industries (DOGAMI) developed a publication based on the Oregon Resilience Plan CSZ scenario for the state of Oregon. The publication, open-file report O-13-06, primarily consists of GIS data of site conditions, ground motions, ground deformations, and other hazards associated with a magnitude 9.0 event on the CSZ (Madin and Burns, 2013). Datasets of interest for this project include:

- Shear Wave Velocity within 30 meters of the Ground Surface (V_{s30})
- Bedrock and Site Peak Ground Acceleration (PGA)
- Bedrock and Site 1-second Spectral Acceleration (SA_1)
- Bedrock and Site Peak Ground Velocity (PGV)
- Liquefaction Susceptibility, Probability, and Permanent Ground Displacement (PGD)
- Earthquake-Induced Landslide Susceptibility, Probability, and PGD

The provided methodology indicates that, within the TVWD service area, the majority of these datasets were derived based on the Relative Earthquake Hazard Map of the Portland Metro Region (IMS-1; Mabey and others, 1997), the Oregon Geologic Data Compilation Release 5 (OGDC-5; Ma and others, 2009), the Statewide Landslide Information Database for Oregon Release 2 (SLIDO-2; Burns and others, 2011). The bedrock ground motions included in the publication were provided to DOGAMI by the U. S. Geological Survey (USGS) and are based on the USGS Cascadia M 9.0 scenario ShakeMap®.

Following the publication of O-13-06, DOGAMI published 3D geology and shear wave velocity models for the area (Roe and Madin, 2013) and Release 3 of the Statewide Landslide Information Database for Oregon (SLIDO-3; Burns and Watzig, 2014). The 3D geology and shear wave velocity models are based on the LiDAR-based surficial geologic map of the Greater Portland Area (Ma and others, 2012), which is shown in Figure 3. These recent publications have not yet been incorporated into DOGAMI's CSZ scenario datasets.

SITE RECONNAISSANCE

Based upon the preliminary review of the hazard maps developed for this project, Shannon & Wilson performed a site reconnaissance on July 15, 2014, for selected TVWD facility sites. These facilities were selected for the site reconnaissance because the hazard maps indicated that the facilities were located on or near relatively steep slopes or mapped landslides. The purpose of the site reconnaissance is to observe the site conditions with respect to the hazard maps. We performed the site reconnaissance for six sites including: Rosander reservoir and future pump

station, the Sunset reservoir and pump station, the Somerset reservoir, the North Road reservoir, the Bonny Slope reservoirs and pump station, and the Thompson Road reservoir and pump station. Our field observations made during the site reconnaissance are consistent with the slope sliding hazards shown on the hazard maps. Photographs of selected sites are included in Attachment A.

SEISMIC HAZARD MAPS

The purpose of the maps are to delineate the ground shaking and permanent ground displacement hazard across the service area based on a magnitude 9.0 CSZ earthquake. Ground shaking hazard is delineated in terms of:

- Peak ground acceleration (PGA)
- 1-second spectral acceleration (SA1)
- Peak ground velocity (PGV)

Permanent ground displacement (PGD) hazard is delineated by:

- Probability of liquefaction
- Liquefaction-induced lateral spread PGD
- Liquefaction-induced settlement PGD
- Probability of earthquake-induced sliding
- Landslide-induced PGD

These maps were either taken directly from the published DOGAMI O-13-06 magnitude 9.0 CSZ scenario maps or were derived using the same approach as the DOGAMI maps but using more recently published geologic information. For the hazard maps incorporating the more recently published geologic information, we provide maps of the updated information (i.e., most recent geologic map in Figure 3) and maps developed as intermediate steps (i.e., Figure 4, Liquefaction Hazard, and Figure 5, Landslide Susceptibility) in deriving the final hazard maps. Modifications to the O-13-06 methodology are summarized below.

Shear Wave Velocity, V_{s30}

We generally used the *Vs30_3D_final* raster from O-13-12 as input for calculations requiring V_{s30} . However, where the model was modified to include Site Class F material (where Artificial Fill and Landslide Deposits were mapped in O-12-02 and SLIDO-2), we replaced the values with those in the *Vs30_3D_raw* raster. We then replaced values with shear wave velocities greater

than 982 m/s with a value of 982 m/s, consistent with O-13-12. In our opinion, the mapped fill and landslide deposits within the TVWD service district do not meet the criteria of Site Class F material, as defined in the Hazus® -MH 2.0 Technical Manual (FEMA, 2011).

Liquefaction Hazard

The liquefaction susceptibility map in O-13-06 for the TVWD service district is based on the relative liquefaction hazard map included in IMS-1. The notes on IMS-1 indicate that the thickness of liquefiable material and the depth to groundwater were incorporated into the liquefaction hazard categories. Therefore, we used the O-13-06 map as a base for our map rather than assigning relative susceptibilities based solely on geologic unit. However, comparison of the O-13-06 map with the recent geologic map and the LiDAR for the area indicated that there were areas of alluvial deposits and colluvium along stream channels that were mapped as having no liquefaction hazard. We incorporated the areas mapped as Alluvium of Lowland Streams, Alluvium of Minor Streams, and Missoula Floods Silt Colluvium into the O-13-06 map as areas of high hazard for our liquefaction maps. The resulting map is shown on Figure 4.

Landslide Susceptibility

We generally followed the methodology and Geologic Group assignments as described in O-13-06, using the more recent O-12-02 geologic map units with SLIDO-3 landslide mapping as the base map. We assigned Geologic Group C (relatively weak material) to areas mapped as “volcanic rocks with loess” because the unit descriptions indicate that there may be several meters of loess overlying the rock. It appears that all areas categorized as “volcanic rocks” were assigned to the relatively stronger category, Group B, in the O-13-06 maps. We calculated a slope map from LiDAR data of the area to complete the landslide susceptibility map because DOGAMI’s slope map was not included in O-13-06. The landslide susceptibility map is shown on Figure 5.

PGA, SA₁, and PGV

The site amplification factors in O-13-06 were calculated based on the statewide Site Class map provided with the publication and a single V_{s30} was assumed for each Site Class due to the lack of 3-dimensional shear wave velocity mapping of the entire state. We calculated the PGA and SA₁ site amplification factors for the TVWD service district from the V_{s30} raster described above using the approach referenced in O-13-06 (Boore and Atkinson, 2008) and applied them to the provided bedrock PGA and SA₁ maps to produce PGA, SA₁, and PGV maps modified for Site

Class. Maps of Peak Ground Acceleration, 1-Second Spectral Acceleration (SA_1), and Peak Ground Velocity are shown on Figures 6, 7, and 8, respectively.

Probability of Liquefaction

We used the refined liquefaction hazard map described above and followed the methods presented in O-13-06 to develop a map of liquefaction probability. The resulting map is shown on Figure 9.

Liquefaction-Induced PGD

Lateral Spreading

We used the refined liquefaction hazard map described above and followed the methods presented in O-13-06 to calculate permanent ground deformations from liquefaction-induced lateral spreading. The map of estimated PGD due to lateral spreading is included on Figure 10.

Settlement

DOGAMI did not include a map of predicted ground settlement associated with liquefaction in O-13-06. We calculated estimated liquefaction-induced settlements following the methodology in Chapter 4 of the Hazus® -MH 2.0 Technical Manual (FEMA, 2011) using the refined liquefaction hazard map discussed above. The FEMA method associates each susceptibility category with a unique settlement amplitude value. Each of the values is assumed to have an uncertainty with a uniform probability distribution from one-half to two times the respective value. The map of estimated PGD due to liquefaction-induced settlement is included on Figure 11.

Probability of Earthquake-Induced Landslides

We used the refined landslide susceptibility and PGA maps described above and followed the methods presented in O-13-06 to calculate and map probability of earthquake-induced landslides, shown on Figure 12.

Earthquake-Induced Landslide PGD

The earthquake-induced landslide PGD map is based on the methodology in Hazus® -MH 2.0 Technical Manual (FEMA, 2011), which is referenced in O-13-06. We retained the acceleration term that DOGAMI chose to remove from FEMA equation 4-25 because the acceleration is in

“decimal fraction of g’s”, not cm/sec^2 , as DOGAMI indicated. Additionally, the equation given for the displacement factor did not produce a curve similar to the FEMA Figure 4.14 relationship; therefore, we based our calculations on relationships that we believe provide a better fit to the upper bound curve for ratios of critical acceleration to induced acceleration. One relationship was used for ratios of 0.6 or less and a different relationship was used for ratios between 0.6 and 0.9. Our map of estimated earthquake-induced landslide permanent ground deformations based on the FEMA methodology is shown on Figure 13.

SEISMIC HAZARD ASSESSMENT

Earthquake-induced geologic hazards include liquefaction and associated effects (e.g., lateral spreading, settlement), slope instability/landslide, and ground surface fault rupture. We have used published geologic maps and the hazard maps described above to assess the potential for these hazards in the service area. No site specific analyses were performed.

Liquefaction

Soils susceptible to liquefaction are loose, saturated, cohesionless soils. Liquefaction occurs when these soils are subjected to strong ground shaking that cause the pore water pressure in the soil to approach the effective overburden pressure, resulting in a dramatic loss of soil shear strength and a quick-sand like condition. Soils that undergo liquefaction may undergo permanent lateral displacement (e.g., lateral spreading or flow failure) and settlement. Such movement may strain infrastructure (e.g., pipelines, wells, cables) buried within or in overlying soils. Liquefaction may also result in bearing capacity failure of structures founded on or above these soils.

As discussed above, the liquefaction hazard map shown in Figure 4 incorporates assumptions on depth to groundwater, reducing or eliminating the mapped hazard where the liquefaction-susceptible sediments are not anticipated to be saturated. Based on our experience, zones of perched groundwater are often present during the wet winter months within some fine-grained sediments, such as loess and fine-grained Missoula flood deposits. In our opinion, the risk of “wide spread” liquefaction in areas of perched groundwater is low; however, site-specific liquefaction analyses and groundwater monitoring may be warranted for sensitive facilities.

The probability of liquefaction map shown in Figure 9 was developed using the methodology in the Hazus® -MH 2.0 Technical Manual (FEMA, 2011). A probability factor “quantifies the

proportion of a geologic map unit deemed susceptible to liquefaction (i.e., the likelihood of susceptible conditions existing at any given location within the unit)” (FEMA, 2011). For example, 20 percent of the map area is assumed to be susceptible to liquefaction in areas mapped with a high liquefaction hazard. The probability factor is combined with the PGA, a factor to account for duration, and a groundwater correction factor to estimate a probability of liquefaction for a given earthquake event. Based on the resulting map, none of the existing reservoirs or pump stations are located in areas with a high probability of liquefaction. As seen on Figure 9, there are large-diameter pipelines that are mapped through areas where 10 to 20 percent of the area may liquefy. The longest segment of large-diameter pipeline through a 15 to 20 percent probability zone occurs along the 42-inch diameter pipeline south of the Bethany pump station, in the vicinity of Highway 26. Higher liquefaction probabilities are often associated with stream channels.

Estimated PGDs due to lateral spreading and liquefaction-induced settlement are shown in Figures 10 and 11, respectively. Where liquefaction does occur, the GIS analysis indicates that liquefaction-induced displacements may be in the range of 12 to 24 inches of lateral spreading and 3 to 12 inches of settlement for many of the large-diameter pipeline alignments. Displacements of this magnitude may impact the 48- and 54-inch pipelines entering the district near the intersection of SW Beaverton-Hillsdale Highway and SW Scholls Ferry Road, as well as other 30- to 42-inch diameter pipelines throughout the district.

Slope Instability

Slopes subject to instability under static conditions are also susceptible to instability during earthquake ground shaking. The landslide susceptibility map in Figure 5 combines slope angle data with generalized material strength categories to rate the susceptibility of an area on a scale of 0 to 10. The material strengths were assigned assuming that the material is wet. For reference, locations of mapped existing landslides included in SLIDO-3 are also shown on Figure 5. In general, the existing landslides are in areas mapped as weak material.

The probability of earthquake-induced landslides map shown in Figure 12 combines the landslide susceptibility map with assumed critical accelerations, PGAs, and probability factors. The critical acceleration is defined as the minimum acceleration that will induce movement within a given susceptibility category. The probability factor is similar to the liquefaction probability factor and provides a percentage of map area that is assumed to fail during an event that exceeds the critical acceleration. Several reservoirs and pump stations are located in areas

with relatively high probabilities of earthquake-induced landslides, many where the GIS data indicate that 20 to 30 percent of the map area may fail. Reservoir and pump station sites that do not appear to be at a relatively high risk of earthquake-induced landslides are: Catlin Crest, Cooper Mountain, Florence Lane, Garden Home, Schell, Springville, Taylors Ferry, and Teufel. We recommend that the district complete or review site specific geotechnical explorations and slope stability evaluations for the remaining sites. Pipelines in the vicinities of the pump stations and reservoirs may also be impacted by landslides. Two pipelines that are located in areas mapped as existing landslide deposits and as a relatively high probability area are the 30-inch pipeline south of the Inglewood reservoir and pump station and the 20-inch pipeline south of the Teufel reservoir and pump station.

Permanent ground deformations due to earthquake-induced landslides, calculated as described above, are shown on Figure 13. Our calculations indicate that displacements on the order of 1 to 3 feet, with some locations up to 5 feet, can be expected in the areas with relatively high probabilities of earthquake-induced landslides.

Ground Surface Fault Rupture

This assessment and the associated hazard maps apply only to the magnitude 9.0 earthquake scenario defined in the Oregon Resilience Plan. Ground surface fault rupture associated with a CSZ event off the coast of Oregon is not a hazard within the TVWD service area. However, for reference, the Quaternary faults mapped by USGS in the vicinity of the TVWD service area are shown in Figure 14. As shown, mapped portions of the Beaverton fault zone, the Oatfield fault, and the Canby-Mollala fault are within or adjacent to the service area.

LIMITATIONS

The conclusions and recommendations contained in this letter are based on the site conditions as they reportedly exist and assume that the subsurface conditions are not significantly different from those inferred from the published maps.

This letter report is prepared for the exclusive use of the Tualatin Valley Water District Water Master Plan and Water Management and Conservation Plan Update project team. It should be made available for information of factual data only, and not as a warranty of subsurface conditions, such as those interpreted from published maps, and discussions of subsurface conditions included in this letter.

Mr. David Kraska
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Please note that our scope of services did not include any environmental assessment or evaluation regarding the presence or absence of hazardous or toxic materials in the soil, surface water, groundwater, or air, on or below the site.

Shannon & Wilson has prepared the attached, "Important Information About Your Geotechnical/Environmental Report," to assist you and others in understanding the use and limitations of our reports.

Sincerely,

SHANNON & WILSON, INC.

Aimee E. Holmes, PE, CEG
Senior Engineer / Engineering Geologist

Risheng (Park) Piao, PE, GE
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William J. Perkins
Vice President

AEH:RPP/WJP/ah

Mr. David Kraska
Carollo Engineers, Inc.
August 5, 2014
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Enc: Figure 1 – Vicinity Map
Figure 2 – TVWD Service Area Map
Figure 3 – Geologic Map
Figure 4 – Liquefaction Hazard
Figure 5 – Landslide Susceptibility
Figure 6 – Peak Ground Acceleration, PGA
Figure 7 – 1-Second Spectral Acceleration, SA₁
Figure 8 – Peak Ground Velocity, PGV
Figure 9 – Probability of Liquefaction
Figure 10 – Liquefaction-Induced Lateral Spreading Permanent Ground Displacement, PGD
Figure 11 – Liquefaction-Induced Settlement Permanent Ground Displacement, PGD
Figure 12 – Probability of Earthquake-Induced Landslides
Figure 13 – Earthquake-Induced Landslide Permanent Ground Displacement, PGD
Figure 14 – Quaternary Faults in the TVWD Service Area Vicinity
Attachment A – Site Reconnaissance Photographs
Attachment B – Important Information About Your Geotechnical/Environmental Report

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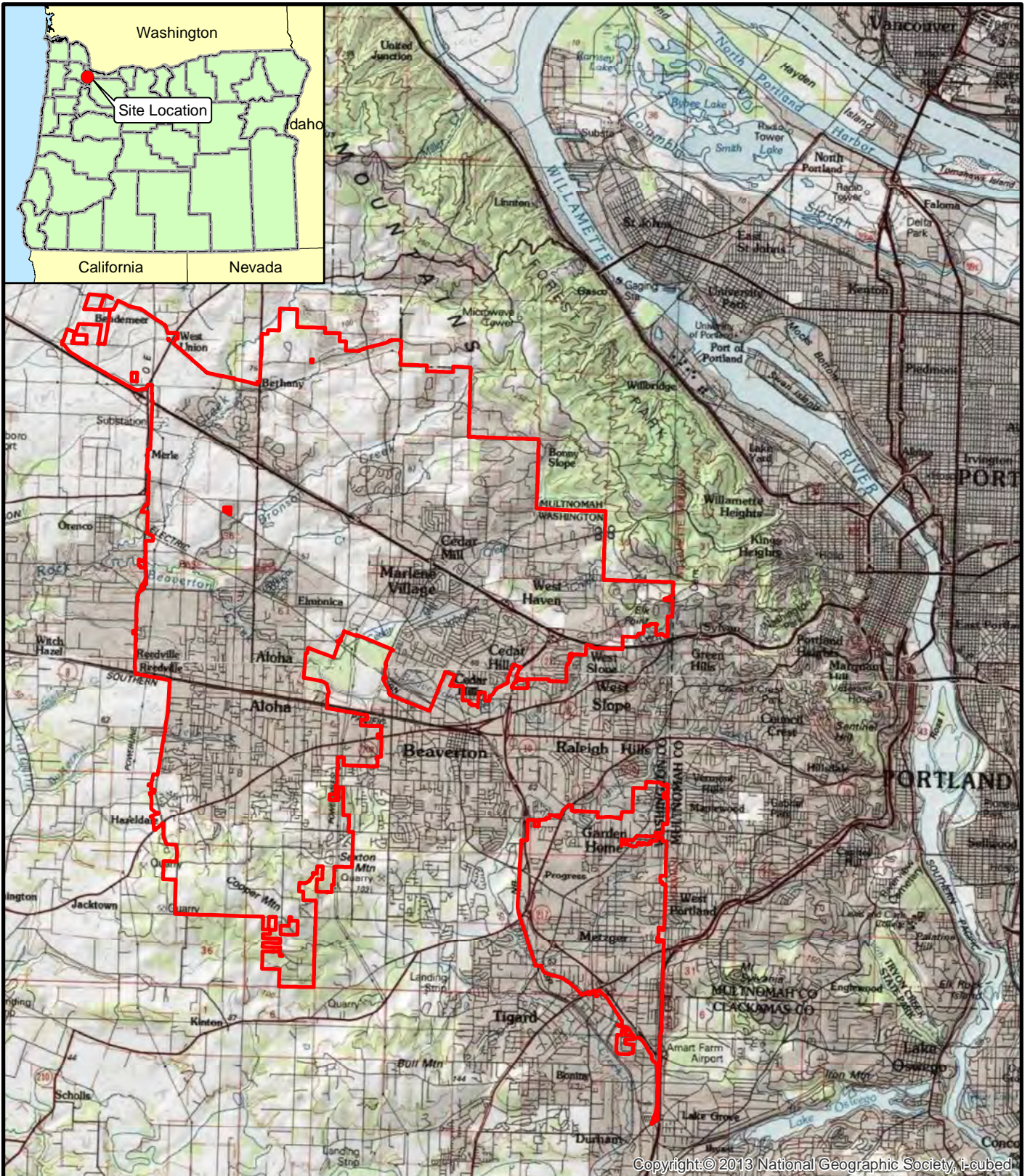
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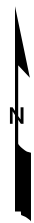
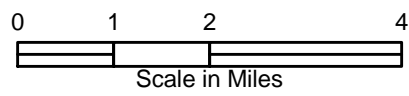
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TVWD Water Master Plan
Washington County, Oregon

VICINITY MAP

August 2014

24-1-03887-001

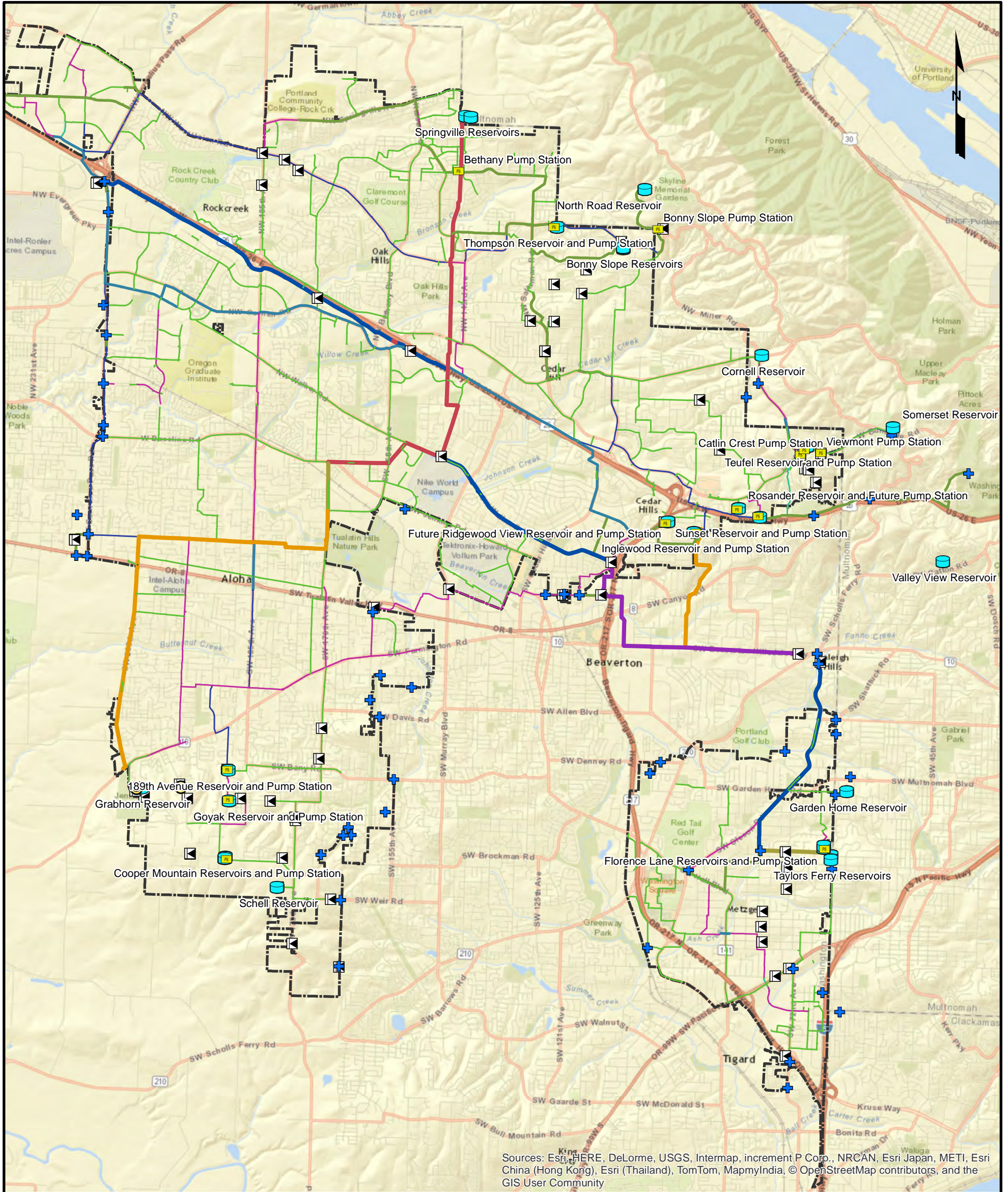
EXPLANATION



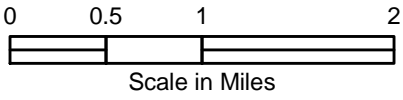
Tualatin Valley Water District Service Area

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FIG. 1



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24
	ASR Well		12		30
	Pump Station		14		36
	Reservoir		16		42
	Intertie		18		48
	Pressure Reducing Valve		20		54

TVWD Water Master Plan
Washington County, Oregon

TVWD SERVICE AREA MAP

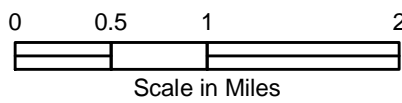
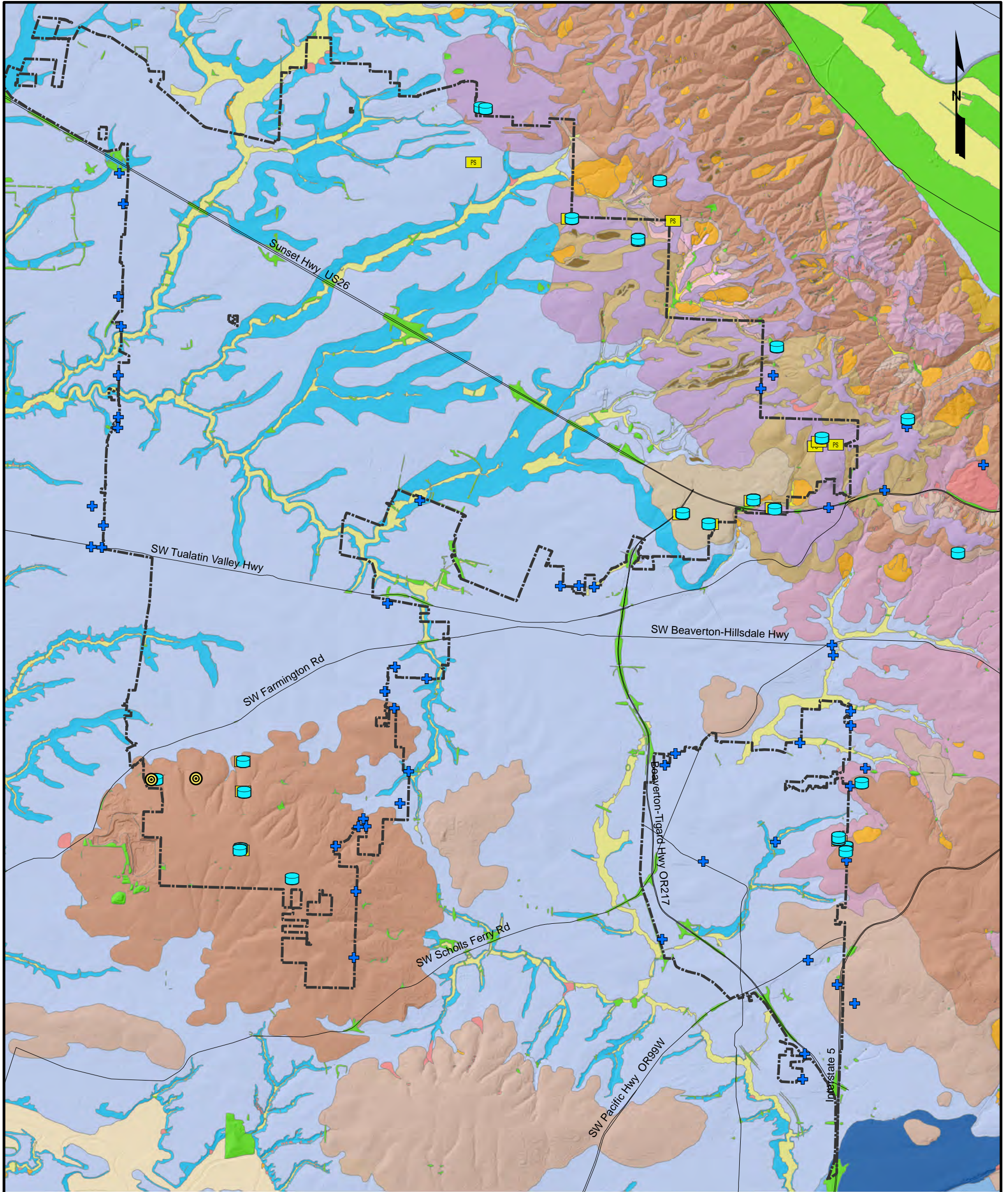
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FIG. 2

FIG. 2



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. Geologic map data provided with DOGAMI publication O-12-02. See report for details.

EXPLANATION

TVWD Service Area	Basalt of Ginkgo	Debris flow fans	Recent or active landslide deposits
ASR Well	Basalt of Kaiser Road and loess	Hillsboro Formation	Scappoose Formation
Reservoir	Basalt of Mount Sylvania	Hillsboro Formation and loess	Sentinel Bluffs Member and loess
Pump Station	Basalt of Mount Sylvania and loess	Landslide deposits	Terrace deposits of the Tualatin Mountains
Intertie	Basalt of Sand Hollow	Missoula flood deposits, channel facies	Troutdale Formation, conglomerate
Map Unit Name	Basalt of Wapshilla Ridge and loess	Missoula flood deposits, coarse-grained facies	Undifferentiated Columbia River Basalt Group
Alluvium of lowland streams	Basaltic andesite of Barnes Road	Missoula flood deposits, fine-grained	Winter Water Member and loess
Alluvium of minor streams	Basaltic andesite of Bonny Slope and loess	Missoula floods silt colluvium	
Alluvium of the Tualatin River	Basaltic andesite of Elk Point and loess	Ortley Member	
Alluvium of the Willamette River		Primary loess	
Artificial fill			

TVWD Water Master Plan
Washington County, Oregon

GEOLOGIC MAP

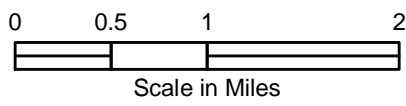
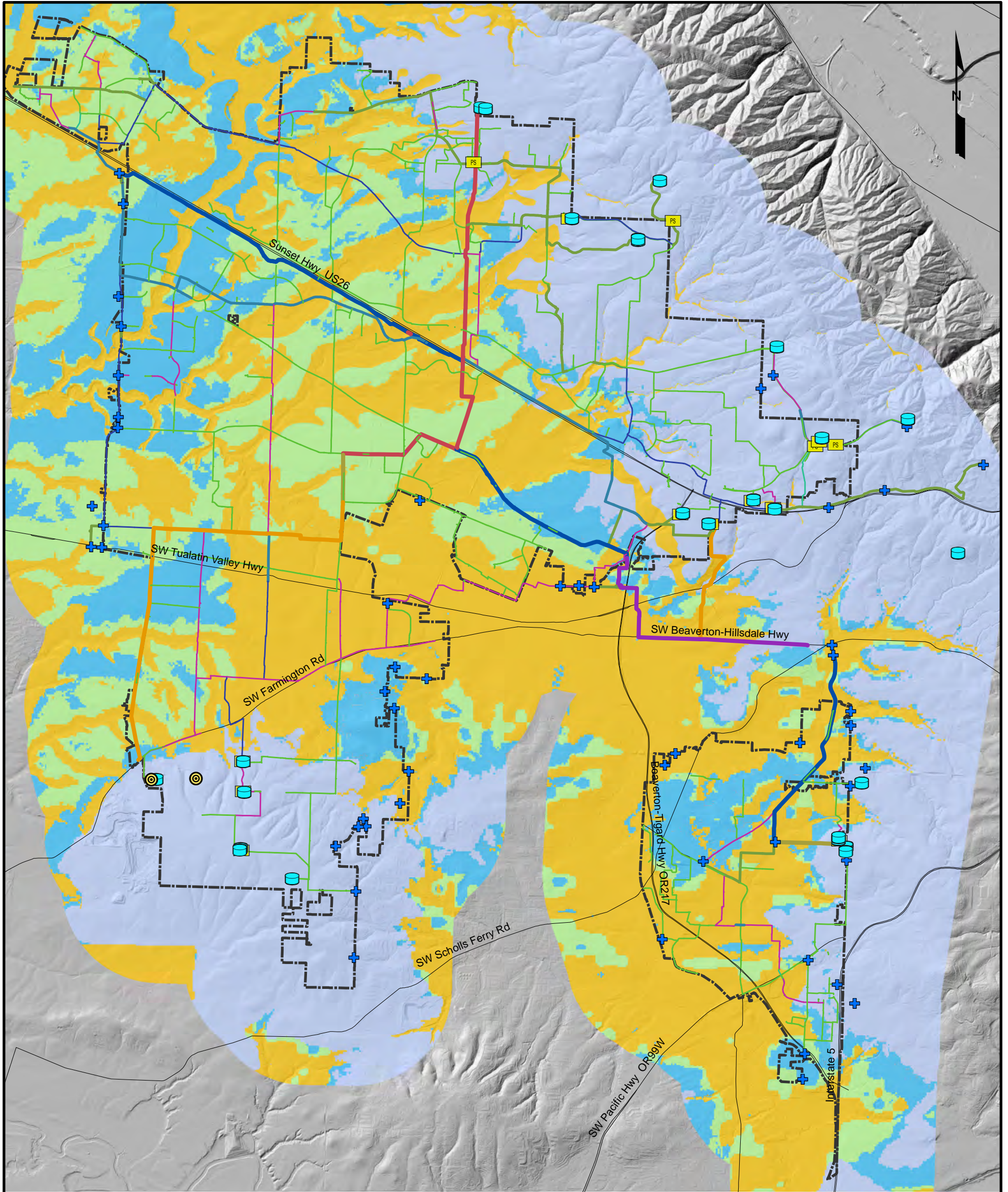
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FIG. 3

FIG. 3



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Liquefaction hazard map developed from data provided with DOGAMI publications O-12-02 and O-13-06. See report for details.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24		Liquefaction Hazard		None
	ASR Well		12		30		Low		Moderate
	Reservoir		14		36		High		Very High
	Pump Station		16		42				
	Intertie		18		48				
			20		54				

FIG. 4

TVWD Water Master Plan
Washington County, Oregon

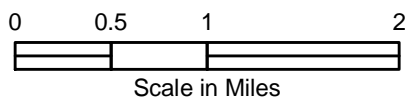
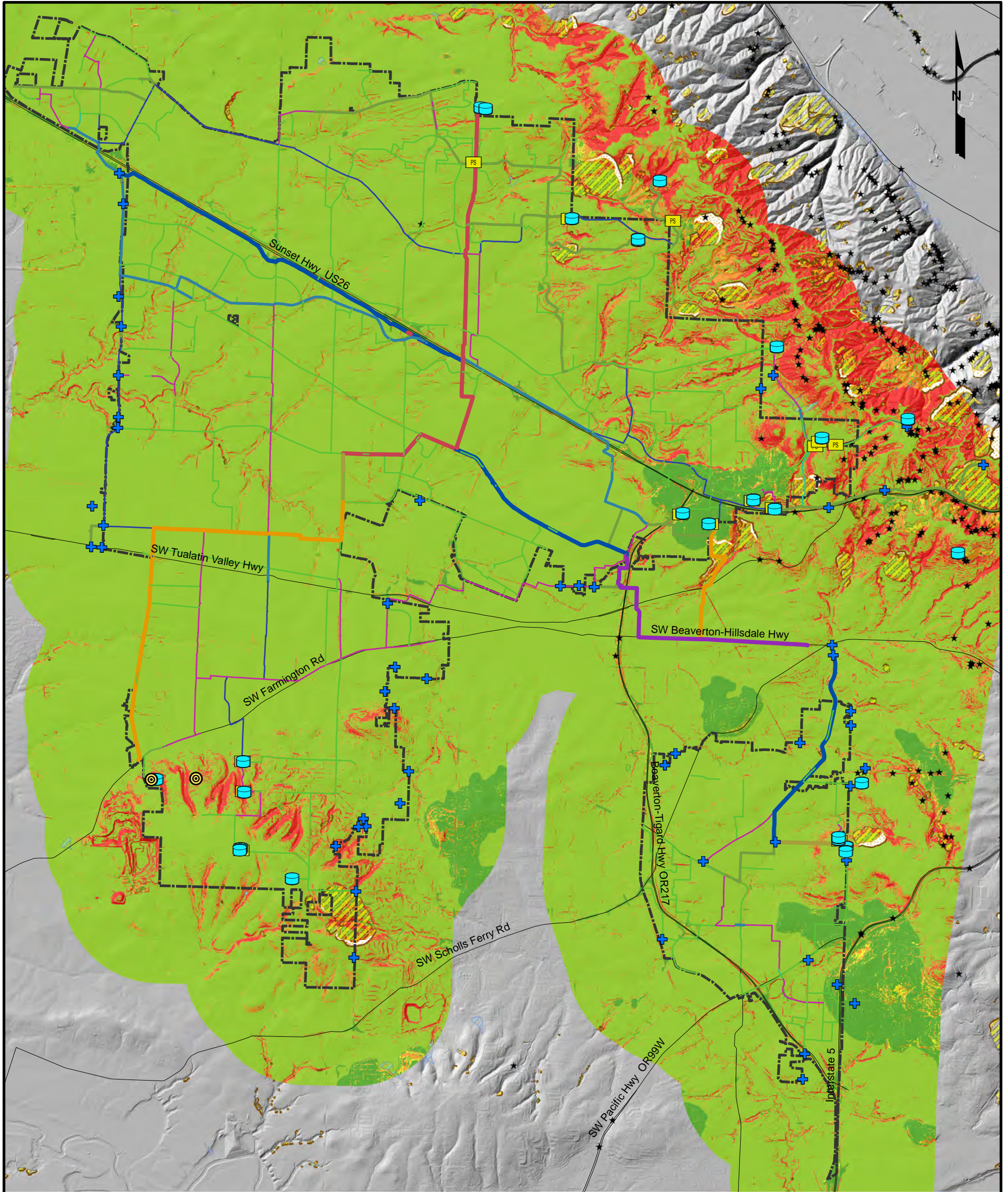
LIQUEFACTION HAZARD

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FIG. 4



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Landslide susceptibility calculated from data provided with DOGAMI publications SLIDO-3, O-12-02, O-13-06, and O-13-12. See report for details.
5. Historic Landslides, Scarps, Flanks, and Existing Deposits are provided with SLIDO-3.

EXPLANATION

TVWD Service Area	Pipelines Diameter (in)	24	Scarp	Landslide Susceptibility (Scale of 0 - 10)
ASR Well	12	30	Scarp Flank	
Reservoir	14	36	Existing Deposit Type	5
Pump Station	16	42	Landslide	7
Intertie	18	48	Fan	8
Historic Landslide	20	54		9
				10

TVWD Water Master Plan
Washington County, Oregon

LANDSLIDE SUSCEPTIBILITY

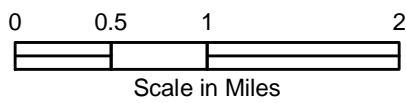
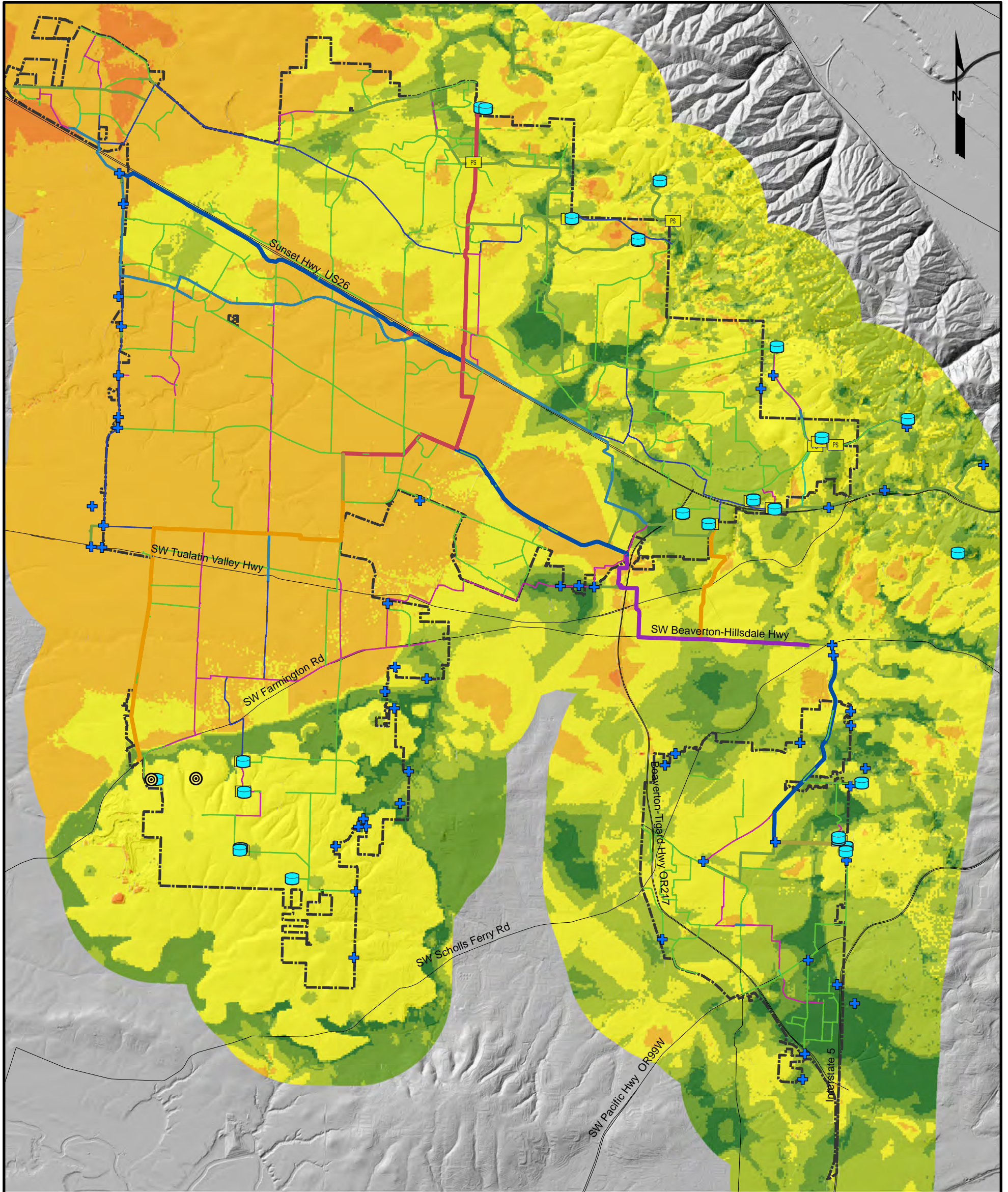
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FIG. 5

FIG. 5



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. PGA data for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications O-13-06 and O-13-12. See report for details.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24		Site PGA (g)	0.12 - 0.14
	ASR Well		12		30		0.14 - 0.16	
	Reservoir		14		36		0.16 - 0.18	
	Pump Station		16		42		0.18 - 0.20	
	Intertie		18		54		0.20 - 0.22	
			20				0.22 - 0.24	
							0.24 - 0.26	

TVWD Water Master Plan
Washington County, Oregon

**PEAK GROUND
ACCELERATION, PGA**

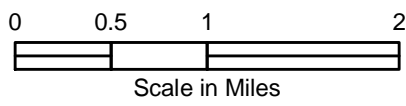
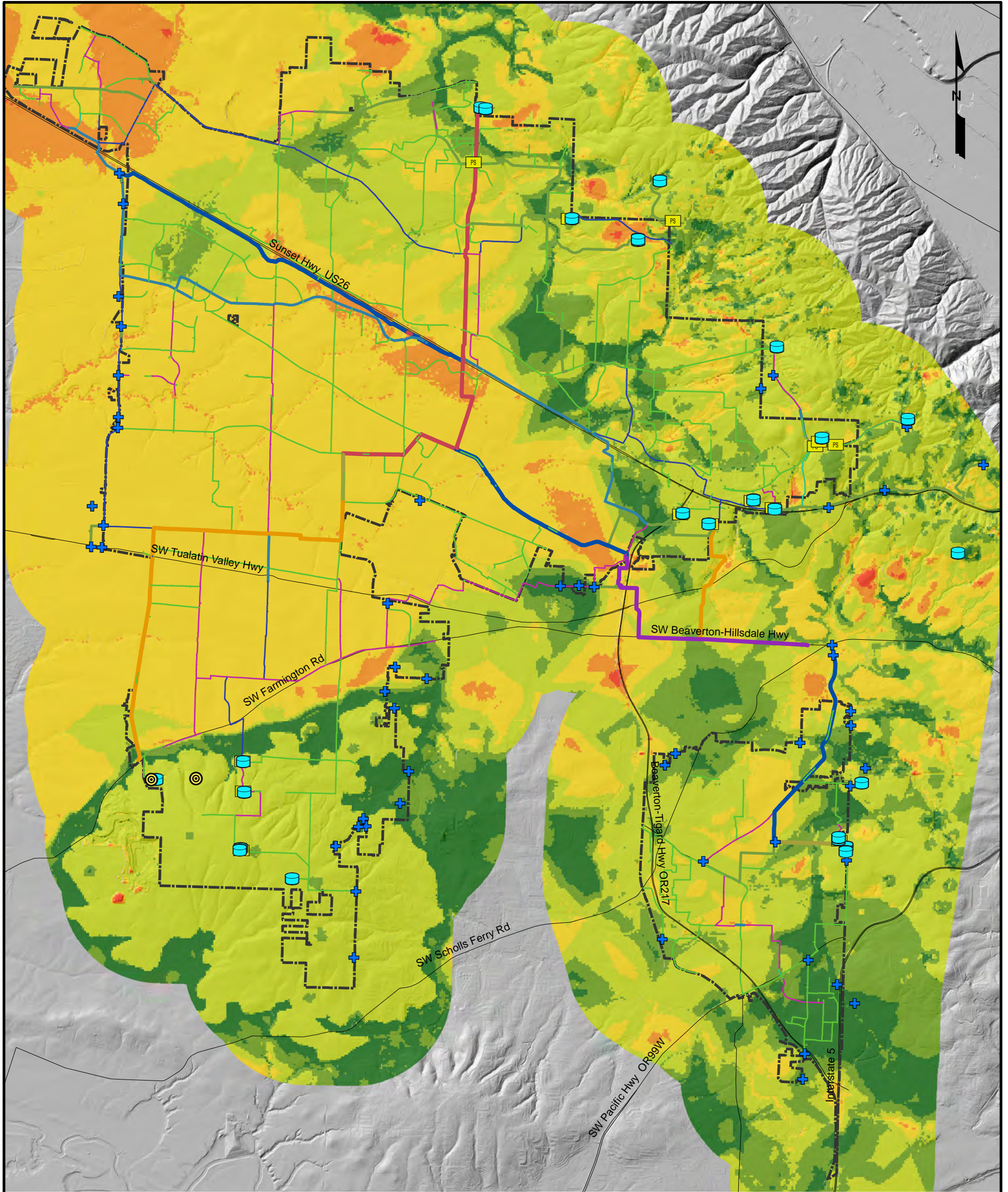
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GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 6

FIG. 6



NOTES

1. Data for TVWD facilities was provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. SA1 data for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications O-13-06 and O-13-12. See report for details.

EXPLANATION

<ul style="list-style-type: none"> TVWD Service Area ASR Well Reservoir Pump Station Intertie 	<p>Pipelines Diameter (in)</p> <ul style="list-style-type: none"> 12 14 16 18 20 24 30 36 42 48 54 	<p>Site SA1 (g)</p> <ul style="list-style-type: none"> 0.10 - 0.15 0.15 - 0.20 0.20 - 0.25 0.25 - 0.30 0.30 - 0.35 0.35 - 0.40
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TVWD Water Master Plan
Washington County, Oregon

**1-SECOND SPECTRAL
ACCELERATION, SA1**

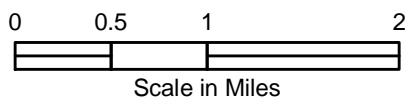
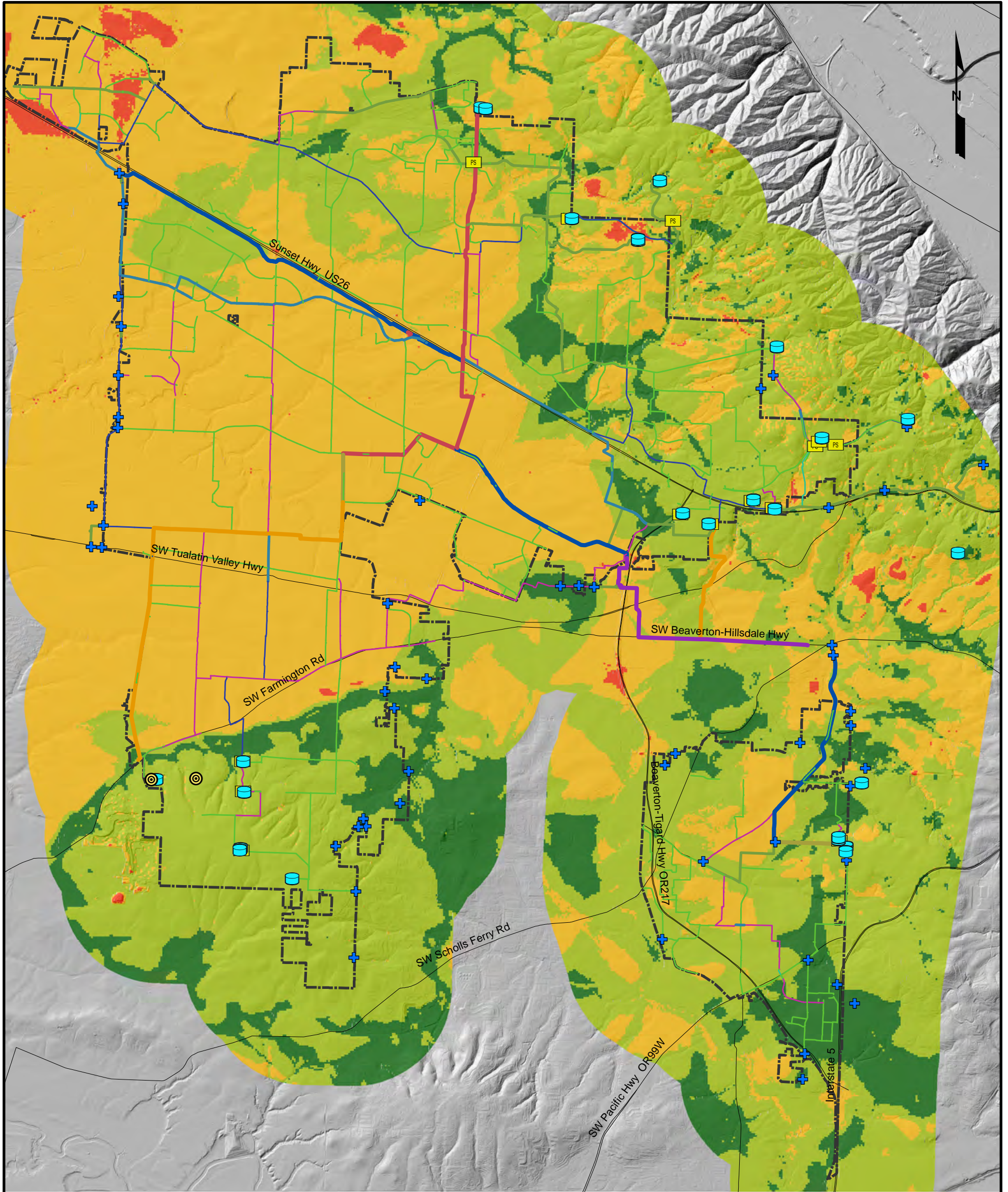
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FIG. 7

FIG. 7



NOTES

1. Data for TVWD facilities was provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. PGV data for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications O-13-06 and O-13-12. See report for details.

EXPLANATION

<ul style="list-style-type: none"> TVWD Service Area ASR Well Reservoir Pump Station Intertie 	<table border="0"> <tr> <th>Pipelines Diameter (in)</th> <th>Color</th> </tr> <tr> <td>12</td> <td></td> </tr> <tr> <td>14</td> <td></td> </tr> <tr> <td>16</td> <td></td> </tr> <tr> <td>18</td> <td></td> </tr> <tr> <td>20</td> <td></td> </tr> <tr> <td>24</td> <td></td> </tr> <tr> <td>30</td> <td></td> </tr> <tr> <td>36</td> <td></td> </tr> <tr> <td>42</td> <td></td> </tr> <tr> <td>48</td> <td></td> </tr> <tr> <td>54</td> <td></td> </tr> </table>	Pipelines Diameter (in)	Color	12		14		16		18		20		24		30		36		42		48		54		<table border="0"> <tr> <th>Site PGV (in/sec)</th> <th>Color</th> </tr> <tr> <td>3 - 6</td> <td></td> </tr> <tr> <td>6 - 9</td> <td></td> </tr> <tr> <td>9 - 12</td> <td></td> </tr> <tr> <td>12 - 15</td> <td></td> </tr> </table>	Site PGV (in/sec)	Color	3 - 6		6 - 9		9 - 12		12 - 15	
Pipelines Diameter (in)	Color																																			
12																																				
14																																				
16																																				
18																																				
20																																				
24																																				
30																																				
36																																				
42																																				
48																																				
54																																				
Site PGV (in/sec)	Color																																			
3 - 6																																				
6 - 9																																				
9 - 12																																				
12 - 15																																				

FIG. 8

TVWD Water Master Plan
Washington County, Oregon

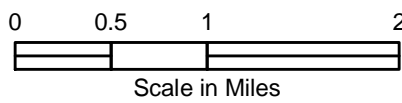
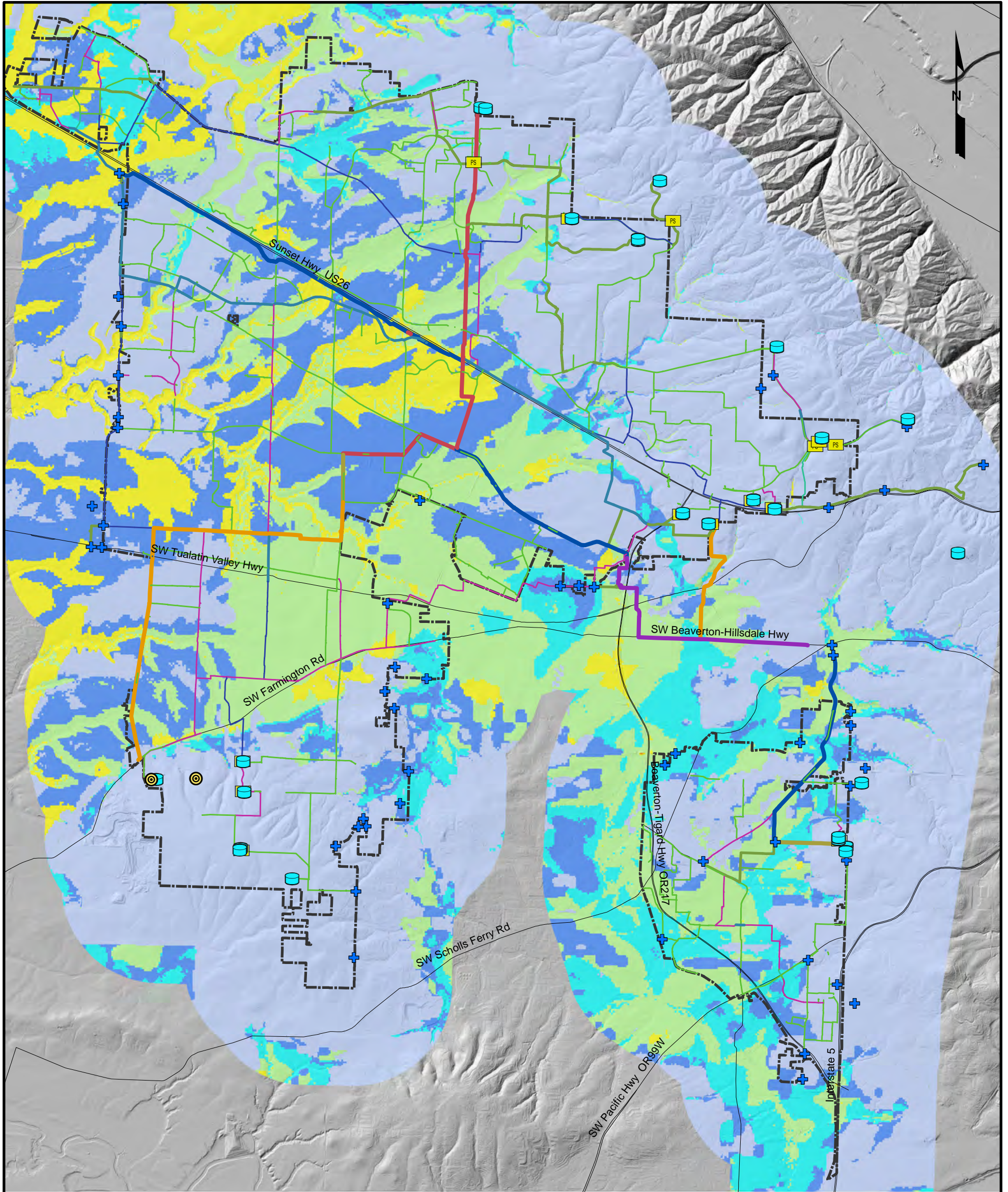
PEAK GROUND VELOCITY, PGV

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FIG. 8



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Probability of liquefaction for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications O-12-02, O-13-06, and O-13-12. See report for details.

EXPLANATION

	TVWD Service Area		24	Liquefaction Probability (%) (Proportion of Area Expected to Liquefy)
	ASR Well		30	
	Reservoir		12	
	Pump Station		14	
	Intertie		16	
			42	
			48	
			54	
			20	

	0 - 1
	1 - 5
	5 - 10
	10 - 15
	15 - 20
	20 - 25
	25 - 29

FIG. 9

TVWD Water Master Plan
Washington County, Oregon

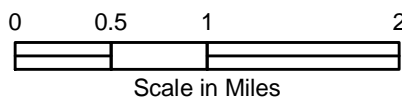
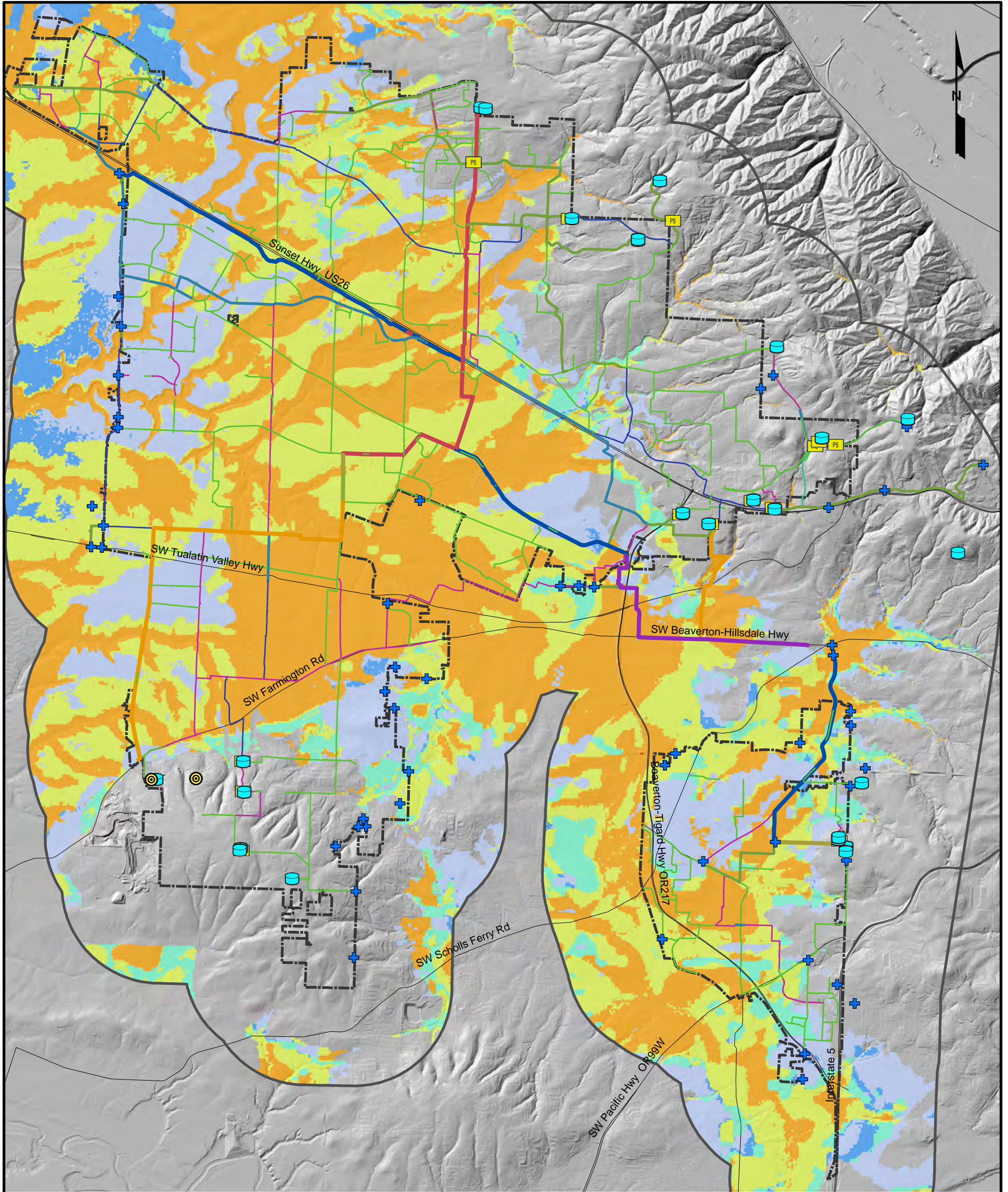
PROBABILITY OF LIQUEFACTION

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FIG. 9



NOTES

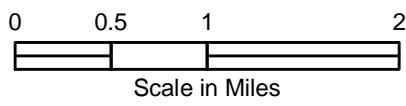
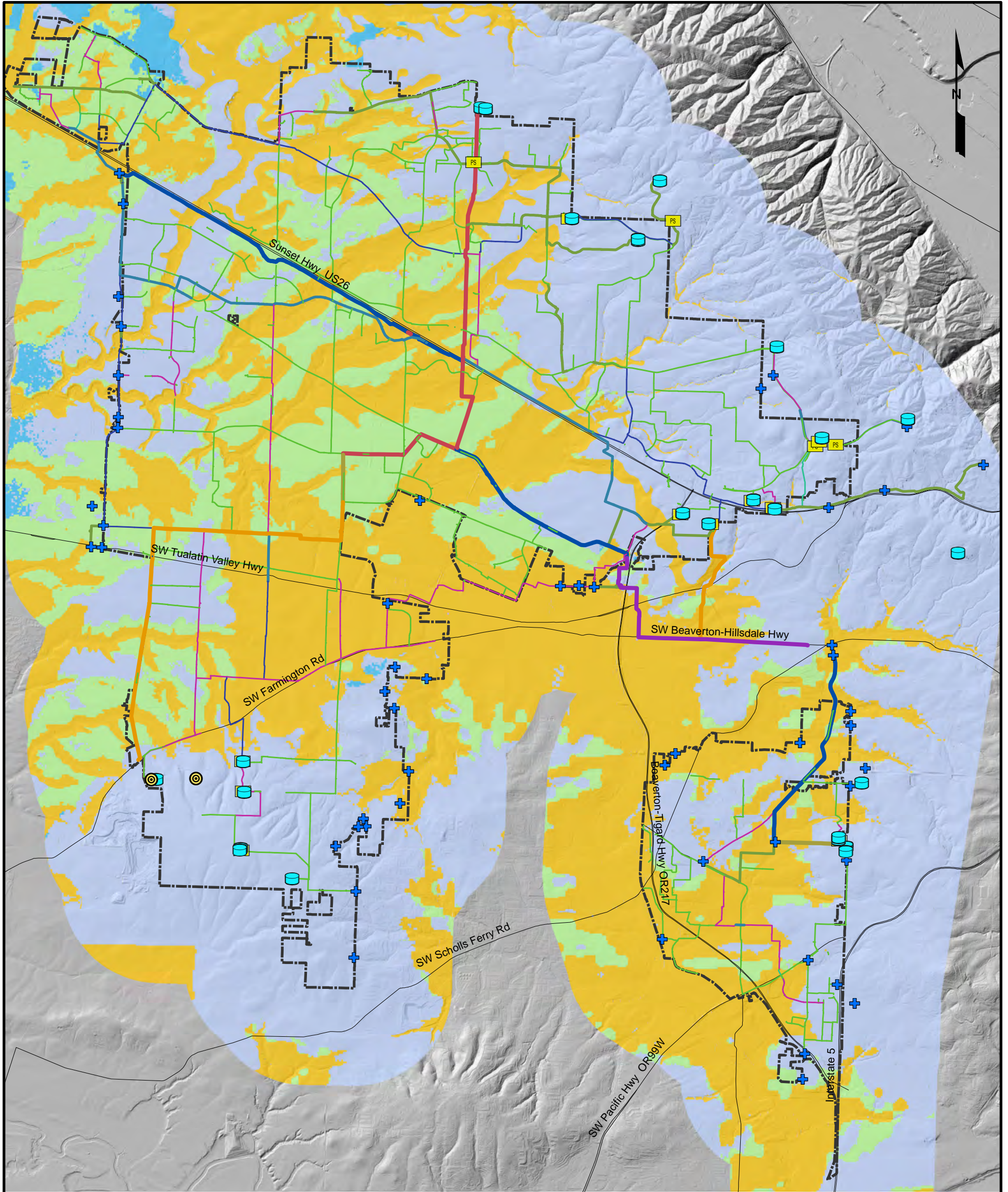
1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Liquefaction-induced lateral spreading PGD for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications O-12-02, O-13-06, and O-13-12. See report for details.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24		Liquefaction-Induced Lateral Spreading PGD (in)
	ASR Well		12		30		0 - 0.1
	Reservoir		14		36		0.1 - 2
	Pump Station		16		42		2 - 6
	Intertie		18		48		6 - 12
			20		54		12 - 24
							24 - 36

TVWD Water Master Plan Washington County, Oregon	
LIQUEFACTION-INDUCED LATERAL SPREADING PERMANENT GROUND DISPLACEMENT, PGD	
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FIG. 10



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Liquefaction-induced settlement PGD for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications O-12-02, O-13-06, and O-13-12. See report for details.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24		Liquefaction-Induced Settlement PGD (in)	0
	ASR Well		12		30		0.5 - 2	
	Reservoir		14		36		1 - 4	
	Pump Station		16		42		3 - 12	
	Intertie		18		48		6 - 24	
			20		54			

FIG. 11

TVWD Water Master Plan
Washington County, Oregon

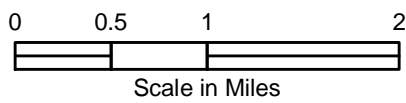
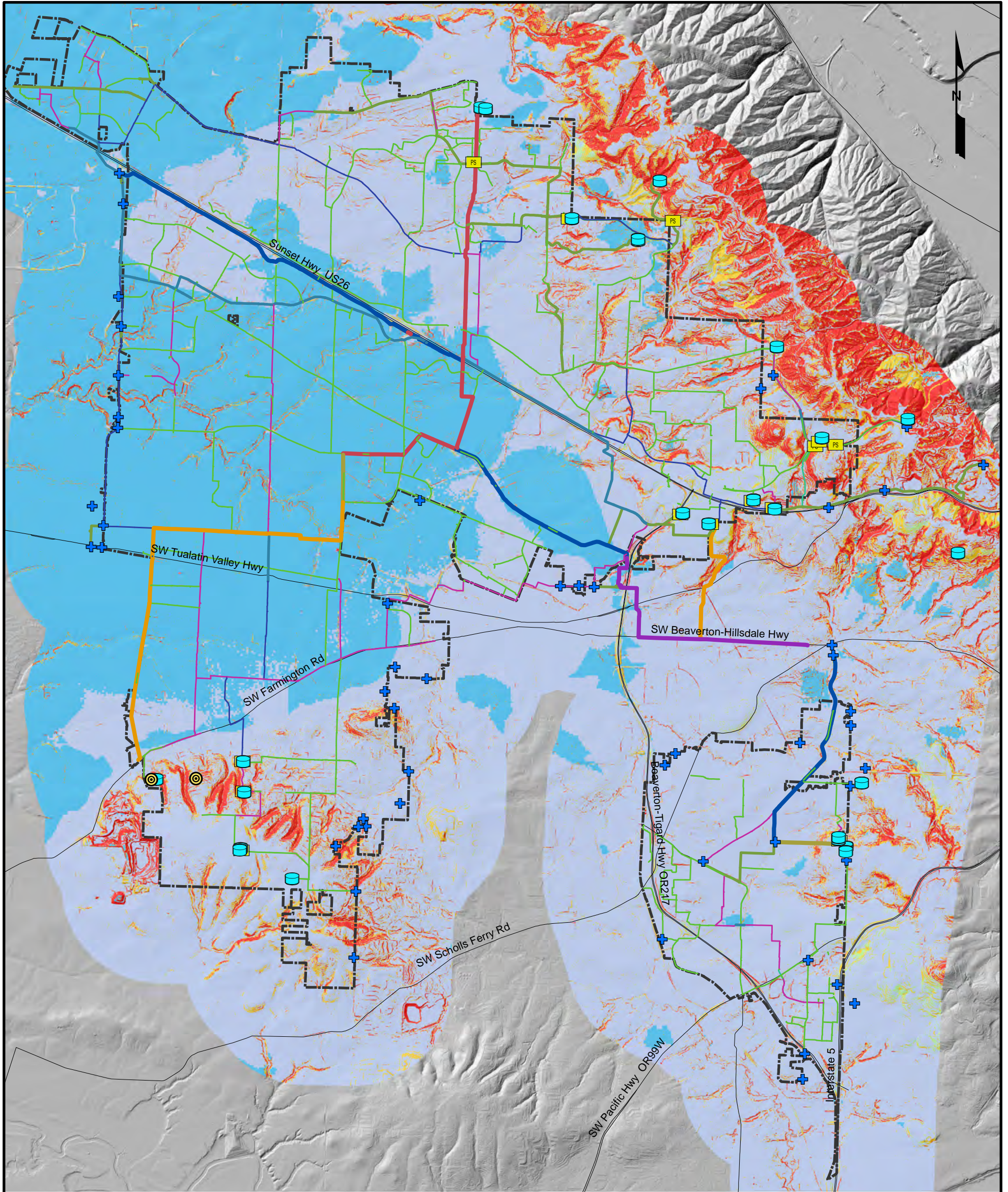
**LIQUEFACTION-INDUCED
SETTLEMENT PERMANENT
GROUND DISPLACEMENT, PGD**

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FIG. 11



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Earthquake-induced landslide probability for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications SLIDO-3, O-12-02, O-13-06, and O-13-12. See report for details.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24		0	Earthquake-Induced Landslide Probability (%) (Proportion of Area Expected to Fail)
	ASR Well		12		30		15	
	Reservoir		14		36		20	
	Pump Station		16		42		25	
	Intertie		18		48		30	
			20		54			

TVWD Water Master Plan
Washington County, Oregon

PROBABILITY OF EARTHQUAKE-INDUCED LANDSLIDES

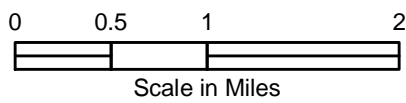
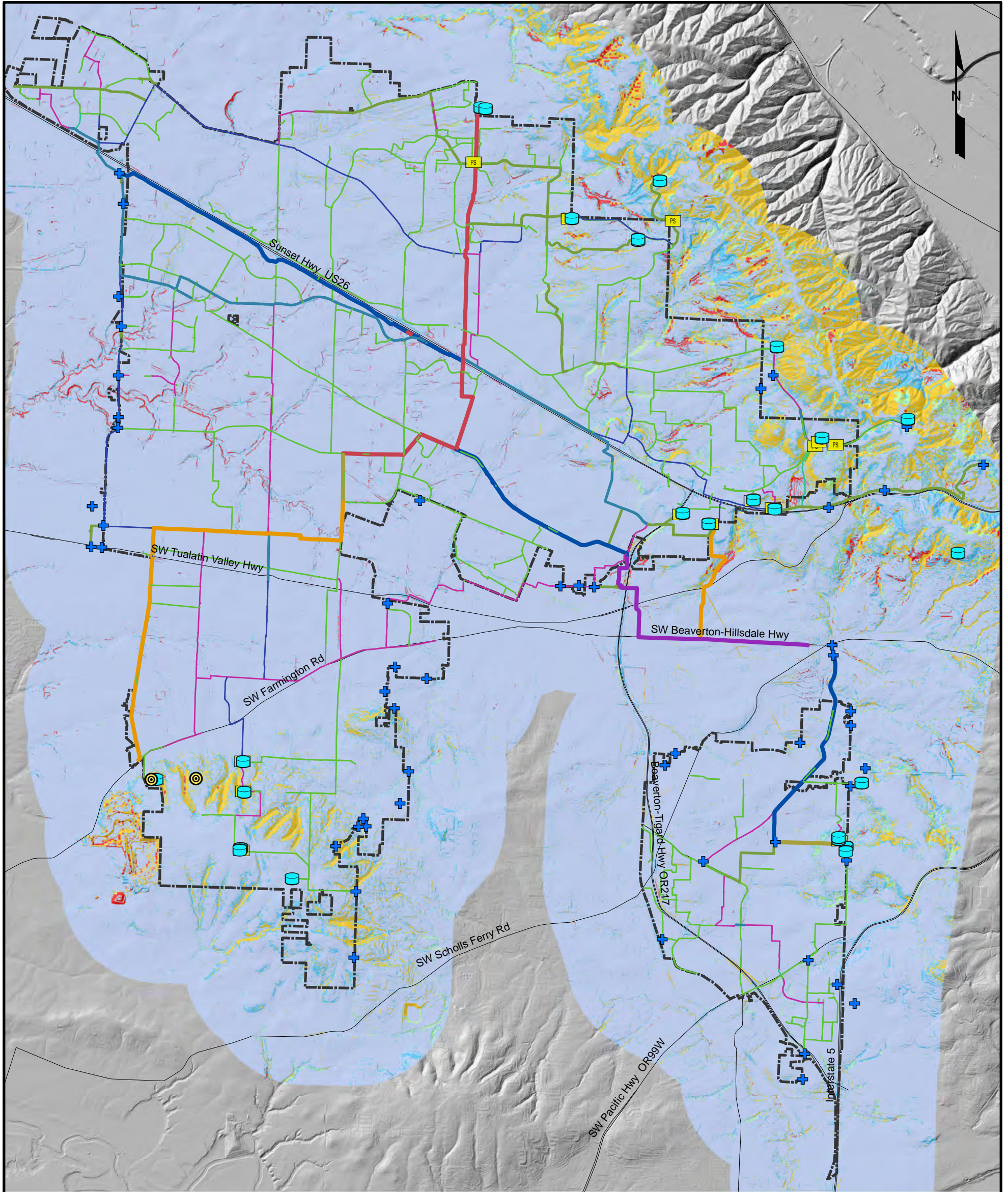
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FIG. 12

FIG. 12



NOTES

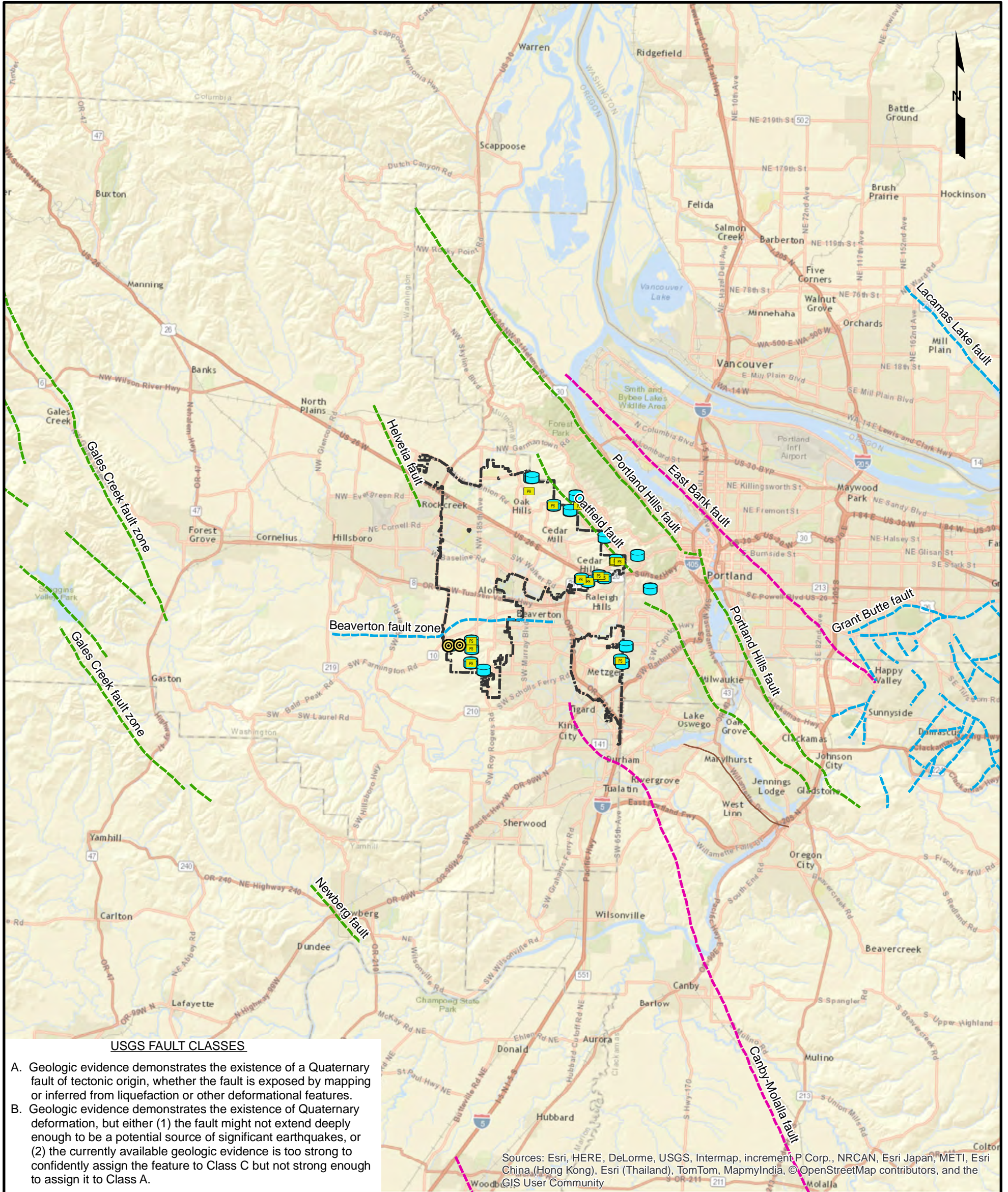
1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. For clarity, pipelines smaller than 12 inches are not shown.
4. Earthquake-induced landslide PGD for the magnitude 9.0 Cascadia Earthquake Scenario calculated from data provided with DOGAMI publications SLIDO-3, O-12-02, O-13-06, and O-13-12. See report for details.

EXPLANATION

	TVWD Service Area		Pipelines Diameter (in)		24		Earthquake-Induced Landslide PGD (ft)		0 - 0.1
	ASR Well		12		30		0.1 - 1		0.1 - 1
	Reservoir		14		36		1 - 2		1 - 2
	Pump Station		16		42		2 - 3		2 - 3
	Intertie		18		48		3 - 5		3 - 5
			20		54				

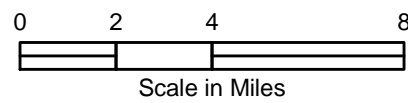
FIG. 13

TVWD Water Master Plan Washington County, Oregon	
EARTHQUAKE-INDUCED LANDSLIDE PERMANENT GROUND DISPLACEMENT, PGD	
August 2014	24-1-03887-001
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USGS FAULT CLASSES

- A. Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features.
- B. Geologic evidence demonstrates the existence of Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A.



NOTES

1. Data for TVWD facilities were provided by Carollo Engineers, Inc., on July 1, 2014.
2. TVWD service area from the Metro Regional Land Information System (RLIS) database.
3. Faults from the USGS Quaternary Fault and Fold Database of the United States. GIS data downloaded on April 23, 2014, last updated by USGS on November 3, 2010.

EXPLANATION

	TVWD Service Area		Quaternary Faults
	ASR Well		Age (Years since most recent deformation)
	Pump Station		<15,000 - Class A
	Reservoir		<750,000 - Class A
			<1,600,000 - Class A
			Class B

TVWD Water Master Plan
Washington County, Oregon

QUATERNARY FAULTS IN THE TVWD SERVICE AREA VICINITY

August 2014

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FIG. 14

FIG. 14

ATTACHMENT A
SITE RECONNAISSANCE PHOTOGRAPHS



Photo 1: Facing west toward Sunset Reservoir and Pump Station. Hwy. 26 is to the left.



Photo 2: Facing north toward Somerset Reservoir from West Burnside Road.

TVWD Water Master Plan
Washington County, Oregon

**SITE RECONNAISSANCE
PHOTOGRAPHS**

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Geotechnical and Environmental Consultants

FIG. A1
Page 1 of 2



Photo 3: Facing south from the Bonny Slope Park parking area.



Photo 4: Facing southeast toward the Thompson Reservoir and Pump Station.

TVWD Water Master Plan Washington County, Oregon	
SITE RECONNAISSANCE PHOTOGRAPHS	
August 2014	24-1-03887-001
SHANNON & WILSON, INC. Geotechnical and Environmental Consultants	FIG. A1 Page 2 of 2

ATTACHMENT B

**IMPORTANT INFORMATION ABOUT YOUR
GEOTECHNICAL/ENVIRONMENTAL REPORT**



Date: August 2014

To: Mr. David Kraska, PE

Carollo Engineers, Inc.

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include: the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used: (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors which were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the
ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland