Water Supply Forum

Regional Water Supply Resiliency Project

Summary Report

Snohomish, King, and Pierce Counties, Washington

Prepared by

HDR, Inc.

WATER SUPPLY FORUM
Serving Snohomish, King & Pierce Counties
Resiliency Project

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Abbreviations

ALA	American Lifelines Alliance
BIP	Bellevue-Issaquah transmission pipeline
CWA	Cascade Water Alliance
Forum	Water Supply Forum
PE-LOS	Post earthquake level of service
M_w	moment magnitude
PUMA	Piloting Utility Modeling Applications
Resiliency Project	Regional Water Supply Resiliency Project
SCADA	supervisory control and data acquisition
SPU	Seattle Public Utilities
USGS	United States Geological Survey

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Executive Summary

The Water Supply Forum (Forum) is a voluntary organization with representatives from public water systems and local governments from King, Pierce, and Snohomish Counties in Washington State. Forum membership represents most, but not all, of the water systems in the three-county area and most of the population served and water supplied. The Forum's members represent a diverse group of public water utilities, ranging from large municipally owned systems to water and sewer districts and regional water associations.

In an unprecedented planning effort spanning three counties, the Forum member utilities have come together to help the central Puget Sound region better prepare for the impacts of significant system stresses and enhance water supply system resiliency. The Forum recognizes that a characteristic of strong communities is how they respond to threats.

The four major water utilities in the central Puget Sound region are: Seattle Public Utilities (SPU), Everett Public Works, Tacoma Water, and Cascade Water Alliance (CWA). In total, these utilities serve approximately 2.3 million people over 1,200 square miles. The region served includes approximately 60 cities/water districts, a major metropolitan area, three bustling ports, and world-class businesses with international headquarters or major operations in the Seattle area, including Weyerhaeuser, Starbucks, Amazon, Microsoft, and Boeing.

Without crises or mandated efforts, the Forum member utilities have worked across jurisdictional boundaries and brought together staff with expertise in engineering, planning, and the sciences to evaluate the water supply system risks facing the central Puget Sound region and to identify opportunities to improve the region's resiliency to these risks.

Resiliency Evaluation Objective and Approach

The objective of this Regional Water Supply Resiliency Project (Resiliency Project) is to help the water utilities of King, Pierce, and Snohomish Counties take proactive steps in evaluating and enhancing this region's water supply system resiliency across and between individual utility service area boundaries. Project evaluations will contribute to public education on regional water system risks and resiliency plans.

Resiliency is generally defined as the ability to reduce the impact of and recover rapidly from disruptive events, so that an acceptable level of service (LOS) is maintained and the impacts on public health and safety and the economy are minimized.

The Forum selected four initial risk topics: earthquakes, water quality, drought, and climate change. For each risk topic, a utility-led team was formed that included Forum representatives from multiple agencies, augmented by risk-area consultants. After 15 months of evaluations and collaboration, the risk teams have issued initial conclusions and recommendations. This report summarizes the evaluations conducted by each risk team and the initial findings of those evaluations.

Earthquake Resiliency Evaluation

The Puget Sound region is susceptible to earthquake hazards produced predominantly by the three shallow crustal faults (South Whidbey Island Fault, Seattle Fault, and Tacoma Fault) and the deep Cascadia Subduction Zone.

The Earthquake Team selected the following four scenarios to capture the range of earthquake source zones and earthquake return periods that occur in the Puget Sound region:

- Cascadia Subduction Zone, moment magnitude (M_w) 9.0, 500-year return period
- South Whidbey Island Fault, M_w7.4, 2,700-year return period
- Seattle Fault – M_w6.7, 1,000-year return period
- Tacoma Fault – M_w7.1, 4,500-year return period

The Earthquake Team used previously completed vulnerability evaluations, high-level seismic vulnerability models, and engineering judgment, in conjunction with the hazard and ground shaking maps, to estimate water system facility damage and system response for these four earthquake scenarios. This earthquake evaluation was conducted using high-level analysis methods. Although these methods provide a general understanding of how a water system would respond to a specific earthquake scenario, the results should be considered preliminary and highly approximate. More detailed analyses and site investigations are needed to supply a more precise estimate of system performance, economic impacts, and post-earthquake response.

Preliminary results suggest that for each earthquake scenario, at least one of the major water suppliers (SPU, Everett Public Works, Tacoma Water) in the three-county area could take up to 60 days to restore water at average winter day demand to at least 90 percent of customers' taps after a major seismic event. This performance is below the PE-LOS performance goals that surveyed utilities in other regions have set for their seismic programs. These programs generally call for restoring water service within 14 to 30 days of the event and for the system to at least remain functional enough to provide firefighting water immediately after the event. The Earthquake Team determined that the potential direct and indirect economic losses from water system damage alone could exceed $2 billion.

Water Quality Resiliency Evaluation

The Water Quality Team defined water quality risk as any event disruptive to the continued delivery of safe and acceptable drinking water. The Team identified a comprehensive range of potential risk events that could affect drinking water quality for water systems in the three-county area. The Team developed a risk analysis framework based on likelihood and consequence to prioritize the initial list of risk events. Based on this prioritization process, the Team selected six risk events for further evaluation: wildfires, volcanic eruptions, resource supply chain disruption, accidental contamination, severe adverse weather, and earthquakes. These six risk events have a low likelihood of occurrence, but the consequence of an occurrence would be a severe, negative impact on a utility's ability to provide safe drinking water. Specific implications for the three-county area include the following:

- Wildfire in the watershed can increase water turbidity, nutrient loading, pH, alkalinity, temperature, and metals, as well as pose risks from the effects of suppression chemicals.
- Volcanic hazards can reduce water availability and can increase turbidity and acidity.
- Water treatment supply chain issues could significantly upset water treatment plant operations and thereby potentially have an immediate adverse effect on public health, lead to regulatory violations, or require boil water orders.
- Accidental contamination can contaminate a utility's water supply and create unsafe drinking water conditions. The use of early warning systems and a multibarrier approach can help reduce the impacts of such an incident.
- Severe adverse weather could result in treatment facility failure, equipment damage, communication loss, supervisory control and data acquisition (SCADA) loss, and supply chain disruptions.

- Earthquakes can damage critical infrastructure, lead to supply chain disruptions, reduce water availability, and potentially damage or disrupt groundwater supplies.

The Water Quality Team further defined the consequences of these risk events and developed potential mitigation measures for each risk event. These mitigation measures were assigned to the following subcategories: preventative, pre-event, detection, immediate response, and recovery.

Drought Evaluation

Under drought conditions, reduced precipitation or extended warm, dry periods may reduce water availability to meet normal instream and out-of-stream water needs. Those same conditions can also increase demands for municipal water supply as outdoor uses increase. The result can be insufficient water supply to support essential and desired uses. To evaluate the resiliency of SPU, Tacoma Water, and Everett Public Works' supplies, the Drought Team evaluated two drought scenarios: an actual historic drought scenario and a potential extreme drought scenario. In addition, the Drought Team evaluated regional groundwater supplies in the three-county area and surveyed smaller water utilities in the area regarding their risk exposure to droughts.

The evaluation of drought susceptibility generally showed that the region is well-positioned for relatively severe droughts of the type evaluated in this evaluation. The evaluation revealed that SPU, Everett Public Works, and Tacoma Water would have sufficient supply to meet the 2035 forecast hot, dry summer demand levels if the worst drought on record (1987) repeated itself. Under this scenario, SPU, Everett Public Works, and Tacoma Water were able to manage supply and demand relationships by using existing water shortage response tools—short of implementing mandatory curtailments—to meet customer demands. However, SPU and Tacoma Water would be unable to meet 2035 demands if an extreme drought were to occur that had approximately 25 percent lower inflows than the low flows of the 1987 drought. Everett Public Works would retain some supply buffer at this level of reduced inflow. Groundwater sources are less vulnerable to a single-year drought than surface water. However, multiyear periods of reduced precipitation could lead to aquifer decline or depletion. The drought survey found that water utilities in the region consider drought an important issue and have implemented some measures to prepare for water shortages. Additional mitigation measures, beyond existing measures, could be developed to better respond to drought conditions.

Climate Change Evaluation

Climate change is projected to alter the water cycle and sea levels in varying ways around the globe. These alterations could include, but are not limited to, increases in temperature affecting snowpack accumulation and the timing of snowpack melt, increases in the intensity of rainfall and in the frequency and/or intensity of drought and the length of dry spells, effects on evapotranspiration, and increases in water levels along marine shorelines.

To better understand how these conditions may affect the three-county area, the Climate Change Team evaluated: surface water supplies, groundwater supplies, migration of people, water quality, and wildfire. The work built on original climate research conducted through a partnership between SPU and the National Oceanic and Atmospheric Administration Regional Integrated Sciences and Assessments program for the Pacific Northwest, the 2014 Climate Assessment, and other related research. Overall, the results of these evaluations suggest that climate change may have the following effects on water suppliers in the three-county area:

- Water availability may be significantly reduced. This and other climate change impacts would likely be similar throughout the three-county area given that streamflows of the five major rivers are the main sources of the region's existing and potential future surface water supplies.
- Groundwater resources are likely to be relatively robust in the face of climate change compared with surface water. Mainland aquifers that currently provide significant supplies appear to not be at significant risk of inundation from sea level rise.
- A sudden and dramatic population increase attributable to climate-driven migration is unlikely to occur.
- Continued water quality management strategies in the Puget Sound region and additional research are needed to better understand and address potential water quality risks resulting from climate change, such as increased water temperatures, increased variability in streamflows, increased nutrient loading, decreased oxygen saturation, altered lake stratification and turnover, increased turbidity levels, and increased harmful algae blooms. The specific impacts of these potential risks on water supply operations were not determined as part of this assessment.
- Climate change is likely to increase the frequency of high fire danger days.

Recommendations and Next Steps

The results of each risk evaluation should be considered preliminary and subject to further evaluation. As such, the risk teams recommend that additional evaluations be performed to build on these initial results to better understand water system vulnerabilities in the region and measures that could mitigate these risks. The risk teams recognize that the Resiliency Project findings may not apply to all water utilities in the region. Therefore, the Teams recommend that individual drinking water utilities also consider their own utility's resiliency against each risk and which mitigation measures are reasonable and feasible for their systems. Further analysis is needed to determine the cost-effectiveness of recommended resiliency measures and to develop a regional plan of action. Future Resiliency Project investigations would contribute to the region's understanding of these risks and to improving the resilience of water systems in the three-county area to counter these risks.

1.0 Introduction

The Water Supply Forum (Forum) is a voluntary organization with representatives from public water systems and local governments from King, Pierce, and Snohomish Counties in Washington State. The Forum was created in July 1998 to address current and future water supply issues in the region, including water supply planning and resiliency.

Forum membership represents most, but not all, of the water systems in the three-county area and most of the population served and water supplied. The Forum's members represent a diverse group of public water utilities: large municipally owned systems, water and sewer districts, regional water associations (with their large and small, publicly and privately owned members), and counties. These entities share the common goal of increasing communication and coordination for water supply planning in the three-county area. The Forum members are:

- City of Everett (Everett Public Works)
- City of Seattle (Seattle Public Utilities, SPU)
- City of Tacoma (Tacoma Water)
- Cascade Water Alliance (CWA)
- Regional Water Cooperative of Pierce County
- Everett Water Utility Committee
- East King County Regional Water Association
- King County

1.1 Large Water Systems

The four major water utilities in the central Puget Sound region are: SPU, Everett Public Works, Tacoma Water, and CWA. Of these, SPU, Everett Public Works, and Tacoma Water are the major water suppliers in the region. CWA currently receives its water from SPU. In total, these utilities serve approximately 2.3 million people over 1,200 square miles. The region served includes approximately 60 cities/water districts, a major metropolitan area, three bustling ports, and world-class businesses with international headquarters or major operations in the Seattle area, including Weyerhaeuser, Starbucks, Amazon, Microsoft, and Boeing.

Water supplies for SPU, Everett Public Works, and Tacoma Water come from four surface water and various groundwater sources in the central Puget Sound region. The following are the major existing surface water supplies:

- Everett Public Works – Sultan River Watershed (Spada and Chaplain Reservoirs)
- SPU – Tolt River Watershed (South Fork Tolt Reservoir) and Cedar River Watershed (Chester Morse Lake)
- Tacoma Water – Green River Watershed (Howard Hansen Reservoir)

SPU and Tacoma Water also own groundwater supplies that can be used to supplement their surface water supplies. In addition to these existing supplies, CWA owns Lake Tapps in Pierce County. Although Lake Tapps is not currently used as a source of water supply, CWA plans to use Lake Tapps for this purpose in the future. Figure 1, at the end of this report, shows the major supply, transmission, and storage components of the SPU, Everett Public Works, Tacoma Water, and CWA water supply systems and the areas currently served by these water utilities.

1.2 Resiliency Project Objective and Approach

In a planning effort spanning three counties, the Forum member utilities have come together to help the central Puget Sound region better prepare for the impacts of significant system stresses and enhance water supply system resiliency. Without crises or mandated efforts, the Forum member utilities have worked across jurisdictional boundaries and brought together staff with expertise in engineering, planning, and the sciences to evaluate the water supply system risks facing the central Puget Sound region and have identified opportunities to improve the region's resiliency to these risks.

The objective of this Regional Water Supply Resiliency Project (Resiliency Project) is to help the water utilities of King, Pierce, and Snohomish Counties take proactive steps in evaluating and enhancing this region's water supply system resiliency across and between individual utility service area boundaries.

Resiliency is generally defined as the ability to reduce the impact of and recover rapidly from disruptive events, so that an acceptable level of service (LOS) is maintained and the impacts on public health and safety and the economy are minimized.

The Forum selected four initial risk topics: earthquakes, water quality, drought, and climate change. For each risk topic, a utility-led team was formed that included Forum representatives from multiple agencies, augmented by risk-area consultants. To provide direction and support to these risk teams, the Forum created an Ad Hoc Committee consisting of leadership from Forum member utilities.

The purpose of these resiliency evaluations is to evaluate the adequacy of regional municipal water supplies when confronted with water quality, drought, and climate change risk events. Risk teams were tasked with identifying water system vulnerabilities and, where appropriate, evaluating proactive and responsive measures that could mitigate these risks beyond the measures that currently exist. These project evaluations are one step in helping to determine how the region's utilities can better prepare together for the impacts of significant system stresses. Project evaluations will also contribute to public education on regional water system risks and resiliency plans. After 15 months of evaluations and collaboration, the risk teams have issued initial conclusions and recommendations.

1.3 Overview of Report Contents

This report summarizes the methodology and findings of the four risk evaluations: Earthquake (Section 2.0), Water Quality (Section 3.0), Drought (Section 4.0), and Climate Change (Section 5.0). Section 6.0 provides a discussion of overall conclusions and recommendations for future investigations.

2.0 Earthquake Resiliency Evaluation

2.1 Overview of Resiliency Evaluation

Western Washington is a geologically active region of the United States and is susceptible to significant earthquake hazards. The principal earthquake source zones that threaten the three-county area are the Cascadia Subduction Zone, which is capable of producing interplate and deep intraplate earthquakes, and shallow crustal faults predominated by the South Whidbey Island, Seattle, and Tacoma fault zones. The Earthquake Team evaluated the seismic vulnerability of the water systems in the three-county area and developed potential intra- and interagency seismic mitigation recommendations.

The evaluation objectives were to evaluate earthquake hazards for the four earthquake scenarios, estimate post-earthquake water system response and restoration times, and identify potential mitigation measures to improve seismic resiliency for the three-county area. The Earthquake Team also reviewed post-earthquake level of service PE-LOS goals used by other water utilities and evaluated potential economic impacts from water loss following an earthquake event.

It is important to note that this earthquake evaluation was conducted using “high-level” analysis methods. Although these methods provide a general understanding of how a water system would respond to a specific earthquake scenario, more detailed analyses and site investigations are needed to more accurately estimate system performance and post-earthquake response. As such, the results of this evaluation should be considered preliminary and are subject to further detailed analysis. In some cases, more in-depth seismic studies are being conducted by individual utilities, independent of the Resiliency Project. Considering the greater depth of these studies, it is possible that the results of independent studies could vary significantly from the results summarized in this report. The results of independent studies could be incorporated into the regional earthquake evaluation during a later phase of the Resiliency Project.

2.1.1 Earthquake Scenarios

For this evaluation, the Earthquake Team selected the following four scenarios to capture the range of earthquake source zones and earthquake return periods that occur in the Puget Sound region. One subduction zone earthquake and three crustal fault zones were considered:

- Cascadia Subduction Zone, moment magnitude (M_w)[1] 9.0, 500-year return period
- South Whidbey Island Fault, M_w7.4, 2,700-year return period
- Seattle Fault – M_w6.7, 1,000-year return period
- Tacoma Fault – M_w7.1, 4,500-year return period

These scenarios are depicted in Figures 2 through 5, respectively, at the end of this report. The United States Geological Survey (USGS) estimates that there is a 14 percent chance of an M_w9.0 Cascadia Subduction event in the next 50 years and a 15 percent chance of an M_w6.5 or larger surface fault event in the Puget Sound in the next 50 years.

Cascadia Subduction Zone Scenario: The Cascadia Subduction Zone is a large zone that runs approximately 1,000 km (620 miles) from the southern end of British Columbia to the northern portion of California and would produce widespread ground motions west of the Cascade Mountains. For this earthquake scenario, an M_w9.0 event along the entire Cascadia Subduction Zone was modeled, focusing on impacts to the central Puget Sound.

South Whidbey Island Fault Zone Scenario: The South Whidbey Island Fault Zone Scenario evaluated an M_w7.4 event assumed to occur between Everett and the upper portion of the Snoqualmie Valley near North Bend, Washington. The scenario evaluated an M_w7.4 seismic event with the epicenter near Silver Lake, Washington

Seattle Fault Zone Scenario: The Seattle Fault Zone runs west-to-east across Puget Sound, through south Seattle, and along the Interstate 90 corridor, ending near Fall City, Washington. The scenario evaluated an M_w6.7 seismic event with the epicenter near south Bellevue, Washington.

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[1] M_w is the moment magnitude scale commonly used to measure the size (energy released) of an earthquake.

Tacoma Fault Zone Scenario: The Tacoma Fault Zone originates near the Hood Canal and runs eastward, splitting into three strands. The scenario used relocates the ground motion footprint to the southern strand, which passes along the edge of Commencement Bay and terminates just inland. The scenario evaluated an M_w7.1 seismic event.

2.2 Summary of Earthquake System Vulnerability Analyses

2.2.1 Facilities and Transmission System Analysis

Methodology

The transmission and supply facilities analysis evaluated large, critical infrastructure including surface and groundwater sources, headworks, treatment plants, transmission pipelines, terminal and major storage reservoirs, major water supply pump stations, and pipelines that supply or interconnect neighboring utilities. The system components selected for this analysis were those within the Everett Public Works, SPU, Tacoma Water, and CWA systems that the Earthquake Team considered critical to supply water to the distribution systems.

For each of the four earthquake scenarios, the Earthquake Team developed ground motion maps using ground motion data developed by USGS and provided in geographic information system format. These maps are presented in Figures 2 through 5 at the end of this report. The Team then used these ground motion maps to evaluate potential impacts on major water utility infrastructure.

The Earthquake Team analyzed impacts on facilities using the results of previous analyses, engineering judgment, and approximate methods developed in HAZUS-MH (Federal Emergency Management Agency 2015). Through this process, the Team identified the likelihood of damage to a facility and its associated functionality. Based on the damage, the Earthquake Team and utility representatives estimated the time it would take to restore a facility to operation either using temporary fixes or full repair. The restoration times took into account the damage state, available resources, and available repair crews.

The Earthquake Team analyzed impacts on transmission pipelines using the results of previous analyses, engineering judgment, and the methodology developed by the American Lifelines Alliances (ALA) (2001). The methodology includes damage relationships for pipe subjected to shaking and permanent ground deformation. The estimated restoration time of any particular pipeline is a function of the number and severity of leaks and breaks, and the available resources and repair crews. In some cases, system components would be bypassed to restore service while those components are repaired.

For this evaluation, restoration of water system functionality was defined as being able to supply average winter day demand to at least 90 percent of customers' taps.

Note that methodologies outlined by the ALA and HAZUS are appropriate for a high-level analysis but have some limitations. The performance of water systems is expected to range by plus 100 or minus 50 percent from the performance that may occur in any given earthquake. Although these methods provide a general understanding of how a water system would respond to a specific earthquake scenario, the results should be considered preliminary and highly approximate.

Water System Facilities and Transmission System Performance

The following discussion summarizes the results for each earthquake scenario. Note that the estimates for restoration times in this section are for the facilities and transmission systems only; these estimates do not include the time required to restore the distribution system.

Cascadia Subduction Zone Scenario, M_w9.0: This event would cause strong ground shaking intensity for 2 to 3 minutes, affecting all of the evaluated utilities. While the ground shaking of this event may not be as severe as a shallow fault earthquake, the duration and widespread nature of the Cascadia Subduction Zone event could have devastating impacts. Everett Public Works could have complete damage to Reservoir 2 and approximately 15 transmission system breaks/leaks. SPU's major transmission facilities (treatment facilities, pump stations, etc.) would remain functional, but SPU could have over 40 transmission pipeline breaks/leaks. Tacoma Water could have extensive damage to several key facilities and over 60 transmission pipeline breaks/leaks. CWA could have approximately two breaks in its Bellevue-Issaquah transmission pipeline (BIP). Under this scenario, the preliminary results of the earthquake evaluation suggest that it could take up to 30 days to restore average winter day demand to 90 percent of customers.

South Whidbey Island Fault Zone Scenario, M_w7.4: This event would result in strong shaking intensity near Everett Public Works' and SPU's Tolt supply facilities, and moderate shaking intensity at Tacoma Water's Green River facilities and CWA's BIP. Everett Public Works could have complete damage to Reservoir 2, extensive damage to several key facilities, and approximately 50 transmission pipeline breaks/leaks. SPU could have some moderate damage to several key facilities and over 50 transmission pipeline breaks/leaks. Tacoma Water could have slight or moderate damage to key facilities and over 12 transmission pipeline breaks/leaks. CWA could experience approximately three breaks in the BIP. Under this scenario, the preliminary results of the earthquake evaluation suggest that it could take up to 60 days to restore average winter day demand to 90 percent of customers.

Seattle Fault Zone Scenario, M_w6.7: This event would cause strong ground shaking intensity in Seattle and Bellevue and moderate to small shaking intensities in Everett and Tacoma. Everett Public Works could have no or slight damage to its facilities and approximately six transmission pipeline breaks/leaks. SPU could have extensive damage to several key facilities and over 50 transmission pipeline breaks/leaks. Tacoma Water could have slight or moderate damage to key facilities and over 20 transmission pipeline breaks/leaks. CWA could experience approximately three breaks and two leaks in the BIP. Under this scenario, the preliminary results of the earthquake evaluation suggest that it could take up to 60 days to restore average winter day demand to 90 percent of customers.

Tacoma Fault Zone Scenario, M_w7.1: This event would cause strong ground shaking in Tacoma, moderate to low shaking intensity in Seattle, and small shaking intensity in Everett. Everett Public Works could have no damage to its facilities and no breaks/leaks in its transmission system. SPU could have no or only slight damage to key facilities and potentially a few breaks/leaks in transmission pipelines. Tacoma Water could have complete or extensive damage to key facilities and over 60 transmission pipeline breaks/leaks. CWA would experience approximately two breaks and one leak in the BIP. Under this scenario, the preliminary results of the earthquake evaluation suggest that it could take up to 40 days to restore average winter day demand to 90 percent of customers.

2.2.2 Distribution System Analysis

Methodology

The ALA water pipeline seismic vulnerability models used to estimate transmission pipeline failures were also used in the distribution system analysis. A geographic information system overlay analysis was performed for the Everett Public Works, Tacoma Water, and SPU water distribution systems to determine the total number of distribution system failures. Pipeline material and joint type are key factors in estimating pipeline vulnerability. Rigid and brittle pipelines typically suffer higher failure rates than ductile pipelines.

The Earthquake Team held a workshop for interested water utilities in the three-county area to show them how to use the earthquake scenario and hazard maps to estimate water distribution system damage. Where possible, information on distribution system performance provided by workshop attendees was used in the analysis. The overall number of distribution system pipeline failures throughout the three-county area was estimated by extrapolating the available distribution system results. It is important to note that these results were generated using high-level analysis methods. As such, the results of this analysis should be considered preliminary and highly approximate.

Distribution System Performance for Full Three-county Region

Based on the extrapolation, the following water main failures are estimated in the three-county area for each scenario:

- M_w9.0 Cascadia Subduction Zone Earthquake – possibly as many as 5,000 to 6,000
- M_w6.7 Seattle Fault Zone Earthquake – possibly as many as 3,000
- M_w7.1 Tacoma Fault Zone Earthquake – possibly as many as 3,000
- M_w7.4 South Whidbey Island Fault Zone Earthquake – possibly as many as 4,000

Based on the number of water main failures in the distribution system, the preliminary results of the earthquake evaluation suggest that it could take up to 60 days to restore average winter day demand to 90 percent of customers.

2.3 Level of Service Goals

Post-earthquake level of service (PE-LOS) goals is the measure of performance of water systems following a seismic event. At the highest level, PE-LOS goals should measure the restoration time of water delivery to customers. Immediately after an earthquake, providing water for fire suppression and to critical facilities, such as hospitals, is the most important consideration. To restore economic activity and allow residents to return to normal activities, providing treated water to customer taps as quickly as possible is the next most important consideration. A complete analysis and designation of PE-LOS goals for the region and/or individual water utilities was not performed as part of this study. Each utility faces its own unique seismic risks, stakeholders, economic conditions, and costs to mitigate impacts, so a uniform set of PE-LOS goals may not be appropriate.

However, as an initial step in evaluating PE-LOS goals, the Earthquake Team conducted a survey of PE-LOS from agencies or professional organizations in the United States to identify parameters for measuring performance of water systems following a seismic event. Using these parameters, the Team estimated the current performance of SPU, Everett Public Works, and Tacoma Water systems. Based on this and the vulnerability analyses, the Earthquake Team estimated potential economic impacts associated with each earthquake scenario. The following discussion summarizes the results of these analyses.

2.3.1 Regional Water Treatment and Water Availability Performance

The Earthquake Team identified two commonly used parameters for evaluating PE-LOS performance: water supply, treatment, and transmission service levels and distribution system service levels. Water supply, treatment, and transmission service levels address the availability to provide treated water to terminal reservoirs or up to the distribution system connection points (that is, turn outs). Distribution system service levels address the availability of water to specific customer classes within the distribution system, such as hospitals, commercial and industrial users, and residential customers.

Based on the analysis of earthquake scenarios, the Earthquake Team estimated performance of the existing systems in the three-county region. The results suggest that following the Cascadia Subduction Zone scenario, water suppliers could provide full treatment service levels to their wholesale customers within 3 days and full distribution system average winter day demand service levels to 90 percent of all customers within approximately 30 days. Following one of the crustal earthquake scenarios, water suppliers could provide full treatment service levels to their wholesale customers within 7 days and full distribution system average winter day demand service levels to 90 percent of all customers within approximately 60 days. Because of pipeline damage under all scenarios, “disinfect before drinking” orders would likely be in place for a month or more.

This performance is below the performance goals that other utilities have set for their seismic programs, which generally call for the restoration of water service within 14 to 30 days of the event and for the system to at least remain functional enough to provide firefighting water immediately after the event

2.3.2 Potential Economic Impacts

Each Forum utility member is at a different level of understanding and analyses of economic losses attributable to an earthquake. Tacoma Water has recently conducted a detailed economic analysis for all earthquake scenarios except for the Seattle Fault scenario. For this study, the Earthquake Team used a simplified approach for Everett Public Works and SPU/CWA to calculate the potential economic impacts resulting from water loss following an earthquake. The simplified approach focuses on the economic loss to the community due to complete water outage, based on the Federal Emergency Management Agency value of $103/person/day. Based on the earthquake scenario vulnerability evaluations, the Earthquake Team estimates that the potential direct and indirect economic losses from water system damage alone could exceed $2 billion (see Table 1). This result should be considered preliminary. Additional economic analysis would be needed to determine the true economic losses from water loss related to an earthquake event.

2.4 Earthquake Mitigation Measures

The Earthquake Team identified initial potential mitigation options that would enhance the resiliency of the three-county area and provide the ability to respond and recover quickly following an earthquake event, thus improving service levels following an earthquake. These measures could help bring the water system performance in the three-county area closer to the post-earthquake performance defined by other utilities surveyed.

The Team identified mitigation options in three categories: interutility mitigations, intrautility mitigations, and general mitigation measures. These initial mitigation measures are based on the analysis of the four earthquake scenarios, expert opinion, and discussions with utility representatives. These mitigation measures would need to be evaluated in detail during a later phase of the Resiliency Project.

2.4.1 Intersystem Mitigation

Interties between systems would allow the movement of water from systems that experienced less damage after an earthquake to systems that experienced more damage. The Earthquake Team considered four proposed potential interties that could benefit the region: an SPU-

Tacoma Water Intertie, an SPU-Everett Public Works Intertie, a Tacoma Water-Lakehaven Intertie, and a Tacoma Water-Lakewood Intertie.

2.4.2 Intrasystem Mitigation

Mitigation options for individual utilities might include upgrading vulnerable facilities and transmission lines, developing earthquake response plans, performing regular updates to seismic vulnerability evaluations, investing in secondary water supplies, and securing necessary equipment and materials to perform system repairs.

2.4.3 General Mitigation

In addition to the mitigation options listed above, the Earthquake Team identified the following general mitigation measures that could contribute to individual utility and/or regional earthquake resiliency:

- Evaluate emergency power supplies for surface and groundwater facilities.
- Stockpile pipe repair materials for transmission and distribution mains and necessary equipment such as excavators.
- Exercise essential wells regularly.
- Replace high-risk pipes with seismically resilient pipes.
- Develop and maintain groundwater supplies.
- Consider the installation of seismic valves at major zones of liquefiable soils and at large reservoirs.
- Enhance regional emergency preparedness and response planning by working with local fire departments, sharing emergency potable water supply equipment such as bladders, developing mutual aid programs, and developing a regional emergency response plan.

2.5 Conclusions

Table 1 summarizes the estimated number of days each utility would need to restore its facilities and transmission and distribution system to deliver average winter day demand levels to 90 percent of all customers. Table 1 also summarizes the associated direct and indirect economic losses resulting from water shortages following each earthquake scenario.

Note that the restoration times and economic losses shown in Table 1 are for the facilities and conveyance systems (transmission and distribution) required to deliver average winter day demand to 90 percent of all customers; these estimates do not include the restoration time or cost required to restore the entire system to pre-event level. These results were generated using high-level analysis methods. Although these methods provide a general understanding of how a water system would respond to a specific earthquake scenario, the results should be considered preliminary and highly approximate.

Table 1 Facilities and Conveyance System Restoration Times and Associated Economic Losses (Preliminary Estimates)

Utility	Earthquake Scenario (Days to restore supply to 90 percent of customers' taps at average winter day demand, economic losses in $ million attributable to water shortages)[a]			
	Cascadia Subduction Zone	**South Whidbey Island Fault**	**Seattle Fault**	**Tacoma Fault**
Everett Public Works	7 days, $70M	30 days, $490M	$10M[b]	$0[b]
SPU/CWA	14 to 30 days, $810M	30 to 60 days, $1,550M	30 to 60 days, $1,770M	3 to 7 days, $240M
Tacoma Water	30 days, $750M	$20M[b]	not evaluated	40 days, $1,110M
Total loss	$1,630M	$2,060M	$1,780M	$1,360M

[a] Results presented in this table were generated using high-level analysis methods. Therefore, these results should be considered preliminary and highly approximate.

[b] Greater than 90 percent of customers are expected to have water service immediately following the earthquake event.

At the conclusion of this Phase 1 work, the Earthquake Team identified various opportunities for additional research, data development, and analysis that extended beyond the Phase 1 effort described in this report. These include: further development of mitigation measures; outreach to customers, utilities, and elected officials; definition of PE-LOS goals for water utilities in the three-county region; further evaluation of infrastructure damage (including damage to other lifeline infrastructure); further evaluation of economic impacts; and coordination with other lifeline sectors.

3.0 Water Quality Resiliency Evaluation

3.1 Overview of Water Quality Resiliency Evaluation

In general, water quality risk includes any events that disrupt the continued delivery of a safe and acceptable drinking water supply. The primary objectives of the water quality resiliency evaluation were to identify a comprehensive list of possible risk events that could compromise drinking water quality, use a risk analysis framework to prioritize possible risk events, select the top six prioritized risk events, and identify effective mitigation measures for each of the six selected risk events. The evaluation focused on better understanding risk events that could have a considerable impact on regional water quality and conducting a preliminary review of options for mitigation.

3.2 Summary of Risk Identification Process

3.2.1 Methodology

The Water Quality Team identified an initial comprehensive list of possible risk events that could compromise water quality in the three-county area. A list of 25 risk events was developed through this effort. Definitions were given for each event to ensure that the risk was evaluated based on the Water Quality Team's perception of that event definition.

Next, the Water Quality Team categorized risk events within the context of a multibarrier approach to protecting public health and developed a list of existing water system assets that fell within each multibarrier category. Multibarrier approach categories include: source water protection; effective source and system treatment; transmission, storage, and distribution integrity; and monitoring and testing.

The Water Quality Team developed a risk analysis framework based on likelihood and consequence to prioritize the initial list of risk events. The Team ranked risk events based on likelihood of occurrence, ranging from once every 100 years to once per year. The Team ranked the consequence of the event for three subareas: water quality, financial/economic, and population affected. A consequence scale was applied to each subarea. The total risk event consequence was then determined by summing the subarea scores for each risk event.

3.2.2 Priority Risks Identified

The Water Quality Team sorted the risk events based on the likelihood and consequence scores to determine whether each risk event would be best addressed by day-to-day operations, routine tactical planning, immediate emergency planning, or strategic planning. Based on this evaluation, the Team selected six risk events to advance toward mitigation measure identification: wildfire, volcanic eruption, resource supply chain, severe adverse weather, accidental contamination, and earthquake (in the context of water quality). While these six topic areas are not necessarily independent of each other (an earthquake can cause an interruption to the supply chain, for example), individual analyses considered different details.

These risk events were selected since each event (1) would apply to or affect many small, medium, and large-sized utilities in the tri-county area; (2) has common mitigation measures that can be readily identified and developed for all utilities to use; and/or (3) is not necessarily already covered by readily available published literature or current utility planning and operating procedures. Each of these risk events is discussed in detail in the following sections.

3.3 Water Quality Implications of the Six Risk Events

The following sections provide an overview of the work related to each prioritized risk event.

3.3.1 Wildfire

The potential water quality effects of a wildfire vary widely and are site-specific. Because the vast majority of the region's drinking water comes from surface water resources, the impacts of wildfire are potentially significant. The watershed recovery rate is highly variable depending on the intensity and duration of the fire. In general, water quality impacts to surface water supplies resulting from wildfire include increases in turbidity and total suspended solids, nutrient loading, pH, alkalinity, temperature, and metals, as well as effects of suppression chemicals.

3.3.2 Volcanic Eruption

Each volcano can differ in the severity and extent of hazards it produces. Mt. Baker, Mt. Adams, Glacier Peak, Mt. Rainier, and Mt. St. Helens are all active volcanoes in Washington State. Volcanic hazards most likely to occur and posing the greatest threat to water quality in this region include ash fall, tephra falls (rock fragments ejected during an eruption), and lahar flows (debris flows caused when pyroclastic material mixes with snow, causing rapid mudflows with the potential to travel long distances). In general, water quality impacts on surface water supplies due to volcanic eruptions include increases in turbidity, acidity, and metal concentrations.

3.3.3 Resource Supply Chain

Water treatment supply chain issues could significantly upset water treatment plant operations and thereby potentially have an immediate adverse effect on public health, lead to regulatory violations, or require boil water orders. A resource supply chain risk event was defined as an inability to get staff, chemicals, fuel, or equipment to water treatment facilities by road. The definition also included inadequate availability of water treatment chemicals and critical equipment and issues with chemical quality. This could result in the inability to produce safe and reliable drinking water despite adequate water supply.

3.3.4 Accidental Contamination

An accidental contamination risk event is defined as when a fuel, oil, or any hazardous material contaminates a utility's water supply and creates unsafe drinking water conditions. For this study, the focus of accidental contamination is at the source water prior to reaching the withdrawal point (intake or well). Naturally occurring contamination or internal chemical overdosing are not included. Unless the source water lies in a completely protected environment where human activity is minimized, the source water is subject to accidental contamination. If utilities lack an alternative water source, the option to close off their treatment facilities may not be feasible and contaminants may bypass treatment, which could eventually lead to the distribution system and put consumers at risk.

The use of early warning systems has been implemented by many utilities across the nation as a means of detecting a spill. Early detection of an accidental contamination event can help delay or prevent a chemical spill from reaching the withdraw point. In addition, understanding where water flows and areas that can be used to divert a spill are some ways utilities can prevent a contaminant from reaching the withdraw point. Utilities can also apply a multibarrier approach, which involves installing instrumentation and monitoring systems that can measure various parameters to detect changes in water quality throughout the system.

3.3.5 Severe Adverse Weather

While the focus of this particular risk is short-term adverse weather events rather than long-term climate change, it has generally been recognized that the frequency of high-intensity, short-duration events in the region (for example, wind and rain) appears to be increasing. Examples of severe, adverse weather include intense wind, snow, rain, lightning, or ice storms of sufficient magnitude to trigger flooding, freezing, fires, landslides, or power loss that affect systems and could jeopardize water quality. Impacts could include treatment facility failure, equipment damage, communication loss, supervisory control and data acquisition (SCADA) loss, supply chain disruptions, and inability for employees to come to work.

3.3.6 Earthquake

Earthquakes can pose risks to water quality by damaging critical infrastructure, producing tsunamis that inundate low-elevation areas, leading to supply chain disruptions, causing major landslides, and potentially damaging or disrupting groundwater supplies—nearly simultaneously. Water quality risks to surface waters include increased turbidity because of earthquake-induced landslides. Potential impacts on groundwater quality can result from mixing of water between different aquifers, influx of water from different areas, changes in dissolved gas and mineral concentrations, and infiltration of pollutants from soil or ground surface. Earthquakes can also damage source water treatment facilities, thereby affecting their ability to ensure continued operation and production of clean drinking water. Earthquakes can also damage pipelines, resulting in cross-connection contamination and/or introduction of microbial or chemical contaminants.

3.4 Water Quality Mitigation Measures

To prepare for and respond to these six risk events, the Water Quality Team identified potential mitigation measures. The Team considered the following five types of mitigation measures:

- Preventative: measures to lessen the long-term probability of a water quality risk occurrence
- Pre-event: measures to lessen the severity of a water quality risk, if it were to occur
- Detection: measures to determine whether the risk event has occurred
- Immediate response: measures to response to the risk event as it is occurring
- Recovery: measures to clean up after the risk event and return production of safe, acceptable drinking water

The Team developed a comprehensive list of potential mitigation measures for each risk event. General measures identified include the following:

- Emergency preparedness and response planning
- Incident training
- Mutual aid agreements
- Mapping of risk locations
- Increased system monitoring and surveillance
- Interties and water storage redundancy
- Supply (chemicals/parts/fuel) redundancy and backup power and vendors
- Public outreach including messaging for boiled water and access to drinking water
- Mandatory curtailment

3.5 Conclusions

This water quality evaluation identified a comprehensive range of potential risk events that could affect drinking water quality in the central Puget Sound region. From this, the Team determined that wildfire, volcanic eruption, resource supply chain, accidental contamination, severe adverse weather, and earthquake would pose risks of an immediate, emergency nature with high consequences to water quality if they were to occur. The Team identified preventative, pre-event, detection, immediate response, and recovery mitigation measures that could be implemented to help alleviate the impact of these risk events. Individual drinking water utilities should consider their own utility's resiliency against each risk event and which mitigation measures are reasonable and feasible to implement in the short- and long-term.

At the conclusion of this Phase 1 work, the Water Quality Team recognizes that this effort has framed the risk topics, and additional effort is needed to better delineate the conditions where each of the risk areas pose an actual failure threat. This "break the system" analysis would better inform the level of effort and investment needed to enhance regional resiliency. Additional work done in Phase 2 might include evaluation of critical risk locations, worst-case scenarios capable of leading to water quality failure, impacts on water utilities in the three-county region, and mitigation measures that could be implemented.

4.0 Drought Resiliency Evaluation

4.1 Overview of Drought Resiliency Evaluation

Under drought conditions, reduced precipitation and/or extended warm dry periods may reduce water availability to meet normal instream and out-of-stream water needs. Those same conditions can also increase demands for municipal water supply as outdoor uses increase. The result can be insufficient water supply to support essential and desired uses, causing adverse environmental, economic, and social consequences.

The drought resiliency evaluation examined the adequacy of regional municipal water supplies during drought conditions, with the intent of identifying drought vulnerability and evaluating proactive and responsive measures that could mitigate drought risk beyond the measures that currently exist.

To this end, the Drought Team completed a water supplier survey, evaluated two drought scenarios, and evaluated regional groundwater supplies. The following subsections summarize the methodology and findings from the analyses and survey.

4.2 Summary of Water Supplier Survey

The drought resiliency evaluation focused on the region's three major water suppliers (Tacoma Water, SPU, and Everett Public Works) plus a generalized review of regional groundwater resources. CWA was evaluated as part of the SPU analysis. To understand potential areas of vulnerability within the region, the Drought Team also surveyed the smaller water utilities in the region to gather information on their concerns and preparedness for drought.

The survey results suggest that water utilities in the region consider drought an important issue and have implemented some measures to prepare for water shortages, including primarily demand management tools, emergency interties, and emergency/backup water supplies. Survey respondents considered their water supply sources (surface water reservoirs, wells, and tanks) as the system components most vulnerable to drought risks. Approximately 40 percent indicated that they would be better prepared for drought and other risks if emergency/backup water supplies were implemented. The Drought Team considered these survey results while framing and conducting the drought resiliency evaluation.

4.3 Summary of Drought Scenario Analyses

4.3.1 Drought Scenarios and Methodology

The Drought Team evaluated whether each of the major water suppliers in the region (SPU, Tacoma Water, and Everett Public Works) would have enough supply to meet 2015 and 2035 forecast demand levels under a severe drought. CWA was evaluated as part of the SPU analysis, which includes CWA's block contract in the demand forecast. The Team defined meeting demand as the ability for water suppliers to manage supply and demand factors using existing water shortage response tools, short of implementing mandatory curtailments. If mandatory curtailments were required, the Team considered that a failure to meet customer demands. However, voluntary curtailments, changes to reservoir operations, use of emergency supplies, and other existing shortage response tools could be employed to allow water suppliers to meet customer demands.

This evaluation included defining and testing two drought scenarios: an actual historic drought scenario and a potential extreme drought scenario. In both scenarios, the analysis assumes that water suppliers continue to meet existing requirements and commitments for instream flows and mitigation, including existing tribal agreements, instream flow rules, and commitments made to regulating agencies. The analysis was based on existing water supplies; it does not evaluate potential new sources.

Historical Drought (Scenario 1)

The Drought Team selected the chosen Scenario 1 drought event based on historical records. Through review and analysis by the major regional suppliers, a historical hydrologic drought was identified. This proved to be the 1987 drought, which was the most severe 1-year drought on record. SPU, Tacoma Water, and Everett Public Works analyzed their surface water system performance under 1987 hydrologic conditions given planning-level 2015 and 2035 demands. The utilities also adjusted their respective demand forecasts to “hot, dry summer” demand levels that could also occur in a drought year. Based on the length of the historical record, this drought was expected to represent the most severe conditions in 50 years.

This drought resiliency assessment was performed in 2015, which coincidentally turned out to be a State-wide drought year. As such, the 2015 drought was subsequently analyzed for comparison with the 1987 drought (worst drought on record). The 2015 drought was hydrologically different than the 1987 drought. The 1987 drought was primarily a “summer and fall drought” in which there was very little precipitation and extremely low stream flows that persisted into early December before conditions improved. The 2015 drought began with extremely low snowpack levels and hot, dry conditions from roughly late-March through early July. A rain event in July and another in August improved the 2015 conditions, and fall rains returned in late October – effectively ending the drought. SPU, Tacoma Water and Everett Public Works analyzed the 2015 drought using the same assumptions and modeling techniques as the 1987 drought.

To explore potential multiyear effects of a prolonged drought, the Drought Team considered water supply impacts of the worst drought year on record (1987) by evaluating a continuous time series from 1986 to 1988, and observing the reservoir level impacts that occurred. The Drought Team determined that the impact on surface water supplies was not worsened by this type of multiyear drought. This is because carryover storage in SPU’s, Tacoma Water’s, and Everett Public Works’ reservoirs is already limited to allow for winter flood events. Therefore, reservoir levels essentially reset each year, and there was no compounding effect over multiple years. Therefore, the Drought Team decided that for this study a multiyear drought scenario did not require additional evaluation beyond that of Scenario 1.

Extreme Drought (Scenario 2)

The Drought Team developed a second scenario, which increased the severity of the 1987 drought to a point where the supply systems failed to meet projected demands, even with certain demand and supply management measures taken. The Team reduced inflow conditions from the 1987 recorded flows to identify the point when the three regional systems would fail to meet projected demands. The Team determined that a drought with inflow conditions at least 25 percent lower than the low flows of the 1987 drought was needed to reach this threshold, based on analysis of SPU’s and Tacoma Water’s systems. For consistency and comparison purposes, Everett Public Works’ water system was also analyzed under this scenario.

4.3.2 Drought Scenario Findings

The following summarize the findings from each drought scenario analysis:

Historical Drought Scenario (Scenario 1)

SPU, Tacoma Water, and Everett Public Works would have sufficient supply to meet the 2015 and 2035 forecast hot, dry summer demand levels if the worst drought on record (1987) repeated itself. To meet these demands, a variety of existing tools would need to be used. Existing tools implemented in this scenario to meet 2035 demands included modifications to reservoir operations, use of emergency or reserve supplies, voluntary customer curtailments, and reductions in instream flows.

When comparing the 1987 and 2015 drought experiences, SPU, Tacoma Water and Everett Public Works all found that the 1987 drought was still considered the worst on record. Modeling of 2015 drought conditions revealed that existing supplies would be able to meet 2035 forecasted demand levels if the 2015 drought were repeated.

Extreme Drought Scenario (Scenario 2)

This drought resiliency evaluation found that if the region were faced with a drought that had approximately 25 percent lower inflows than the 1987 drought, SPU's and Tacoma Water's available supplies would begin to fall below levels needed to meet 2035 demands. This is even with the use of wells, switching to the lowest allowable minimum instream flows, and reducing demands through voluntary customer curtailments. Everett Public Works would retain some supply buffer at this level of reduced inflow. Under this scenario, Everett Public Works would implement voluntary customer curtailments and reductions in instream flows.

4.4 Summary of Regional Groundwater Analysis

4.4.1 Goundwater Analysis Methodology

The Drought Team developed a separate evaluation of the resiliency of groundwater supplies and the level of coincidence of groundwater depletion with surface water shortages. This evaluation included examining the susceptibility of different types of aquifers to drought, and the various drought conditions that affect groundwater resources in the short- and long-term. Additional information on this analysis and findings can be found in the *Regional Groundwater Drought Risk Resiliency Evaluation* (Robinson Nobel 2015).

4.4.2 Goundwater Analysis Findings

Groundwater sources are generally more resilient to drought than surface water sources. Many groundwater sources appear to be relatively unaffected by short-term events. Nonetheless, drought conditions can stress groundwater resources in the central Puget Sound region. In particular, extended, multiyear drought with low precipitation (not just low snowpack) would have the largest potential impact on groundwater resources. This would be especially problematic if the extended drought included hot, dry summers that increase demand and prompt larger withdrawals from aquifers.

There are three main landform regimes in the Puget Sound region: major river valleys, glaciated uplands, and foothills/mountains. In general, the foothills/mountain aquifers are typically the most vulnerable, and the major river valley aquifers are the least vulnerable. This is largely due to the size of the aquifers in these regimes.

In general, improving retention of water during wet periods and promoting infiltration or direct injection would contribute to improving conditions for vulnerable aquifers. Development of aquifer storage and recovery systems or other enhanced recharge techniques can also offer potential means of improving the resiliency of groundwater supplies to droughts.

4.5 Drought Mitigation Measures

The Drought Team evaluated potential additional measures, beyond existing tools, that could be implemented to mitigate drought conditions. Potential measures identified include developing new sources of supply, expanding storage, constructing interties between systems, implementing operational modifications, promoting additional demand reduction, and using reclaimed water. Note that the accessibility of these potential measures during a critical drought year would need to be evaluated further.

4.6 Conclusions

The evaluation of drought susceptibility generally showed that the three-county area is well-positioned for relatively severe droughts of the type anticipated in this evaluation. Water utilities in the region consider drought an important issue and have implemented some measures to prepare for water shortages. SPU, Everett Public Works, and Tacoma Water would have sufficient supply to meet the 2035 forecast hot, dry summer demand levels if the worst drought on record (1987) repeated itself. Under this scenario, SPU, Everett Public Works, and Tacoma Water were able to manage supply and demand relationships by using existing water shortage response tools, short of implementing mandatory curtailments, to meet customer demands. However, SPU and Tacoma Water would be unable to meet 2035 demands if a drought with approximately 25 percent lower inflows than the 1987 drought were to occur. Everett Public Works would retain some supply buffer at this level of reduced inflow. Groundwater sources are less vulnerable to a single-year drought than surface water. However, multiyear periods of reduced precipitation could lead to aquifer decline or depletion. Additional mitigation measures, beyond existing measures, could be developed to better respond to drought conditions.

At the conclusion of this Phase 1 work, the Drought Team identified additional investigations that contribute to the understanding of drought impacts. These additional investigations include evaluation of 2015 drought conditions, refinement of drought preparedness criteria, evaluation of mitigation measures, review of institutional and regulatory challenges affecting drought response, analysis of vulnerabilities facing the region’s smaller water systems, and further analysis of groundwater systems.

5.0 Climate Change Resiliency Evaluation

5.1 Overview of Climate Change Resiliency Evaluation

Climate change is projected to alter the water cycle and sea levels in varying ways around the globe. These alterations could include, but not be limited to, increases in temperature affecting snowpack accumulation and the timing of snowpack melt, increases in the intensity of rainfall as well as increases in the frequency and/or intensity of drought and the length of dry-spells, effects on evapotranspiration, and increases in water levels along marine shorelines. What alterations occur and their magnitude and intensity will vary temporally and spatially across the world, as well the resulting impacts on water resources. It is critical that water utilities enhance their understanding of how the water cycle will be altered by climate change in the geographic area where they operate to determine whether the alterations will introduce new risks or exacerbate existing ones.

To this end, the objectives of the Climate Change evaluation were to investigate how climate change may affect surface and groundwater supplies, migration of people, water quality, and wildfire in the region. Section 5.2 summarizes the methodology and findings of these five evaluations.

5.2 Summary of Climate Change Evaluations

The Team relied on existing research or analysis conducted by others rather than conducting new and original research. As a result, the findings described here have varying degrees of specificity and applicability to the central Puget Sound region, as well to individual utilities. In aggregate, however, they provide an indication of additional areas of exploration for the Forum and individual utilities to consider.

5.2.1 Surface Water Supply Evaluation

Background – Seattle Public Utility's PUMA Analysis

In 2013, SPU initiated a project called Piloting Utility Modeling Applications (PUMA) to update Seattle's impacts evaluation that was included in the Forum's 2009 Regional Water Supply Outlook. This project is ongoing, and SPU has not yet generated final results. As such, the initial results of a subset of potential worst-case scenarios should be considered preliminary and are subject to further quality review and analysis. Initial climate scenario modeling results suggest that SPU's existing available water supply could be reduced by 0 to 50 percent from 2001 to 2050, and by 18 to 73 percent from 2051 to 2099. These preliminary and partial results suggest a larger decrease in available supply for SPU's system under climate change than previous studies.

Correlation Analysis

Methodology

SPU's PUMA project focused only on Seattle's surface water supplies. To determine whether the findings of SPU's PUMA analysis could be extrapolated to the Everett Public Works and Tacoma Water systems, the Climate Change Team developed a correlation analysis of the streamflows feeding utilities' major water supply sources in the central Puget Sound area and a potential future source. The four major existing sources are: (1) Sultan River (Everett Public Works), (2) South Fork Tolt River (SPU), (3) Cedar River (SPU), and (4) Green River (Tacoma Water). A potential future source is the White River (CWA). Where possible, the Climate Change Team used unregulated flows on these river systems to get a more accurate estimate of flow correlations. The Team developed a flow correlation among the five river flows using mean monthly historic flows from the USGS.

Findings

The results of the correlation analysis suggest that there is a strong correlation between the five major water supply sources. Additionally, the analysis found that the closer the river basins, the stronger the correlation.

Based on this correlation analysis, the Climate Change Team determined that there would be value in extrapolating SPU's PUMA analysis to the Everett Public Works and Tacoma Water systems. This work would be completed during a later phase of the Resiliency Project. In addition, that Team determined that interties would likely not increase resiliency to droughts, since during a drought all systems would experience similar streamflow conditions. This was exemplified during the 2015 drought when precipitation, snowpack, streamflows, and storage values were very similar between Everett Public Works, SPU, and Tacoma Water. However, the Team recommends additional analysis before drawing a firm conclusion on the value of interties for drought resiliency. In particular, the drought evaluation presented in Section 4.0 of this report suggests that although streamflow conditions may be similar, the water supply available to each utility during a drought would differ.

5.2.2 Groundwater Supply Analysis

Building on the groundwater evaluation described in Section 4.4, the Climate Change Team evaluated the vulnerability of groundwater supplies in the three-county area to sea level rise and the long-term effects of climate change. Additional information on this analysis and findings can be found in the *Regional Groundwater Drought Risk Resiliency Evaluation* (Robinson Nobel 2015). In addition to the sea level rise analysis, the Climate Change Team conducted a desktop review of aquifer exposure to inundation attributable to sea level rise.

Findings

The following discussion summarizes the findings of the groundwater evaluation:

- Climate change is projected to produce only small changes in total annual precipitation in the three-county region. Therefore, groundwater sources in the three-county area may continue to receive the same recharge volumes as they currently do. This result could vary depending on the potential sensitivity of aquifer recharge to rainfall intensity and future land use changes that could limit infiltration.
- Climate change is projected to produce drier, warmer summers, which could decrease surface water flows. This could result in water level declines in aquifers that are in direct continuity with river flow levels. Climate change could result in snowmelt and runoff occurring earlier in the season. This could shorten the groundwater recharge season.
- Mainland aquifers that currently provide supplies do not appear to be at a significant risk of inundation from sea level rise. Given the cursory nature of this review, additional studies are merited before drawing firm conclusion about relative exposure to sea level rise.

5.2.3 Climate-induced Migration Analysis

There is an emerging concept that the central Puget Sound region may be spared from severe climate change impacts and, therefore, might experience significant immigration to the region from other areas that experience dramatic reductions in water supply, unbearable temperatures, and/or coastal inundation. As a result, questions have been raised whether utilities are appropriately incorporating climate-induced migration into their population growth assumptions.

Methodology

For this analysis, the Climate Change Team drew on existing research conducted by a graduate student, Alison Saperstein, at the University of Washington. As part of her research paper, Saperstein conducted a systematic review of peer-reviewed literature, media coverage, and government reports to assess a “climate refugee hypothesis.” The findings below are a distillation of Saperstein’s graduate research paper, *Climate Change, Migration, and the Puget Sound Region* (Saperstein 2015).

Findings

The results of Saperstein’s study suggest that there is not a direct, unimpeded causal link between climate change and population flows. Migration is considered to be multicausal, but driven primarily by economic factors. Therefore, a sudden and dramatic population increase resulting from climate migration is unlikely to occur. In general, migration tends to be self-perpetuating (future migration tends to follow current migration).

5.2.4 Water Quality Analysis

One of the anticipated impacts of climate change within the Pacific Northwest is the long-term change in streamflow and streamflow temperatures because of changes in flow volume associated with anticipated increased variability in runoff timing and intensity and increased air temperatures. These changes are expected to produce commensurate impacts on water quality in the lakes, rivers, and streams of the central Puget Sound region.

Methodology

The Climate Change Team developed a literature review of research materials that would help the Forum better understand the threats to water quality because of the impacts from climate change as they relate to the Puget Sound region. The Team also reviewed Washington State Watershed Management standards to better identify climate impacts that would result in the exceedance of these standards.

Findings

Overall, the literature indicates that water quality risks resulting from climate change may include increased temperatures, increased variability in streamflows, increased nutrient loading, decreased oxygen saturation, altered lake stratification and turnover, increased turbidity levels, and increased harmful algae blooms. The impact of these potential risks on specific water supply operations in the three-county area and the ability to provide water to customers was not determined as part of this literature review.

However, from this information, the Climate Change Team identified water quality implications specific to the three-county area. The Team identified the following implications:

- Continued robust water management strategies are needed to maintain clean water for people.
- Stream temperatures will likely increase in the future. This may lead to secondary impacts of nutrient and sedimentation loading and harmful algae blooms.
- Increased variability in streamflows is expected to produce significant adjustments to short-term and long-term water management decisions.
- Changes in nutrient loading, dissolved oxygen levels, and lake stratification and turnover could affect the water quality of reservoirs in the Puget Sound region. For example, changes in nutrient loading could increase algae formation.
- Increases in wintertime precipitation and runoff may increase turbidity levels in the reservoirs of the Puget Sound region.
- Analysis of the potential risk of an increase in harmful algae blooms in the Puget Sound region is needed, especially in shallower reservoirs such as Lake Tapps.

5.2.5 Wildfire Risk Analysis

The drinking water watersheds for the large surface water providers in the central Puget Sound region are heavily forested and/or adjacent to large tracts of forested land. As such, wildfire has long been considered a potential risk to the landholdings of the region’s water suppliers and to drinking water quality. Given that climate change will likely lead to higher temperatures and possibly drier summers in the central Cascades, a working assumption is that climate change may exacerbate current wildfire risk.

Methodology

SPU conducted an evaluation of the risk of wildfire related to climate change. This analysis was conducted using SPU's PUMA project and an index developed by the National Fire Danger Rating System called the Energy Release Component. This approach was used to assess how fire intensity could potentially be affected by climate change. The PUMA project is ongoing, and SPU has not yet generated final results. As such, the initial results presented here should be considered preliminary and are subject to further quality review and analysis.

SPU conducted this wildfire analysis independent of the Resiliency Project. However, the results of this analysis are applicable to the region since the geographic area covered in this analysis includes northwestern Washington (including the central Puget Sound watersheds) and central Washington.

Wildfire Findings

The draft findings from the PUMA project are subject to change. Initial results suggest that climate change is likely to increase the frequency of high fire days, with the most increases during the peak season in August. Increases in high fire danger days are projected to be smaller on the western side than the eastern side of the Cascade Range.

5.3 Conclusions

The climate change evaluation generally showed that climate change may have the following impacts on water suppliers in the three-county area:

- Reduction in water availability may be greater than suggested by previous studies.
- There is a strong correlation between the five major water supply sources in the region. The closer the river basins, the stronger the correlation.
- Groundwater resources are likely to be relatively robust in the face of climate change compared with surface water. Mainland aquifers that currently provide significant supplies appear to not be at significant risk to inundation from sea level rise.
- There is not a direct, unimpeded causal link between climate change and population flows. A sudden and dramatic population increase attributable to climate migration is unlikely to occur.
- Continued water quality management strategies are needed in the Puget Sound region and additional research are needed to better understand and address potential water quality risks resulting from climate change such as increased temperatures, increased variability in streamflows, increased nutrient loading, decreased oxygen saturation, altered lake stratification and turnover, increased turbidity levels, and increased harmful algae blooms. Note that the impact of these potential water quality risks on specific water supply operations and the ability to provide water to customers was not determined as part of this analysis.
- Climate change is likely to increase the frequency of high fire days.

At the conclusion of this Phase 1 work, the Climate Change Team identified additional investigations that would contribute to the understanding of climate change impacts. Additional investigation may include extrapolation of the results of SPU's PUMA analysis to Everett Public Works' and Tacoma Water's systems, further evaluation of groundwater resources and sensitivity of recharge, further consideration of migration drivers and pathways, application of water quality evaluation methodologies to the Puget Sound region, and evaluation of wildfire scenario results and assumptions.

6.0 Summary of Resiliency Evaluations and Conclusions

The purpose of the Resiliency Project is to evaluate the adequacy of regional municipal water supplies when confronted with earthquake, water quality, drought, and climate change risk events. To this end, the risk teams evaluated these risk topics and, where possible, identified water system vulnerabilities and measures that could mitigate risks. This section summarizes the findings and regional implications, potential mitigation opportunities, and areas needing further investigation identified by each risk team.

The following subsections summarize the risk evaluation findings and regional implications identified by each risk team.

6.1 Earthquake Resiliency Evaluation

Preliminary results of the earthquake evaluation suggest that for each earthquake scenario, at least one of the major water suppliers (SPU, Everett Public Works, Tacoma Water) in the three-county area could take up to 60 days to restore average winter day demand to 90 percent of customers. This performance is below the performance goals that surveyed utilities in other regions have set for their seismic programs (between 14 and 30 days). The Earthquake Team determined that the potential direct and indirect economic losses from water system damage alone could exceed $2 billion. A subduction earthquake will significantly affect almost all water systems in the three-county area. The surface fault events will create more severe damage, but damage will be more localized. Surface water supplies are likely to be most affected by seismic events. It is important to note that these results were generated using high-level analysis methods. As such, the results should be considered preliminary and highly approximate.

To improve the seismic resiliency of water systems in the three-county area, the Earthquake Team recommends that water utilities perform outreach to increase awareness of this risk, develop more detailed analyses of water system seismic vulnerability, and increase interutility cooperation and knowledge sharing to improve the water system seismic resiliency in the three-county area.

6.2 Water Quality Resiliency Evaluation

The Water Quality Team determined that wildfire, volcanic eruption, resource supply chain, accidental contamination, severe adverse weather, and earthquake would pose risks of an immediate, emergency nature with high consequences to water quality in the three-county area if they were to occur. Specific implications for the three-county area include the following:

- Wildfire in the watershed can increase water turbidity, nutrient loading, pH, alkalinity, temperature, and metals, as well as pose risks from the effects of suppression chemicals.
- Volcanic hazards can reduce water availability and can increase turbidity and acidity.
- Water treatment supply chain issues could significantly upset water treatment plant operations and thereby potentially have an immediate adverse effect on public health, lead to regulatory violations, or require boil water orders.

- Accidental contamination can contaminate a utility's water supply and create unsafe drinking water conditions. The use of early warning systems and a multibarrier approach can help reduce the impacts of such an incident.
- Severe adverse weather could result in treatment facility failure, equipment damage, communication loss, SCADA loss, and supply chain disruptions.
- Earthquakes can damage critical infrastructure, lead to supply chain disruptions, reduce water availability, and potentially damage or disrupt groundwater supplies.

Individual drinking water utilities should consider their own utility's resiliency against each risk event and which mitigation measures are reasonable and feasible to implement in the short- and long-term.

6.3 Drought Resiliency Evaluation

The evaluation of drought susceptibility generally showed that the region is well-positioned for relatively severe droughts of the type evaluated in this study. The evaluation revealed that SPU, Everett Public Works, and Tacoma Water would have sufficient supply to meet the 2035 forecast hot, dry summer demand levels if the worst drought on record (1987) repeated itself. Under this scenario, SPU, Everett Public Works, and Tacoma Water were able to manage supply and demand relationships by using existing water shortage response tools, short of implementing mandatory curtailments, to meet customer demands. However, SPU and Tacoma Water would be unable to meet 2035 demands if a drought were to occur that had approximately 25 percent lower inflows than the 1987 drought. Everett Public Works would retain some supply buffer at this level of reduced inflow. Groundwater sources are less vulnerable to a single-year drought than surface water. However, multiyear periods of reduced precipitation could lead to aquifer decline or depletion. The drought survey found that water utilities in the region consider drought an important issue and have implemented some measures to prepare for water shortages. Addition mitigation measures, beyond existing tools, could be developed to better respond to drought conditions.

6.4 Climate Change Resiliency Evaluation

The climate change evaluation generally showed that climate change may have the following impacts on water suppliers in the three-county area:

- Water availability may be significantly reduced. This and other climate change impacts would likely be similar throughout the three-county area since there is a strong correlation in streamflows of the five major rivers that are the main sources of existing and potential future surface water supplies for the region.
- Groundwater resources are likely to be relatively robust in the face of climate change compared with surface water. Mainland aquifers that currently provide significant supplies appear to not be at significant risk of inundation from sea level rise.
- A sudden and dramatic population increase attributable to climate-driven migration is unlikely to occur.
- Continued water quality management strategies in the Puget Sound region and additional research are needed to better understand and address potential water quality risks resulting from climate change such as: increased water temperatures, increased variability in streamflows, increased nutrient loading, decreased oxygen saturation, altered lake stratification and turnover, increased turbidity levels, and increased harmful algae blooms. Note that the impact of these potential water quality risks on specific

water supply operations and the ability to provide water to customers was not determined as part of this analysis.

- Climate change is likely to increase the frequency of high fire danger days.

6.5 Summary of Mitigation Measures

Table 2 summarizes the potential mitigation measures identified by each risk team. These include proactive and responsive measures that could mitigate each risk, beyond the tools that currently exist. Note that Table 2 does not represent a comprehensive list of the mitigation measures identified by the risk teams. Instead, it focuses on general measures that could be applicable to multiple utilities and/or risk topics.

Table 2 Summary of General Mitigation Measures Identified for Potential Future Investigation

Mitigation	Earthquake	Water Quality	Drought	Climate Change
Construct Interties	x	x	x[a]	Mitigation measures were not identified in this phase of the Resiliency Project.
Upgrade System Components	x			
Enhance Emergency Preparedness and Response Plans	x	x		
Conduct Component-specific Vulnerability Evaluations	x	x		
Expand/Develop Secondary Water Supplies	x	x	x	
Expand/Develop Groundwater Supplies	x		x	
Stockpile Equipment, Materials, Chemicals, etc.	x	x		
Acquire Emergency Power Supplies	x	x		
Conduct Incident Training		x		
Implement Mutual Aid Agreements	x	x	x	
Increase System Monitoring and Surveillance		x		
Conduct Public Outreach	x	x		
Make Operational Modifications		x	x	
Promote Demand Reduction			x	

[a] Initial findings suggest that interties may not contribute to improving the region's resiliency to drought. Therefore, additional future investigation may not be undertaken.

The risk teams recommend that mitigation options be further evaluated to determine the costs and benefits associated with each proposed measure. Future investigation of mitigation measures could potentially prioritize those measures that are common among the risk teams.

6.6 Potential Future Investigations

While conducting Phase 1 of the Resiliency Project, the risk teams identified various opportunities for additional research, data development, and analysis that extended beyond the Phase 1 effort. The following discussion summarizes the potential future investigations identified by each risk team. Note that the future investigations identified here are not in order of priority and do not reflect a complete inventory of necessary potential research or work.

- **Earthquake:** Further develop mitigation measures; conduct outreach to customers, utilities, and elected officials; define PE-LOS goals for water suppliers in the three-county region; further evaluate infrastructure damage (including damage to other lifeline infrastructure); further evaluate economic impacts; and coordinate with other lifeline sectors.
- **Water Quality:** Evaluate critical risk locations, worst-case scenarios capable of leading to water quality failure, impacts on water utilities in the tri-county region, and mitigation measures that could be implemented.
- **Drought:** Evaluate 2015 drought conditions; refine drought preparedness criteria; evaluate mitigation measures; review institutional and regulatory challenges affecting drought response; analyze vulnerabilities facing smaller water systems in the region; and evaluate groundwater vulnerabilities.
- **Climate Change:** Extrapolate the results of SPU's climate change analysis to Everett Public Works' and Tacoma Water's systems; further evaluate groundwater resources and sensitivity of recharge; further consider migration drivers and pathways; apply water quality evaluation methodologies to the Puget Sound region; and evaluate wildfire scenario results and assumptions.

Overall, these and other future Resiliency Project investigations would contribute to the region's understanding of these risks and to improving the resilience of water systems in the three-county area to these risks. This would also contribute to the development of a regional plan for improving the resiliency of the water supply systems in the three-county area.

6.7 Recommendations

The conclusions identified in this report should be considered preliminary and subject to further evaluation. As such, the risk teams recommend that additional evaluations be performed that build on these initial results to better understand water system vulnerabilities in the region and measures that could mitigate risks. Water utilities in the three-county area should also explore ways to increase interutility cooperation and knowledge sharing to improve water system resiliency. In addition, the teams recommend outreach to water utilities, policy makers, and customers to increase awareness of the risks to water systems in the three-county area.

The risk teams recognize that the Resiliency Project findings may not apply to all water utilities in the region. Therefore, the teams also recommend that individual drinking water utilities consider their own utility's resiliency against each risk and which mitigation measures are reasonable and feasible for their systems.

7.0 Figures

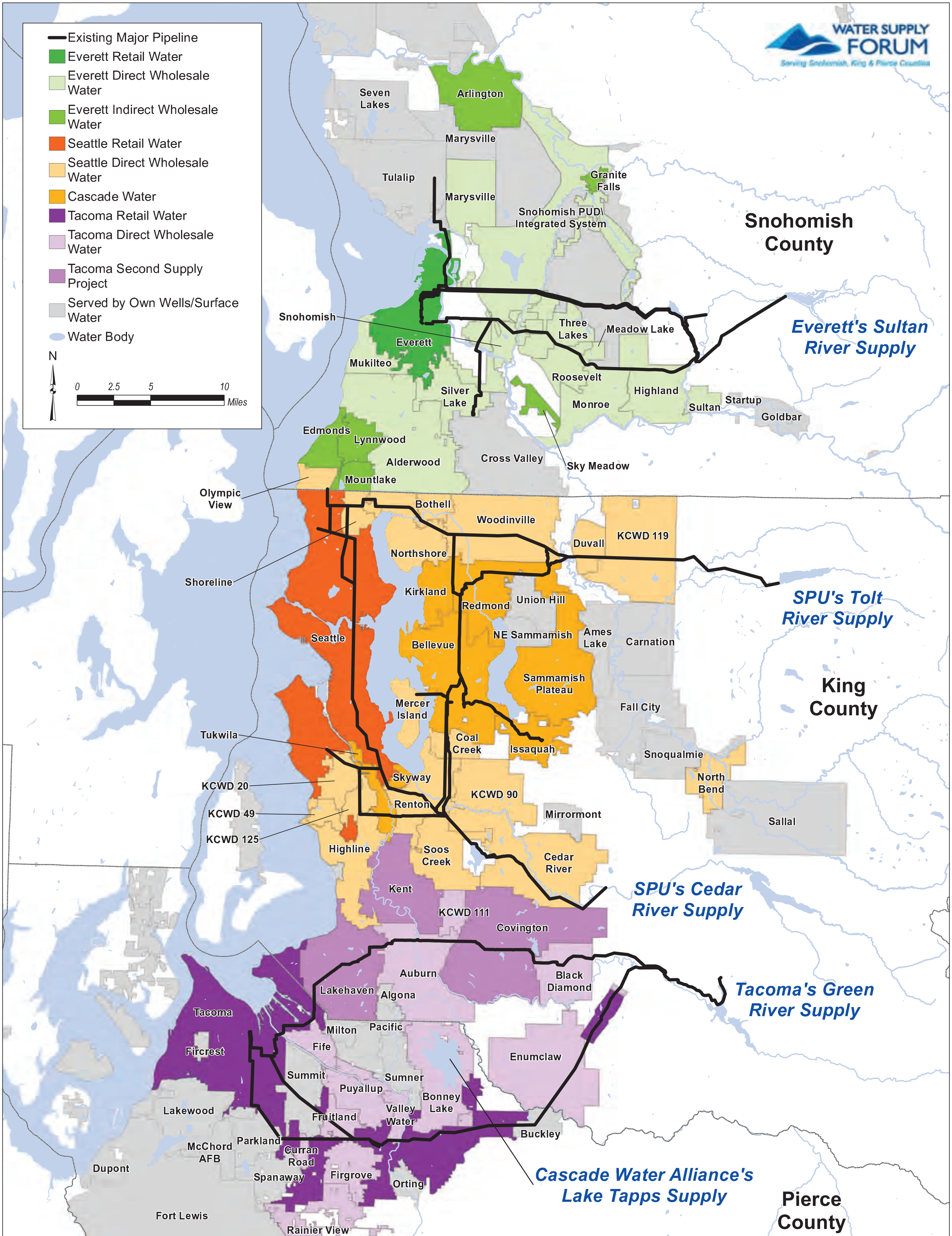

Figure 1 Water Supply Systems in the Three-County Area

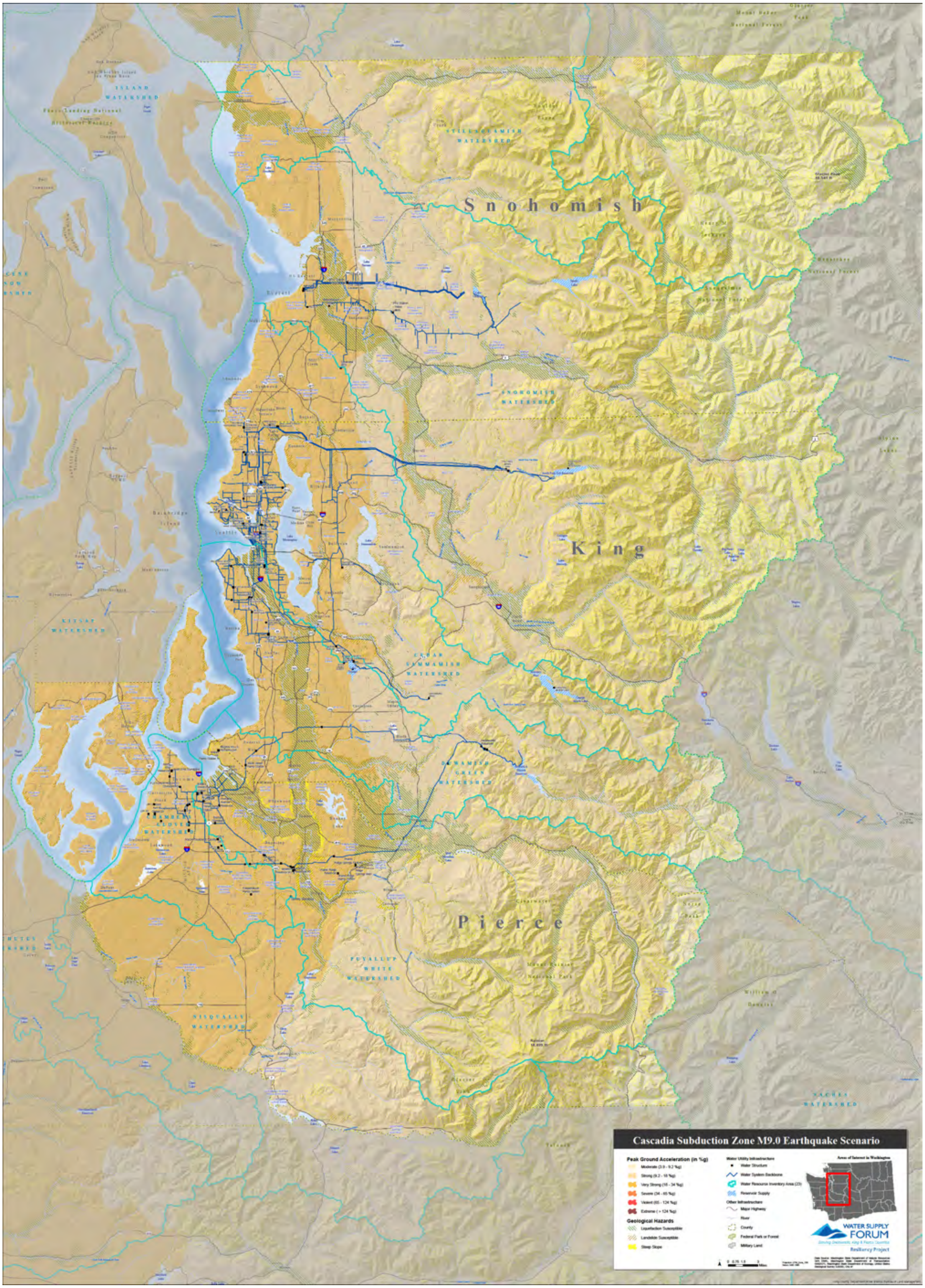

Figure 2 **Cascadia Subduction Zone – M_w9.0**

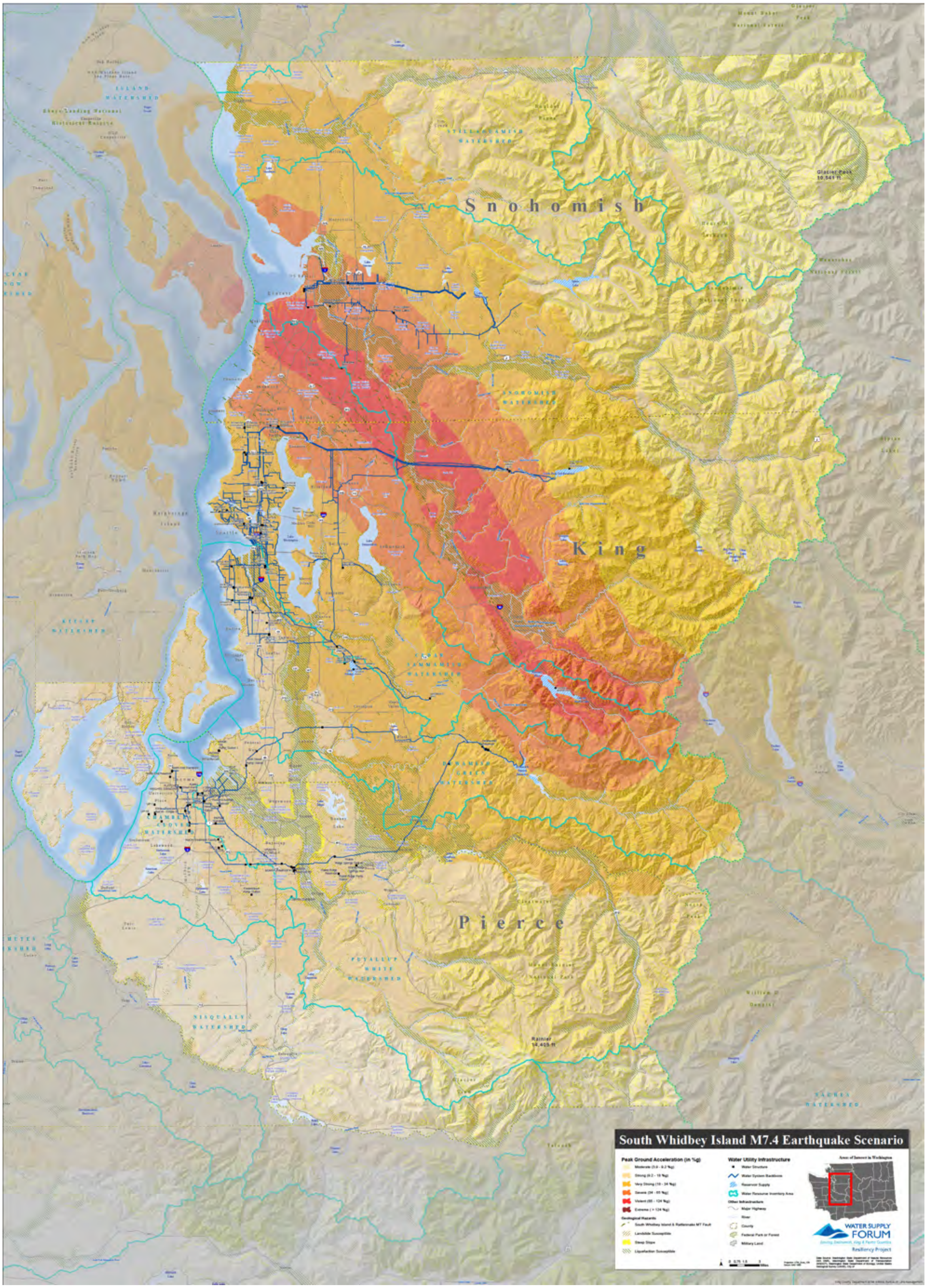

Figure 3 South Whidbey Island Fault – M_w7.4

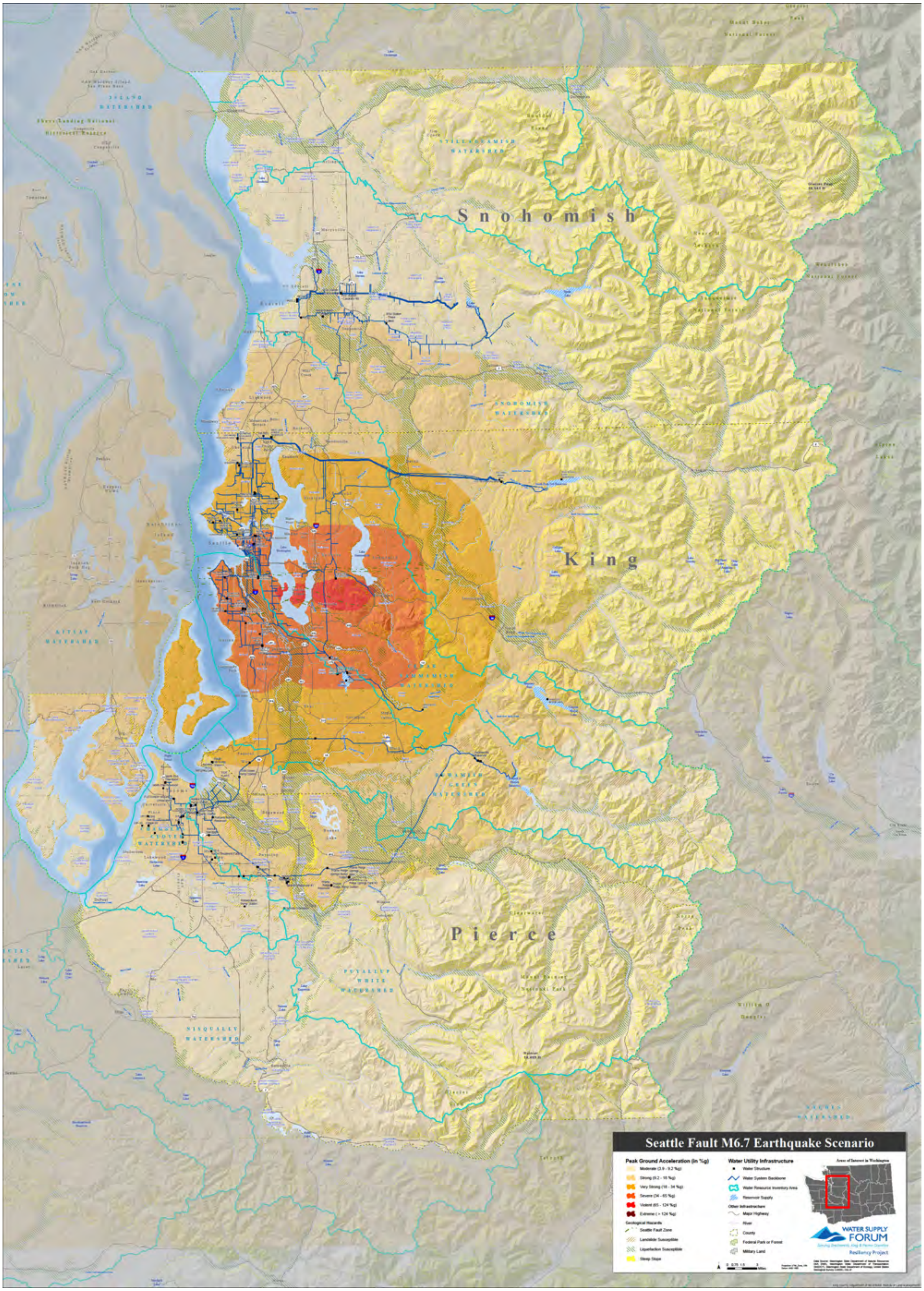

Figure 4 Seattle Fault – M_w6.7

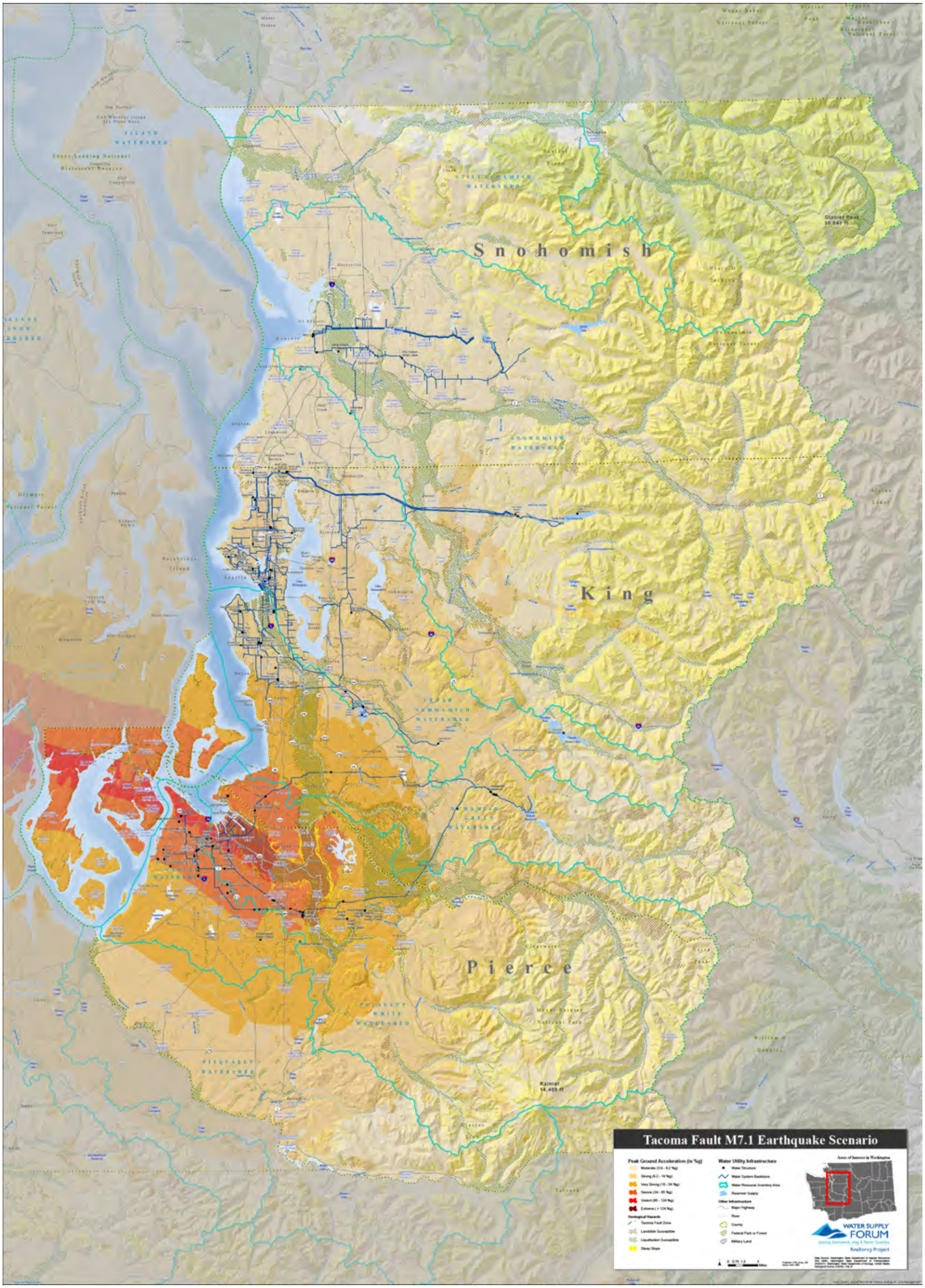

Figure 5 Tacoma Fault – M_w7.1

8.0 References

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