Water Supply Forum

Regional Water Supply Resiliency Project

Phase 2 Summary Report

Snohomish, King, and Pierce Counties, Washington

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

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Abbreviations

AAD	Average Annual Demand
AWWA	American Water Works Association
AWD	Average Winter Demand
CDC	Centers for Disease Control and Prevention
CIP	Capital Improvement Plan
CSZ	Cascadia Subduction Zone
DOC	State Department of Commerce
EPW	Everett Public Works
GIS	Geographic Information System
NCAR	National Center for Atmospheric Research
NIST	National Institute for Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
PE-LOS	Post-Event Level of Service
PGD	Permanent Ground Deformation
PSE	Puget Sound Energy
SEAW	Structural Engineers Association of Washington
SPU	Seattle Public Utilities
SRF	State Revolving Funds
SWIF	South Whidbey Island Fault
TPU	Tacoma Public Utilities
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSDOH (DOH)	Washington State Department of Health
WSDOT	Washington State Department of Transportation
WSF	Water Supply Forum

Preface

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 of the water systems in the three-county area and most of the population served and water supplied. 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 (Cascade). In total, these utilities serve approximately 2.3 million people over 1,200 square miles. Since 2016, the Forum has been collaborating on a Regional Water Supply Resiliency Project with the objective of enhancing the resiliency of water utilities in the three-county region to adverse events.

Executive Summary

Resiliency is defined as the ability to reduce the impact of, and recover rapidly from, disruptive events. Phase 1 of the Water Supply Forum's (Forum) Regional Resiliency project addressed four risks (earthquakes, water quality, drought, and climate change) and provided recommendations on enhancing resiliency to these risks. Phase 2 (the current phase) expanded on three of the four risk factors (excluding drought), and addressed overarching risks that do not apply to a single risk category. This report presents findings and an action plan that includes actions for both the Forum and individual utilities.

Earthquake Evaluation

The Puget Sound region is susceptible to major earthquake hazards associated with three shallow crustal faults that cross the urbanized areas (South Whidbey Island Fault, Seattle Fault, and Tacoma Fault) and the deep Cascadia Subduction Zone lying to the west off the Washington coastline. Phase 2 of this effort focused on earthquake preparedness, response, and mitigation strategies for earthquake damage.

The earthquake preparedness and response evaluation included inventory of transmission line repair materials throughout the region, access to specialized personnel for recovery efforts, and tanker truck availability for emergency supplies. Some utilities stockpile transmission line repair materials, but enhanced stockpiles would be required to fully prepare for extensive transmission line failures. Establishing protocols for sharing materials between utilities could reduce the need for every Forum member to stockpile their own repair materials. The Forum found that responding to a major earthquake would require specialized expertise beyond current utility capabilities in the areas of dam safety, welding skills, and structural engineering. There are numerous companies that can provide tanker trucks for water in an emergency and could likely satisfy short term water demands. However, these services would require extensive contracting and logistical coordination.

The report addressed vulnerabilities of distribution systems and described two primary mitigation methods: isolation of seismically vulnerable areas and seismic retrofit and replacement of vulnerable pipe. Supply redundancy in areas where isolation systems are installed can enhance post-event level-of-service and ensure water can be available in the isolated sections. Also, reducing the number of "back-bone" pipeline connections in areas susceptible to liquefaction improves the ability to isolate particularly vulnerable areas so they do not affect less-vulnerable areas.

The Forum developed post-event level-of-service (PE-LOS) goals, which are formulated as desired timelines for incremental restoration of water service over the days and weeks following an emergency event. The member utilities recognize that it is not practical to rebuild their supply systems all at once to achieve the PE-LOS goals. Substantial investments in critical infrastructure will be needed over a long period of time before the PE-LOS goals identified Phase 2 can be attained. They are designed to serve as a guide to the member utilities for developing capital improvement plans aimed at gradually improving resiliency over as much as 50 years from the present. The pace of progress towards attaining the goals will depend on funding levels available for this purpose in the years and decades ahead.

Water Quality Evaluation

The water quality evaluation in Phase 1 identified 6 risk events of primary concern that could disrupt regional water supplies: wildfires, volcanic eruption, resource supply chain disruption, accidental contamination, severe adverse weather, and earthquakes. Phase 1 developed mitigation measures that could enhance resiliency to these risks. Phase 2 further analyzed the risk events to characterize events that could completely compromise water quality. The Forum identified mitigation measures for these "extreme magnitude" events. Some mitigation measures apply across all water quality risk types, whereas other measures are risk-specific. Also, utility size can determine which mitigation measures would be necessary, feasible, and effective.

Two templates for water quality events were developed for water utilities to use locally: one for addressing and restoring potability after a water quality disruption, and another for facilitating communications to the public regarding potability and restoration. These templates can be adopted for individual utility operations and communication protocols.

Climate Change Evaluation

The Forum convened a climate change workshop with the National Center for Atmospheric Research to learn about up-to-date climate science related to hydrologic conditions in western Washington and to discuss how climate models can be applied effectively to address issues in municipal water-supply management. The presentation included “Dos and Don’ts” of climate science regarding climate change studies, model selection, and data interpretation. NCAR plans to maintain this information on a website.

Emergency Short-Term Water Supplies

The Forum analyzed customer needs that will require emergency short-term water supply following a disruptive event, and identified potential sources for emergency short-term supply. Quality, quantity, and timing of delivery factor into which emergency supplies will best support various short-term water needs. Individual utilities can use this information to develop plans based on which needs are most pertinent to their service area and which emergency supplies could be made available.

Coordination with Other Lifeline Services

The Forum identified three primary lifeline sectors relevant to water system resiliency: transportation infrastructure, fuel supply, and electrical power. Utilities and lifeline sectors maintain communications and have established protocols for emergencies. Coordination with some sectors is more established than others, and there are opportunities for improved engagement.

Action Plan

Following the analyses of each risk factor and associated topics, the Forum developed an action plan that lists specific actions that could improve resiliency based on Phase 2 findings. There are 4 categories of actions: short- and long-term actions for the Water Supply Forum and short- and long-term actions for individual water systems. Actions were placed in sub-categories based on the risk factor they address. Suggested actions include capital projects, planning projects, and future investigations.

1.0 Introduction

Since 2014, the Water Supply Forum (Forum) has been collaborating on a Regional Water Supply Resiliency Project (Resiliency Project). The objective of the Resiliency Project is to help the water utilities of King, Pierce, and Snohomish Counties, Washington take proactive steps in evaluating and enhancing the resiliency of the region's water supply systems to emergency events and long-term changes in climate conditions.

During Phase 1 of the Resiliency Project, the Forum evaluated four risk types: earthquakes, water quality, drought, and climate change. Based on the Phase 1 recommendations, the Forum identified additional evaluations to better understand water system vulnerabilities in the region and measures that could mitigate these risks. Phase 2 developed more detailed information on three of the four risk types: earthquake, water quality and climate change risks[1]. Phase 2 also addresses overarching risks and includes an action plan for the Forum and for water utilities throughout the three-county region.

This summary report summarizes the findings of Phase 2 and presents the Action Plan for the Forum and its members. The Action Plan includes a combination of shorter-term measures that can improve resiliency within 3 to 5 years, and longer-term measures that may require several decades to be fully implemented.

1.1 The Water Supply Forum

The Forum is a voluntary organization with representatives from public water systems and local governments, and the Washington State Department of Health (DOH) also participates in Forum activities. The Forum was created in July 1998 to address current and future water supply issues in the region.

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. Current members of the Forum are:

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

[1] Drought was not addressed in Phase 2 because the Forum members believe the region is reasonably well prepared for drought compared with the other resiliency topics. This does not necessarily mean that further actions aren't needed to improve drought preparation.

1.2 Major Regional Water Suppliers

The four major regional water utilities in the central Puget Sound region are: SPU, Everett Public Works, Tacoma Water, and Cascade. The first three own and operate large water supplies. Cascade currently receives its water from SPU, and also owns the Lake Tapps resource which can be used for municipal supply in the future. In total, these utilities serve approximately 2.3 million people over a land area of 1,200 square miles. The region served includes a major metropolitan area comprised of approximately 60 cities and water districts, three active ports, a major international airport, and global businesses including Weyerhaeuser, Starbucks, Amazon, Microsoft, and Boeing.

The largest volume of water within the region comes from four surface water supplies:

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

In addition to these existing surface water supplies, Cascade owns Lake Tapps in Pierce County. Cascade plans to use Lake Tapps as a source of drinking water supply in the future. Additionally, SPU and Tacoma Water also own groundwater supplies that supplement their surface water supplies.

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 Cascade water supply systems and the areas currently served by these water utilities.

1.3 Phase 2 Objective and Approach

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, safety and economic activity are minimized. Phase 2 of the Resiliency Project investigated select topics in greater depth and identified specific actions that could be taken by the Forum and/or individual utilities to improve the resiliency of water systems against major supply interruptions.

The Forum Ad Hoc Committee on Resiliency continued its role from Phase 1 in providing overall guidance during Phase 2. “Risk Teams” (subcommittees) comprised of personnel from the various Forum members and affiliated organizations were formed to engage with the consulting team on topic-by-topic investigations and recommendations. HDR Engineering led the delivery of consulting services to the Forum and the Risk Teams, with contributions from Ballantyne Consulting LLC, Confluence Engineering Group, and the National Center for Atmospheric Research.

Phase 2 addressed the following topics:

- Post-Event Level-of-Service (PE-LOS) goals
- Earthquake Risk:
    - Materials that could be stockpiled to expedite repair of major regional water transmission pipelines
    - Personnel with specialized expertise needed following a major seismic event (e.g., structural engineers and welders)
    - Review of existing emergency response plans maintained by water utilities

- Mitigation strategies to reduce seismic damage to local water distribution systems

- Water Quality Risk:
  - Evaluation of six specific categories of events that could severely compromise water treatment systems, together with the kinds of capital improvements that could mitigate or reduce the impacts from these risks;
  - General procedures for assessing potability of regional supplies after a system has sustained major damage to its transmission lines with depressurization or treatment plant damage;
  - General procedures for notifying the public that water potability has been restored following such an event
- Climate Change Risk:
  - Best practices for using climate models to support water management and planning;
- Emergency Water Supplies;
- Coordination with Other Lifeline Sectors:

The remainder of this report summarizes the Phase 2 findings on each of these topics, and provides an Action Plan for the Forum and its members. For further context on the kinds of risks facing water suppliers in the region, see the Phase 1 report issued in August 2016.

2.0 Earthquake Risk

The Forum region is susceptible to multiple earthquake scenarios, each of which could cause extensive damage to water systems throughout the region. In Phase 1, the Forum identified 4 earthquake scenarios of interest that could cause damage to Forum water systems:

- Cascadia Subduction Zone (CSZ) (all utilities)
- South Whidbey Island Fault event (SWIF), primarily impacting Everett Public Works, SPU, and surrounding service areas
- Seattle fault event, primarily impacting Seattle Public Utilities
- Tacoma fault event, primarily impacting Tacoma Water

The Forum conducted evaluations of seismic vulnerability of the supply systems and used that information to identify ways that water agencies can work together to improve regional seismic resiliency.

In Phase 2, HDR and the Risk Team developed Post-Event Level of Service (PE-LOS) goals for a major earthquake. The earthquake team also inventoried regional resources (e.g., tanker trucks for emergency water delivery, availability of personnel specialized for post-earthquake recovery activities, transmission line repair materials) that, with inter-agency coordination, could improve preparedness for an earthquake. Phase 2 also addressed methods to mitigate earthquake damage to distribution systems and to reduce the severity of service interruptions.

2.1 Post-Event Level of Service (PE-LOS) Goals

PE-LOS goals provide guidance in design of new (and upgrade of) existing facilities, particularly in the development of Capital Improvement Plans (CIP), and planning for emergency response and recovery. PE-LOS goals do not represent a guaranteed level of service; rather, they are guidelines to inform capital improvement decisions over multiple decades that will enhance resiliency against emergency events. The PE-LOS goals developed as part of this project address supplies, transmission to terminal reservoirs, and service to essential facilities. They do not address the local distribution systems between these facilities and end users.

2.1.1 Goal Establishment Considerations

The following information allows utilities to analyze their current PE-LOS situation and helps inform goals:

- Expected damage following an event
- Time to restore services
- Number of customers facing outages and duration of outages
- Economic impact of customer outages
- Cost to upgrade the water system to reduce impact of customer outages
- Regulatory requirements
- Stakeholder input
- Reference goals established by utilities of similar size and areas of comparable risk profile, and expert opinion.

To establish a methodology for goal development, the Forum looked at examples of PE-LOS goals in Oregon and California, as well as information from the American Water Works Association (AWWA) and the National Institute for Standards and Technology (NIST).

2.1.2 PE-LOS Goal Structure and Development

PE-LOS goals address water quantity, water quality, location of delivery, and the timeframe of achievement of the previous three factors. The goals are risk based, where the higher the risk of emergency event, the stricter the goals should be.. There were three variables that determined how goals would be developed:

- Earthquake type (i.e., crustal vs. CSZ)
- Planning horizon (20 years vs. 50 years)
- Funding level (basic, moderate, aggressive)

In this task, PE-LOS goals were developed for both earthquake types on a 50-year planning horizon. The Forum chose to use the 50-year planning horizon because capital improvement projects to improve resiliency have high costs that require the projects to be phased in over time. Incremental improvements over a long period of time will avoid substantial spikes in costs that would require large increases in water rates. The PE-LOS goals will assist Forum members and other utilities to identify capital projects for strategic, phased development.

The Forum recognizes that more rapid attainment of these goals is desirable, but will be subject to availability of funding. Each utility can establish the appropriate pace of improvements aimed at achieving the PE-LOS goals, consistent with priorities in their respective service areas. As a follow-up to this Resiliency Project, each regional utility should identify interim milestones for capital improvements that will advance towards achievement of the 50-year goals.

Each utility filled out a PE-LOS template table. The table listed system components with their associated service provided and a timeline of restoration of services. The utilities then filled in expected levels of service for each service at each time interval post-event. The “lowest common denominator” was selected from each table and combined into a single table representing regional PE-LOS goals. Table 1 displays the regional PE-LOS goals for a CSZ earthquake scenario, and Table 2 displays the regional PE-LOS goals for a crustal fault earthquake scenario.

Average Winter Demand (AWD) and Average Annual Demand (AAD) are identified as goals at various stages of recovery. AWD represents the quantity of water normally supplied to utility service areas during the winter months when water needs do not include irrigation supplies. AAD is slightly higher than AWD and represents a higher level of demand that could be supplied later in the recovery process.

Table 1. PE-LOS goals for a CSZ earthquake scenario. (Attain within 50 years and establish interim milestones leading to these goals.)

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	Storage	50% AWD[1]	50% AWD[1]	50% AWD[1]	AAD
		Quality	Non-Potable[4]	Non-Potable[4]	Non-Potable[5]	Non-Potable[5]	Potable	Potable
Transmission to End Points[2]	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD	AAD
Transmission/ Supply to Major Regional Essential Services[3]	Serve essential customers (e.g., hospitals).		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		limited water from storage for fire, drinking		Individual utility decision			
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

AWD = Average Winter Demand; AAD = Average Annual Demand

Notes:

1. Percentages represent the estimated percent of total delivery. Not all areas will be feasible to serve within the first month.

2. Transmission to End Points includes one or more transmission pipelines providing the noted level of service connecting the supplies to and including the first terminal reservoirs downstream from each supply. At the utility's discretion, additional transmission pipeline segments and reservoirs can be included in this criterion.

3. Transmission/Supply to Major Regional Essential Services includes a supply, and transmission line supplying water to hospitals designated as essential by the utility. The supply and transmission may be dedicated to supply to essential services and be different than the supply and transmission system serving the overall utility service area. Additional facilities in addition to hospitals such as nursing homes, may be designated by the utility.

4. Water supply and water held in terminal reservoirs are expected to be potable immediately after the event. However, there could be short-term disruptions/damage to water treatment plants and/or transmission pipelines that could compromise potability of water in the terminal reservoirs within 24 hours following the event.

5. Disruptions/damage to the transmission pipelines could result in contamination of water coming from treatment plants or into terminal reservoirs until repairs can be made and normal operations are resumed.

Table 2. PE-LOS goals for a Crustal Fault earthquake scenario. (Attain within 50 years and establish interim milestones leading to these goals)

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	Storage	50% AWD	50% AWD[1]	50% AWD[1]	AWD
		Quality	Non-Potable[4]	Non-Potable[4]	Non-Potable[5]	Non-Potable[5]	Non-Potable[5]	Potable
Transmission to End Points[2]	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)		25% AWD[1]	25% AWD[1]	25% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Transmission/Supply to Major Regional Essential Services[3]	Serve essential customers (e.g., hospitals).		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		limited water from storage for fire, drinking		Individual utility decision			
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

AWD =Average Winter Demand

Notes:

1. Percentages represent the estimated percent of total delivery. Not all areas will be feasible to serve within the first month.

2. Transmission to End Point includes one or more transmission mains providing the noted level of service connecting the supplies to and including the first terminal reservoirs downstream from each supply. At the utility's discretion, additional transmission pipeline segments and reservoirs can be included in this criterion.

3. Transmission/Supply to Major Regional Essential Services includes a supply, and transmission line supplying water to hospitals designated as essential by the utility. The supply and transmission may be dedicated to supply to essential services and be different than the supply and transmission system serving the overall utility service area. Additional facilities in addition to hospitals such as nursing homes, may be designated by the utility.

4. Water supply and water held in terminal reservoirs are expected to be potable immediately after the event. However, there could be short-term disruptions/damage to water treatment plants and/or transmission pipelines that could compromise potability of water in the terminal reservoirs within 24 hours following the event.

5. Disruptions/damage to the transmission pipelines could result in contamination of water coming from treatment plants or into terminal reservoirs until repairs can be made and normal operations are resumed.

Conclusions resulting from this task include:

- Immediately following the event, a limited quantity of water suitable for customer use would remain in storage reservoirs, and that water would remain potable until it ran out and needed to be refilled from the transmission system. There could be short-term disruptions/damage to water treatment plants and/or transmission pipelines that could result in inadequate treatment or contamination of water available to refill the terminal reservoirs. If inadequately treated or contaminated water entered the terminal reservoirs, the stored water would need to be considered non-potable.
- Following a CSZ event, the goal for regional transmission and terminal storage systems is to provide 50 percent of average winter demand (AWD) immediately after the event and achieve delivery of 100% of AWD within 14 days. By one month after the event, the goal rises to 100% of average annual demand (AAD).
- Following a crustal fault earthquake with more severe but localized damage, the corresponding goal is to provide 25 percent of AWD immediately after the event, rising to 50% at 7 days and 100% at one month. This does not guarantee delivery at these levels to all portions of the service area, but simply addresses water production and transmission from each utility's sources to its major reservoirs.
- However, for essential facilities such as major regional hospital centers, 50 percent of AWD should be available from the transmission/supply immediately after the event, rising to 100 percent at one month. This applies to both categories of earthquake events. Supply for essential facilities would come from either existing or alternative reliable supplies that utilities and the customers served will need to identify and evaluate, and where needed, a dedicated resilient pipeline connecting the supply to the essential facilities.
- The crustal fault scenarios are expected to cause greater damage locally and therefore will require more time to restore service compared with a CSZ earthquake. The PE-LOS goals reflect this, with the primary difference being that average annual demand (AAD) could be supplied from the source, transmission and terminal reservoirs within one month for a CSZ earthquake, while these facilities could serve only average winter demand (AWD) one month after a crustal fault earthquake. Average winter demand is lower than average annual demand. However the damage from a crustal fault earthquake would be more localized and would not be likely to damage systems throughout the central Puget Sound region. Also, water supplies are expected to return to potable status at 14 days in a CSZ scenario, whereas it could take up to a month to return to potability for a crustal scenario.

Utilities can use these goals to develop lists of capital improvement projects geared towards goal achievement. Utilities may use their own approaches to achieve results. For more information on PE-LOS goal development and utility specific goal tables, see Appendix A.

2.2 Earthquake Preparedness and Response

Earthquakes are unavoidable and could occur with little-to-no warning. Forum utilities should understand, to the best of their ability, potential water system damage in as much detail as possible for each earthquake scenario, and develop response plans and protocols that can be quickly activated to assist vulnerable areas and promote rapid restoration of potable water service.

2.2.1 Transmission Line Repair Materials

Large transmission pipelines are high priorities for restoration due to critical function of conveying water from sources and treatment facilities to local storage facilities and distribution systems. In Phase 1, transmission pipeline repair estimates were calculated for Everett and SPU for the 4 earthquake scenarios of interest. In Phase 2, Tacoma Water provided results from its seismic assessment and provided pipeline repair information for each scenario except the SWIF. Cascade only owns the Bellevue Issaquah Pipeline, and they provided pipe repair information for that pipe (see Appendix B).

Repair of large-diameter transmission pipes requires custom piping that cannot be procured quickly from manufacturers or vendors. Therefore restoration of transmission lines will be highly dependent on stockpiled repair materials situated within the central Puget Sound region. The Phase 2 analysis consolidated transmission pipe repair information into a table, sorted by diameter and pipe material. The table provides estimates of the number of pipe breaks requiring repair, and lists repair materials that each Forum utility currently had available as of February 2018. Some piping types are used by multiple utilities; and utilities could develop agreements to share piping repair materials if a neighboring utility requires assistance. However many of the specific diameters that may require repair are unique to just one of the regional water utilities.

This inventory of pipe materials shows that there are mismatches between the repair materials currently stockpiled, and the estimated materials that would be needed in the event of a major earthquake, particularly a CSZ earthquake that would affect all of the regional water transmission systems.

Not all size classes are deficient. There is more pipe available within the region than break estimates indicate would be needed in the 24-, 30-, 32-, 60- and 66-inch size classes. However the remaining 27 size classes, ranging from 18- to 96-inch diameters, all have deficiencies in available pipe compared with the estimated repair needs. In these size classes, the deficiencies range from 20 feet of pipe to 600 feet of pipe. The largest deficiencies are in the 36-, 48-, 51-, and 58-inch size classes. The very largest size classes (96- and 98-inch) have no repair pipe on hand in the region, as well as deficiencies in repair materials.

For more information about transmission line repair materials, see Appendix B.

2.2.2 Access to Specialized Personnel

Analysis, mitigation, and restoration of source, treatment, transmission, and storage facilities following a major earthquake will require skills held by specialized personnel not immediately available to utility staff. The specialized personnel of interest to this study are dam safety personnel, welders, and structural engineers.

Earthquakes could compromise dam structure and function. Dam owners should maintain up-to-date information on emergency procedures and contacts, as well as remain informed of the various Washington State agencies that should be notified of dam failure (listed in Appendix C). High hazard dams are legally required to maintain emergency action plans, though this could be helpful for all dams. The Forum consolidated a list of the important contacts regarding dam safety (listed in Appendix C).

It would be valuable to collaborate across utilities to maintain a network of welders and pipefitters in the central Puget Sound region. Welders can perform emergency pipeline repairs, which are vital for meeting level-of-service goals. The Forum and its members should also consider providing welding training to expand the pool of trained utility staff, as well as developing a network of external contacts that can be quickly and strategically dispatched to repair damages following an emergency event.

The Structural Engineers Association of Washington (SEAW) has a white paper outlining guidelines for post-event contracting for safety evaluations. Structural engineers can provide structural and safety evaluations of vertical infrastructure and participate in restoration efforts. The risk team concluded it may be prudent to select and contract with engineering consultant firms (rather than individuals) for the services in advance of an earthquake to better address priorities during an emergency. Utilities could establish a protocol for purchasing and contracting that can be used in an emergency setting; such as the one that Cascade has drafted (see Appendix C).

For more information about the specialized personnel database and recommendations, see Appendix C.

2.2.3 Tanker Truck Availability for Emergency Supply

Tanker trucks can transport water to meet supply needs during the post-earthquake response period. HDR and the Forum collected a list of tanker truck providers potentially available to provide emergency supplies. Information included the company name, contact information, quantity of trucks and truck capacity, and whether the trucks can transport potable or only non-potable water. Use of tanker trucks should be coordinated with disinfect-water orders, since validating potability of the water delivered by individual trucks could be an overwhelming challenge.

This task also included a high-level analysis of potential water needs of hospitals and emergency shelters to determine if the tanker trucks identified would be able to meet those needs. There is limited availability, but through good coordination and quick mobilization, emergency service demands could be met by the tanker trucks potentially available. It is recommended that the Forum develop emergency contracts with companies that own tanker trucks in the Northwest region, and the Washington Department of Ecology has already begun to contact some of these companies.

For further information on the tanker truck database and the methodology for determining emergency water needs, see Appendix D. Also see Section 5.1 with more comprehensive discussion of how the public could receive emergency water supplies while water utility systems are being restored. Utilities should coordinate with FEMA and/or the Washington Military Department in procuring tanker trucks and enabling federal reimbursement.

2.3 Mitigation Strategies for Earthquake Damage to Water Distribution Systems

Water distribution systems pose unique challenges regarding earthquake preparedness and response. Distribution systems are extensive, interconnected matrices of water mains. A consequence of this set-up is potential local (or even widespread) depressurization from pipe cracking, joint separation, and other pipe breaks.

The consequences of pipe failures can be mitigated through four general strategies:

- Isolation of vulnerable areas
- Seismic upgrades to, or replacement of, vulnerable pipes
- Plan and provide for hardware for quick temporary recovery
- Plan for crews, equipment, and materials available for quick restoration

This analysis focused on the first 2 mitigation strategies (isolation and seismic retrofits); the other mitigation strategies were addressed in Section 2.2 of this report.

Historically, areas most vulnerable to pipeline damage are those with geotechnical hazards that could result in permanent ground deformation (PGD), often caused by liquefaction, landslides, or fault zones. Consequences of PGD and associated pipe failures can be measured by supply losses (fire flows, essential services, water quality, etc.), potential available supplies to the area, and size of the impacted area or the number of customers served.

2.3.1 Isolation of Vulnerable Areas

Notable system components vulnerable to seismic damage include tanks, reservoirs, and piping in areas susceptible to liquefaction. Isolation of damaged components is one method of mitigating widespread consequences in a distribution system. When damaged areas of the distribution system are isolated, the less-affected areas nearby can continue to operate (i.e., they will not depressurize due to a broken pipe in the nearby damaged area). A utility can install valves in strategic locations in the distribution system that can isolate vulnerable sections likely to incur damage in an earthquake, preparing the system for the damage and preventing widespread consequences.

Considerations pertinent to incorporation of isolation valves into a distribution system include:

- Supply redundancy in vulnerable areas
- Tank/reservoir isolation, particularly for seismically vulnerable infrastructure
- Minimize “backbone” pipe connections to reduce the number of isolation valves necessary
- Choice of manual valves versus automated or remotely controlled valves (each of these has different advantages and risks).

2.3.2 Seismic Retrofit and Replacement of Vulnerable Pipe

Damage to seismically vulnerable pipeline can be mitigated by retrofitting or replacing pipes to more strict seismic standards. To inform this effort, utilities could produce pipeline damage estimates from seismic hazard maps overlain by the pipe network; these maps should factor in pipeline materials and the materials’ seismic ratings. There are methodologies for this estimation from sources described in Appendix E.

Suggestions for retrofit/replacement were placed into two threat categories: pipes in areas subject to PGD, and pipes in areas not subject to PGD. Furthermore, two categories of pipe services were defined: non-critical and critical pipes (transmission lines, “backbone” lines, pipes to essential facilities). The Phase 2 analysis provided suggestions for materials that are likely to be seismically resilient and cost-balanced for pipe criticality and PGD theat. Due to the high cost of retrofit/replacement, projects should be prioritized so they can be integrated with non-earthquake-related pipeline replacement programs over a period of years or decades.

There are two overall priorities that all distribution system mitigation strategies should satisfy:

1. Return service to essential customers
2. Fix pipelines that restore service to the largest number of users (including both residents and employers)

Long-term operations and maintenance programs are necessary for the perpetuation of distribution system damage mitigation. The Forum utilities should frequently revisit and update their mitigation plans, gather and store materials, and replace materials that deteriorate over time.

For more information on isolation and seismic retrofitting and replacement, see Appendix E.

3.0 Water Quality Risk

Water quality risk is generally defined as events disruptive to the continued delivery of drinking water meeting state and federal health standards for potability.

In Phase 1 of the Resiliency Project the Forum identified 6 risk events of primary concern that could adversely impact water quality. These are: wildfires, volcanic eruption, resource supply chain disruption, accidental contamination, severe adverse weather, and earthquakes. The Forum then developed mitigation measures that could enhance resiliency against those risks.

In Phase 2, HDR and the Risk Team further analyzed these risk events to assess the threshold at which an emergency event could completely compromise water quality, and assessed the ability of utilities of different sizes and capabilities to prepare for, withstand, and recover from the risk event.

With support from Confluence Engineering Group, the water quality risk team also developed two templates: one addressing the determination of potability following large-scale depressurization of one of the regional drinking water supply systems, and the other addressing communications to the public once potability has been restored and the water is safe to drink.

The following subsections summarize results.

3.1 "Break-the-System" Analysis

As an extension of the Phase 1 water quality risk analysis, the Forum and HDR conducted a "Break-the-System" analysis, which identified the severity of a water quality risk event that could completely compromise regional water quality. The analysis considered how water supplies, treatment capabilities, distribution water quality, public health, staffing, financial capability, and monitoring ability for small, medium, and large utility sizes could be affected by each water quality risk factor identified in Phase 1.

A matrix was utilized to assess the impacts the water quality risk events would have on water quality operations for utilities of differing sizes, operational resources and capacity for response actions. It provides insights for determining which utility and water quality operational concerns would be most impacted and potentially could be entirely compromised by a water quality risk event. Table 3 displays the matrix of water quality operational capabilities for utilities grouped by size category. The information in this matrix was used to assess impacts, by utility size, for the various risk events listed above. The technical memorandum prepared for this risk topic characterizes expected outcomes for each size category. This summary report documents the expected outcomes at a summary level.

Table 3. Descriptions of water quality operational capabilities for each water utility size – Water Supply.

Category	Water Supply	Treatment Facilities	Distribution Water Quality	Public Health and Other Customer Impacts
Small	Receives drinking water from large and medium utilities for primary supply or emergency backup. Maintains small surface water or groundwater source to augment water supply from larger utilities.	Small treatment facility that has limited automation and does not require constant operator attention. Basic instrumentation and alarms.	System is in compliance with all regulatory requirements prior to the risk event.	System has no public health or customer impacts prior to the risk event.
Medium	Has its own groundwater or surface water supply to augment water purchased from a regional supply. Utility can supply 40-60% of its own water.	Small treatment facility that requires daytime staffing. Partial automation with extensive instrumentation and alarms.	System is in compliance with all regulatory requirements prior to the risk event.	System has no public health or customer impacts prior to the risk event.
Large	Has its own surface water supply and possibly groundwater supply that meets all of the water demands of the utility and its wholesale customers.	Fully automated treatment facility or facilities. Multiple operations staff working for continuous manned operations.	System is in compliance with all regulatory requirements prior to the risk event.	System has no public health or customer impacts prior to the risk event.

Table 4. Descriptions of water quality operational capabilities for each water utility size - Staffing.

Category	Staffing	Financial Capability	Monitoring Ability
Small	Small field staff that are concurrently responsible for treatment operations, field repairs, water quality inspections, instrumentation, and maintenance.	Small operations budget and cash reserves. Relies upon State Revolving Fund (SRF) loans or bonding to support capital improvements and loans for emergency repairs.	No dedicated central monitoring facility. May have a desktop or laptop for centralized monitoring for basic equipment functions. Limited instrumentation in the distribution system.
Medium	Large organization with most field staff trained in multiple roles, with a limited number that is dedicated to a specific task or activity.	Moderately sized operations budget and reserves. Many smaller improvements are self-funded, with use of SRF loans or bonds for larger projects. Emergency repairs are funded through cash reserves, though multiple emergencies will quickly deplete the reserves.	Central operations and security monitoring from a dedicated desktop. Utility has the ability to monitor most equipment functions and has deployed some distribution system water quality monitoring stations.
Large	Very large, highly structured organization. Individual staff members usually dedicated to one specific task or role.	Large operations budget and reserves. Self-funded improvements for all but the largest of improvements. If required, could sustain multiple repairs through cash reserves.	Continuously staffed central control center that monitors system facilities operations. Comprehensive monitoring of most equipment and utility has deployed multiple water quality stations throughout system.

3.1.1 Conclusions:

- Surface water is the primary concern; groundwater will generally be less affected.
- Impacts from each risk event vary, dependent on the magnitude of the event.
- Most of the emergency water quality events that were assessed can be mitigated by running treatment facilities at lower production rates to adequately treat water (as low as 10 percent of normal capacity).
- Mitigation measures will be most effective if developed at the utility level, based on the high level recommendations provided in the break the system analysis.
- Nearly all risk events result in increased turbidity, which can be mitigated through capital projects such multi-level intake towers in reservoirs and riverbank collector wells for riverbank filtration.
- Impact intensity is not always proportionate to utility size; some risk events will affect all sizes equally, while others will more adversely impact a specific utility size.

3.2 Risk specific analyses and conclusions:

3.2.1 Wildfire

Significant water quality impairments from a fire on the order of several thousand acres in a source watershed would include increased turbidity, increased nutrient concentrations, and introduction of radionuclides, metals, and potentially fire retardant chemicals. Capital improvements to mitigate this risk should be focused on turbidity- and nutrient loading-preventative measures, such as multi-level intake towers in reservoirs and installation of new or covered sedimentation and filtration basins to prevent wind-borne ash from entering water.

Potential capital improvements to mitigate or minimize the impacts of a wildfire to water quality can include:

- If withdrawing from a reservoir, construction of an intake tower that allows withdrawal from different depths to avoid turbidity.
- If withdrawing from a river, installation of riverbank collector wells so riverbank filtration can remove some of the turbidity prior to entering the treatment facility.
- Addition of sedimentation basins and filtration to remove ash-borne turbidity from the water.
- Covering sedimentation, flocculation, and filtration basins to prevent wind-borne ash from entering the water.
- Installing fine air filters on all tank and sensitive engine intakes.
- Upgrade coagulant and alkalinity feed systems to allow for enhanced coagulation for greater turbidity and organics removal. This improvement must coincide with addition of sedimentation basins to prevent clogging the filters.

3.2.2 Volcanic Eruption

Large suburban areas of Pierce County and southern King County could be affected by lahars (mudflows) resulting from a Mt. Rainier eruption. The entire region could be affected by tephra (rock fragments) and ash falls from Mt. Rainier or Glacier Peak. An eruption similar to 1980 Mt. St. Helens eruption could potentially completely compromise water quality for those utilities directly affected. Most peripheral water quality impacts could return to normal after a few days, but total and dissolved carbon may persist due to vegetative die-off. Capital improvements to enhance resiliency specific to volcanic eruption could be construction of physical barriers to lahar flows to direct them around water sources and treatment facilities, installation of sedimentation basins, and covered sedimentation and filtration basins to prevent wind-borne ash from entering the water.

Volcanic hazards can result in a range of negative impacts on water quality, including turbidity, acidity/alkalinity, metals, and physical damage to treatment works from debris flows.

Potential capital improvements to mitigate or minimize the impacts of a volcanic eruption to water quality can include:

- If withdrawing from a reservoir, construction of an intake tower that allows withdrawal from different depths to avoid turbidity from ashfall.
- If withdrawing from a river, installation of riverbank collector wells so riverbank filtration can remove some of the waterborne ash prior to entering the treatment facility.
- Addition of sedimentation basins and filtration to remove ash-borne turbidity from the water.

- Covering any exposed water treatment basins to prevent wind-borne ash from entering the water.
- Installing fine air filters on all tank and sensitive engine intakes.
- Upgrade coagulant and alkalinity feed systems to allow for enhanced coagulation for greater turbidity removal. Note that this improvement must coincide with addition of sedimentation basins to prevent clogging the filters.
- Installation of pH adjustment processes to counteract the short-term pH depression.
- Construction of dikes, barrier walls, and/or channels to divert incoming lahars around or away from the water treatment facility.

3.2.3 Resource Supply Chain

Resource supply chain disruptions can have numerous causes such as issues at the chemical supply source and disruption of transportation infrastructure. The primary chemicals of concern used in the water treatment process are coagulants, pH adjusters like soda ash, and chlorine. Many utilities have the capacity to keep up to 30 days of chemical supply in-house; however utilities are not always fully stocked due to seasonal variations in demand and management of chemical shelf-lives. Any supply chain disruption long enough to deplete the onsite stockpile of a particular chemical would prevent mandated treatment from occurring. Key mitigation measures include improved access to treatment facilities through redundancy of transportation infrastructure; and strategies to ensure that critical chemicals can be either stored, delivered, or produced on-site in quantities sufficient to last through the supply chain disruption.

The potential capital improvements to provide greater resiliency against resource chain disruptions are generally limited to improving access to water treatment facilities. This could include construction of multiple access roads to a treatment facility, upgrading existing access roads to allow for easier snowplowing, and replacing low-lying accesses with new roadways above flood elevations.

An alternative is to house or store more resources at a given facility. For staff, this means providing beds, showers, laundry facilities, and stocked kitchens so that treatment personnel trapped at an isolated facility can properly rest and recover between long shifts until replacement staff can arrive. This improvement could occur at a treatment plant for surface water supplies, or at a central command or maintenance center. A less expensive option would be to requisition mobile housing such as camper trailers or recreational vehicles that could be transported to the site following an emergency event.

Greater equipment resiliency would involve stockpiling of critical replacement parts with long lead times between ordering and delivery. Finally, additional chemical storage volumes lasting more than 30 days may be considered, but careful analysis is required for each chemical. Liquid 12.5 percent sodium hypochlorite is unstable and degrades with time, rendering the stored chemical less potent and usable with long storage periods. Similarly, long storage periods of coagulants can cause some of the metal salt to precipitate or gel, which then causes pumping problems.

3.2.4 Severe Adverse Weather

Severe adverse weather events can cause treatment facility failure, equipment damage, supply chain disruption, and staffing issues. Specific impacts include landslides and floods which can increase turbidity in local waters and damage critical transportation and facility infrastructure. The primary weather events that could completely compromise water quality are snow and ice storms that could effectively prevent access to a utility for at least a week. Utilities with groundwater options are more resilient to this risk, since groundwater is generally unaffected by severe adverse weather, with the possible exception of long-lasting power outages.

3.2.5 Accidental Contamination

This event considers the introduction of chemicals into a water supply that treatment facilities are not designed to treat in normal operations. These chemicals could result in persistent environmental contamination. The primary chemicals of concern are oils and gasoline and related chemicals. The break-the-system scenario involves fuel-bearing transport vehicles (tankers, trains, planes) accidentally spilling high quantities of fuel into a supply source close to the intake point. Proximity to the intake is important, as there are multiple methods to prevent contaminants from entering the treatment process if a spill is distant from an intake.

Some potential capital improvements to minimize the impact of an accidental contamination are to:

- If withdrawing from a reservoir, construction of an intake tower that allows withdrawal from different depths to avoid the contaminant, especially if it is lighter than water.
- If withdrawing from a river, installation of riverbank collector wells so riverbank filtration can remove some of the contaminants prior to entering the treatment facility.
- Installing a powdered activated carbon feed system to adsorb the contaminants from the water. The used carbon is then removed by the downstream filters.
- Installation of granular activated carbon pressure vessels, either on a temporary or permanent basis.

3.2.6 Earthquake Effects on Water Quality

A crustal earthquake would primarily impact just one of the major Forum utilities, whereas a large Cascadia Subduction Zone (CSZ) earthquake would impact the whole region. All sizes of utilities will have similar issues; earthquakes tend to be broad in their extent of damage to the system, meaning the larger recovery capabilities of a large utility will be used for a proportionally larger recovery effort than small utilities. Returning water systems to service after an earthquake would take a large regional effort.

The primary water-quality risks posed by earthquakes are turbidity from landslides in source watersheds or disturbance of aquifer sediments for ground-water supplies; entry of contaminants into water-storage or conveyance facilities, and disruption of treatment facilities or processes.

Capital improvements to mitigate threats to treatment facilities and appurtenances include:

- Allowing range of motion for piping
- Anchoring equipment to floors and walls
- Strengthening basin walls and floors

Each utility faces its own challenges regarding water quality risks. Small utilities will have different planning and mitigation needs/priorities than larger systems, and the same can be said about rural, suburban, and urban utilities. Using the high-level analysis provided in Appendix F, utilities can conduct self assessments and address questions of how to best address risk in the context of their own systems.

A promising new technology currently being developed by USGS is an earthquake early warning system (EEWS) named ShakeAlert. Some utilities in the region are already participating in a pilot program. This system will provide an automated early warning and allow for automated, programmed shutdown of certain valves and pumping systems to protect these assets from damage

For more detailed information on each risk event and mitigation measures, see Appendix F.

3.3 Template for Utilities Restoring Potability

The Forum developed a Guideline for Restoring Potable Water Service for large-scale drinking water systems. The guideline includes high-level procedural recommendations for restoring operations that support potable water status and demonstrating how to regain potable water status. These guidelines apply to large-diameter (approximately >48-inch) pipelines and reservoirs that have experienced an emergency event leading to conveyance of untreated or poorly treated water.

The template describes potential water quality risks after an emergency event as well as mitigation measures for those risks such as inactivation of pathogens, chemical risk responses, and recovery strategies for distribution mains and reservoirs. The study also considered strategies from selected historical recovery efforts and summarizes criteria or conditions that are or were being used to rescind disinfect-water orders[2]. The Washington State Department of Health (DOH) has specific criteria for rescinding a health advisory:

- Meeting public health standards for water quality treatment
- Addressing the cause of contamination
- Taking steps to prevent future contamination

The template outlines a four-step process to restore potability:

1. Re-establish hydraulic capacity
2. Remove contaminants
3. Conduct disinfection
4. Perform validation

This four-step process is a general guideline upon which Forum utilities can craft their potability restoration procedures and establishes a centralized base of information the utilities can use to inform actions to take depending on the type of water quality impairment. Completion of the process may take many days, and a disinfect-water notice should remain in place until all steps are completed and DOH has confirmed the results.

For detail on water quality risks, mitigation measures, and the four-step process, see Appendix G.

3.4 Communications Template for Water Quality Emergencies

The Forum developed an Emergency Communications Planning Template to centralize and align communication protocols pertinent to water quality during an emergency. Common guidance and agreed-upon key messages between all Forum utilities would allow for consistent and efficient communication throughout the region. Specific goals achieved by developing the templates are:

- Help subject matter experts be better prepared for communication needs during an emergency
- Provide guidance for developing utility-specific communications regarding water quality issues
- Develop, compile and share key messages and communication templates between the regional water purveyors and their wholesale customers

[2] This more general term is used instead of “boil water orders” to reflect that customers may not be able to use natural gas stoves to boil water during an emergency, either due to explosion hazards or interruption of the natural gas supply.

- Help identify needed resources and coordination needs

The communications template includes:

1. Document purpose and applicability
2. Template storage protocols – records of staff in possession of templates and records of changes made to templates
3. Information on establishment of a Communications Team with an overarching incident command for the region, and responsibilities delegated to various members of the incident command
4. List of resources necessary to implement plan and staff training
5. Developed and outlined a communication process following a water quality emergency
6. Defined agency coordination methods
7. Public notification and outreach protocols

The template includes additional recommendations to enhance effectiveness of emergency communications:

- Color-coded maps: areas of non-potability, disinfect-water advisories, and estimated times of restoration
- News media ribbons for disinfect-water advisories
- Enhance citizen engagement through communications during the recovery process
- Keep documentation of collaborative efforts for media purposes

Specific communication templates include:

Templates for news releases:

1. DOH template for disinfect-water news release
2. Earthquake specific disinfect-water advisory
3. Update on potable water status
4. Disinfect- water advisory rescinded
5. Restoration of potable water – notice directly to wholesale customers
6. CDC news release relating to disinfect-water orders by other agencies/utilities (Public Notification Rule requirement)
7. DOH chemical related-water quality concerns
8. Basic elements of a spokesperson statement
9. Frequently asked questions by journalists in an emergency

Templates for direct public notification:

1. DOH drinking water warning – E. Coli
2. DOH drinking water warning – surface water treatment issues
3. Mandatory health effects language of regulated contaminants (link)

4. Multiple linguistic translations of drinking water warnings
5. Fact sheets and external references useful for functioning in an impacted water quality situation

For details on the template development process and the final templates, see Appendix H.

4.0 Climate Change Risk

The Forum convened a climate change workshop in April 2018 with presentations from the National Center for Atmospheric Research's (NCAR) Research Applications Laboratory and NCAR's local research partners. As a precursor, NCAR staff interviewed Forum members to establish issues of interest. Based on this, the workshop included a review of up-to-date climate science related to hydrologic conditions in western Washington; and discussion of how climate models can be applied effectively to address pressing issues in municipal water-supply management within the region. The workshop drew extensively from NCAR's work with the USACE, including guiding principles and three categories of "Dos and Don'ts" to apply: 1) when designing a study, 2) when selecting models, and 3) when interpreting climate change data. These guidelines are intended to promote conversation among and between information producers and users and will evolve alongside climate science and applications. Outlined below is the current list (version 1.0, June 2018), that is the foundation of a living document that will be updated and amended with frequently asked questions, real-world examples, and additional Dos and Don'ts over time. Workshop attendees were granted access to the beta version of the website, which will soon be available at: https://ncar.github.io/dos_and_donts.

Guiding Principles:

1. It is important to evaluate climate risk.
2. Models can be helpful tools, if used appropriately.
3. Uncertainty is everyone's responsibility.

Study Design Dos and Don'ts:

1. Do recognize benefits that go beyond climate change preparedness.
2. Do start by determining the level of detail that fits your need and resources.
3. Don't start from scratch; leverage the work and expertise of others.
4. Don't wait to decide evaluation criteria for assessing climate impacts.
5. Do identify the major uncertainties that will impact your decision and assess their magnitude.
6. Don't expect every climate change question will be answerable with currently available models and datasets.
7. Don't wait until new information is available, there will always be new research and models coming soon.
8. Do plan for iterations as the first time you download climate data should not be your last.
9. Do be aware of multiple ways to evaluate future change – climate change scenarios are helpful, but there are other tools too.

Model Selection Dos and Don'ts:

1. Do understand how the decision being evaluated is important to model selection.
2. Do select models that capture important geographic features.
3. Do recognize that results from a single global climate model realization do not capture the full range of uncertainty.
4. Don't treat all future climate change runs the same.
5. Don't use a finer spatial or temporal resolution than what data allow and models adequately and effectively simulate.
6. Do recognize a single hydrologic process representation does not capture the full range of uncertainty.

Data Interpretation Dos and Don'ts:

1. Do interpret probabilistic information with the appropriate context.
2. Don't focus on any single year or even single decade for determining the future climate response.
3. Do only present future results as compared to the historical simulation for the same global climate model.
4. Do average across models in appropriate ways.
5. Don't confuse grid-based output with routed streamflow.
6. Don't use routed streamflow as input to a reservoir model if biases have not been removed.
7. Do use analogies appropriately.
8. Don't get seduced by precision.
9. Do use simplifications wisely.

The workshop included a breakout session for water utility professionals to exchange thoughts on key questions and useful approaches; as well as a final full-group discussion on efforts the Forum could take to maintain effective connections with climate research institutions regionally and nationally.

Workshop materials and discussion notes are included in Appendix I. Key recommendations from the discussion session are presented in Section 7.0.

5.0 Emergency Short Term Water Supplies

Emergency water supply strategies can apply to any scenario in which water supplies are unavailable at the quality and/or quantity of normal operations. To address this topic, the overarching risk team completed tasks including:

- Researched alternative water supplies used in regions where emergency events (notably earthquakes) have significantly damaged water supply infrastructure
- Defined critical services that will require alternative water supplies in an emergency
- Listed potential alternative water supplies available in the region
- Matched critical services with appropriate water supplies

5.1 Alternative Supplies and Critical Needs

Emergency events can damage water system infrastructure, disrupt resource supply chains, and prevent staff from carrying out their duties, rendering the system unable to provide water to some or all customers. Literature was reviewed on provision of emergency water supplies following major earthquakes in North America and abroad in recent decades. This review identified four categories of essential services that would need emergency supplies:

- Fire Flows – Fires are common after earthquakes and the region will need large quantities of water to fight fires.
- Hospitals – Hospitals require timely delivery of high quality water at greater-than-average per capita quantities to serve the immediate needs of health-compromised patients.
- Vulnerable Populations – Populations that cannot actively procure their own water, including people in emergency shelters, senior centers, prisons and detention centers.
- Domestic Needs – Those who remain in their house whose regular service has been interrupted.

The research also identified a range of potential alternative supplies:

- Hardened, dedicated infrastructure
- Water containers stored by customers on-site
- Bottled water deliveries
- Public and private wells
- Tanker trucked water or flexible bladder tanks (blevits)
- Public utility reservoirs
- Water tanks at customer sites
- Rivers, lakes, and seawater
- Truck- or ship-mounted filtration plant
- Rainwater

HDR matched essential water services with appropriate alternative supplies. Considerations for matching included necessary quality and quantity, priority need, and timing of supply source availability. Some broad conclusions that can inform short term emergency supply planning include:

- Multiple, overlapping strategies are necessary to increase resilience; reliance on one supply source could be ineffective due to unpredictable impacts from an emergency event.
- Ensuring availability of large volumes of water for firefighting immediately after an earthquake comes into conflict with the goal of retaining stored, potable water for human consumption; and vice versa. A comprehensive strategy should address both of these needs. Each utility will need to consider how to balance these conflicting needs, given local conditions and system facilities.
- Customers should be advised to keep water on-site (ideally 2 weeks of supply) as a preparatory measure. Potable supply options will be severely limited after an emergency.

- Restoration is often a phased process. Clear documentation of restoration priorities and potential times to restoration can help individual utilities coordinate internally and externally to ensure emergency supplies are strategically directed to the appropriate use in the appropriate volumes.

More work will be needed at the utility level to improve their capacity for provision of short-term emergency supplies appropriate to each community. For more information on the essential services, alternative supplies, and the service-supply matching analysis, see Appendix J.

5.2 Mapping of Emergency Supply Wells

The Forum developed tabular and spatial databases of utility-owned wells that could supply public drinking water immediately following an emergency event. Tabular data gathered included well name, location, supply capacity, regional connectivity, and availability of emergency power. This information can help to identify the wells that could be most useful for emergency supply. In particular the ability to operate in abnormal conditions and regional accessibility (e.g., central location) are important. The Forum and HDR also developed maps of each utility's wells to visualize their geographic distribution.

Static maps show only well locations and do not include tabular data. The original GIS files developed in ArcMap are highly functional maps that include both spatial data as well as tabular characteristics. These maps can only be used if the user owns a copy and license of the ArcMap software.

There are privately owned wells in the region that could also supply emergency water. Utilities should expand this inquiry to look into identifying and coordinating with private well owners that could participate in provision of emergency water supplies.

For more information on the well mapping task, see Appendix K.

5.3 Utility Roles and Coordination with Emergency Response Entities

During Phase 2, each of the regional utilities characterized its own vision of its role in supplying emergency water supplies to the public during the immediate aftermath of a large earthquake or other emergency. This responsibility is complicated by the fact that the utilities must also immediately go to work inspecting system damage and arranging rapid repair operations. The utilities identified differing perspectives on their roles, as discussed in Appendix L.

Further work needs to be done to communicate with other emergency responders in regards to short term water supply that may be provided at public shelters or other sites. These include:

- Each County's designated lead department for emergency response
- Washington State Military Department, Emergency Response Division
- Federal Emergency Management Agency (FEMA)
- American Red Cross, Puget Sound area offices

The Forum anticipates organizing a workshop in the future to address this topic; see Section 7.0 – Action Plan).

6.0 Coordination with Other Lifeline Services

The lifeline services sector includes public and private entities that provide services essential to regular water utility operations. The Forum identified water system vulnerabilities due to interdependencies between the water utility sector and lifeline sectors. Vulnerabilities include long restoration times of lifeline services due to restoration priorities and potential lack of resource availability.

Each lifeline sector has unique considerations in terms of service area boundaries and the ability to coordinate and prioritize local customers or users. The lifeline sectors addressed are electricity, fuel supply, and transportation infrastructure.

6.1 Electricity

Water utilities require power to carry out operations such as water treatment, pumping, reservoir operation, maintenance, system monitoring, and customer service. They maintain emergency generators for short-duration backup purposes, but rapid restoration of normal power will be a high priority following an emergency event. There are multiple power utilities throughout the Forum region. The major regional water utilities receive power services from the following providers:

- SPU: Seattle City Light; PSE
- Tacoma Water: Tacoma Power; PSE
- Everett Public Works: Snohomish County Public Utility District No. 1
- Cascade Water Alliance: PSE

6.2 Fuel Supply

Utilities require fuel for vehicles to make repairs and operate their systems, as well as for backup generators at pump stations, filtration plants and other critical facilities. Therefore fuel supplies will be a critical need following a major emergency event. The Forum utilities can receive emergency fuel aid from the State Department of Commerce (DOC) though a process described in the State's ESF-12 energy plan. Local fuel supplies are typically managed by a local municipal department.

- SPU: Seattle Fleets and Facilities Department
- Tacoma Water: TPU Fleet Services
- Everett Public Works maintains their own three-day fuel supply at the water filter plant
- Cascade Water Alliance does not operate a large fleet or require fuel for its operations

6.3 Transportation Infrastructure

Transportation infrastructure is the primary lifeline enabling movement of staff and resources from place to place to carry out post-incident inspections, repairs, and restoration. Transportation infrastructure is managed at multiple levels, including municipal, county, State, and federal. Washington Department of Transportation (WSDOT) is the largest transportation agency within the region. The Puget Sound Regional Council Transportation Recovery Annex is the primary region-wide coordination tool for route prioritization during an emergency event. Agencies responsible for emergency transportation routes and route restoration within the Forum utilities' service areas are:

- SPU: Seattle Department of Transportation; Office of Emergency Management; WSDOT
- Tacoma Water: Pierce County Emergency Operation Center; WSDOT

- Everett Public Works: EPW Streets Department, Snohomish County; WSDOT
- Cascade Water Alliance: Member cities; King County; Pierce County; WSDOT;

For details about current, future, and potential coordination opportunities between Forum utilities and the lifeline sectors, see Appendix M.

7.0 Action Plan

This section presents actions identified during Phase 2 of the Forum's Resiliency Project that could improve resiliency of water supplies in King, Pierce and Snohomish Counties[3]. The focus of this project has been the large regional water suppliers and mid-sized local water utilities that receive regional supply. However many of the actions listed here may also be applicable to smaller water systems or those with separate, independent sources of supply. Actions are subdivided into: 1) those that would be appropriate for collaboration across the three counties by the Forum and/or other regional organizations; and 2) those that would be most appropriate for implementation within a single water utility organization. Even the latter category may benefit from continued sharing of information and methods regionally. In addition, if the Forum itself determines it will not act on select recommendations, some of those recommendations may still be suitable for local application by individual utilities.

The Action Plan includes a combination of shorter-term measures that can improve resiliency within 3 to 5 years, and longer-term measures that may require several decades to be fully implemented. This longer time frame is appropriate because certain types of capital improvements are far more cost-effective if accomplished through long-term renewal and replacement actions. In particular, the long recurrence interval of major earthquakes makes it difficult to justify costly improvements for seismic resiliency within a short time frame, especially when there are many other regional infrastructure needs apart from water supply resiliency efforts that also deserve funding.

7.1 Short-Term Actions for the Water Supply Forum

7.1.1 Short-term, Emergency Water Supplies

1. **Well Inventory:** Expand the identification of wells that could provide emergency supplies, to include high-capacity public and private wells not owned by the large regional water systems. For example this may include hospitals, schools and colleges, private industries, parks, and golf courses. A capacity of 100 gpm (70,000 gpd) is suggested as a threshold for initial inventory. Depending on results, subsequent work could expand the inventory to include smaller wells.

   Using findings from the well inventory, contact well owners to determine whether those wells could be included in a network of water supplies for major emergencies. Develop contact protocols, activation agreements, and liability protections if needed. Evaluation of policy considerations such as shared insurance or liability protection would be necessary to enable such wells to provide water (potable or non-potable) to the public following a major emergency. Establish public communication protocols for such supplies.

[3] Recommendations from Phase 1 can be found in the Phase 1 summary report issued in August 2016 and the associated Phase 1 technical memoranda.

2. **Public Messaging on Customer Stockpiles of Emergency Water.** Develop and issue consistent public messaging throughout the three-county region, including collaboration with smaller utilities, local governments, state and local emergency managers, and the State DOH. Encourage households to stockpile potable water supplies sufficient for a two-week period following a major emergency and provide literature on safe means to 'stockpile.' Encourage large employers to stockpile water sufficient for their employees for at least three days, and to engage with their employees regarding stockpiling of household emergency supplies. Also provide information on how to preserve potability or on means of treating non-potable water at the household level.
3. **Coordination with Local Emergency Managers on Roles and Responsibilities**. Convene a workshop with federal, State and local agencies and non-governmental organizations that have significant roles in assisting the public following an emergency. Using information on utility plans for short-term emergency water supplies as a starting point, engage these entities in a discussion of their own plans for supplying water to public shelters or at other sites. Use the workshop to identify further actions that may be needed to assure effective post-event coordination and communication. This may include periodic update workshops and/or consideration of this issue in table-top and other emergency exercises and preparation drills. In addition, see Short-Term Actions for Utilities for follow-on communications at the sub-county level.

7.1.2 Transmission Line Repair Materials

1. **Shared stockpiles of repair materials.** Jointly review the inventory of large-diameter transmission line repair materials in Appendix B, and determine whether collaborative action to acquire and stockpile additional materials is justified. If so, put in place arrangements needed to accomplish this. These are typically manufactured as custom orders, so a viable approach may include contracting with pipeline manufacturers to arrange for small-quantity production of sections of select large-diameter pipes in conjunction with larger orders placed by other utilities across the nation. Also consider materials that may be needed to use pipelines segments of slightly different diameters in making emergency repairs, since one utility may acquire pipes of differing diameter from another utility. Also review mutual-assistance agreements for applicability of rapidly sharing required repair materials.
2. **Sharing data on materials inventory.** Periodically update and share data on the respective utilities' inventories of repair materials on hand for large-diameter, regional water transmission lines. This will facilitate communication and collaboration in the event that regional transmission lines owned by any of the Forum utilities are damaged in an earthquake.

7.1.3 Distribution Mains Repair Materials

1. **Plan rapid acquisition of repair materials.** Facilitate development of strategies for accumulating and sharing repair materials. Based on distribution pipe damage estimated during Phase 1, there could be approximately 5,000 distribution pipeline repairs required throughout the region including non-WSF utilities. These are smaller-diameter lines, typically ranging from 8- to 24-inches. Utilities and suppliers in the region only stock a small percentage of the repair materials required to make this many repairs. The Forum should develop a plan to assist its members acquire the remaining repair materials from vendors and or utilities outside the region, immediately following an earthquake.

2. **Mutual Aid Agreements**. Evaluate whether existing mutual aid agreements should be amended to enable procurement of materials by one utility still operating under relatively normal conditions, on behalf of another utility that is engaged in an overwhelming short-term repair effort (with appropriate financial safeguards for the utility providing this assistance). If appropriate, develop standard language that could be incorporated in amended agreements among water utilities throughout the central Puget Sound region.

7.1.4 Lifeline Agencies:

1. **Washington Resilience Plan.** As recommended in Phase 1, make a case to elected officials/lawmakers to further refine the Washington Resilience Plan (http://www.dnr.wa.gov/Publications/ger_ic114_resilient_washington_state.pdf) as necessary and make it an overarching resiliency plan across all lifeline systems in Washington State, similar to the Oregon Resilience Plan.
2. **Aerial support of emergency operations.** Investigate opportunities for partnering with the Washington State Military Department, Emergency Management Division (or with private contractors) to support immediate damage assessment and repair operations through provision of helicopters that can transport skilled utility personnel, repair materials and/or critical supplies such as water treatment chemicals. This would be particularly useful for accessing source reservoirs, water intakes, water treatment plants and transmission lines located in the Cascade Range foothills, which could be cut off from normal access roads under a variety of emergency scenarios.

7.1.5 Water Quality:

1. **Volcanic Hazard Mitigation.** Collaborate to establish best practices for protecting surface reservoirs and intakes from volcanic ash-fall. This could include more in-depth research into the particle size and density characteristics of ash most likely to be produced from Cascade Range volcanoes; practices for temporary shut-down of intakes and management of filtration plants, and protective covers that could be deployed rapidly to protect structures, equipment, or water sources from airborne ash. These measures may also be applicable to some impacts from large wildfires.
2. **Portable treatment equipment for spill mitigation**. Consider joint acquisition of portable treatment vessels (e.g. containing granular activated carbon) that could be rapidly transported and connected at an intake or treatment plant to remove petroleum-based organic compounds in the event of a major spill incident that compromises source water quality. Forum members could share the cost of this equipment and it could be used by any of the regional utilities (or their local wholesale customers) when needed.
3. **Joint training exercises at treatment plants.** Perform training exercises to improve staff familiarity with emergency scenarios and mitigation practices at the water treatment plants. These could be shared exercises where treatment plant operators from all of the regional water systems work together to assess, diagnose and remedy an emergency condition affecting each of their treatment facilities, rotated from year to year. This would enable sharing of ideas and best practices as well as limited cross-training of staff that could be loaned during an emergency affecting just one of the regional systems. This action could include partnering with Washington State Department of Health on performance-based training initiatives in this arena.

7.1.6 Climate Change

1. **Interaction with academic and research community.** Build and sustain routine interactions between the water supplier community and the academic and research community on the subject of climate change and water supply. Hold an annual or biennial symposium to update utilities on evolving research methods and findings; and to promote a research focus on water-utility information needs. Consider opportunities to fund academic or water-industry research with direct application to water supplies in western Washington. Maintain a connection to the National Center for Atmospheric Research, and promote continued presence of this and similar organizations within the Puget Sound region. Engage with federal research programs including liaison with NOAA, USACE, and/or the Bureau of Reclamation, as applicable. Explore opportunities to have imbedded persons – either within utilities (host a scientist at the utility) or within research (be hosted by a research institute).
2. **Standardization of GCMs and drought scenarios for local planning.** Support consistency among utilities in selecting from alternate Global Climate Models, emission scenarios, etc., so that climate-impacted modeling of the different water systems within the region can be based on similar premises. This should be done through first identifying what decisions and associated impacts are of greatest interest regionally, which can then be used to help identify the most appropriate models and methods. Also promote standardization in utility planners' definition of extreme weather events, especially droughts.
3. **Use best available climate science in appropriate ways.** Be a savvy consumer of climate change information – putting information in context and applying models and tools that are most appropriate for the decisions being evaluated. NCAR's Dos and Don'ts guidelines provide suggestions on how to do this - see Section 4.0 for details.

7.2 Long-term Actions for the Water Supply Forum

7.2.1 Climate Change

1. **Climate change effects on water quality**. Collaborate within the region or in nationwide efforts to investigate the effects of climate change on water quality and invasive species and other concerns affecting large surface-water source reservoirs.
2. **Forecasting of weather conditions.** Advocate and partner with federal agencies and the academic research community for development of improved tools for short-term forecasting of rainfall and stream flows. This is particularly important in regards to predicting the timing and magnitude of rainfall in the October to December period, as this informs summer-season management of surface water supplies and public messaging around water shortage response needs.
3. **Lake Tapps.** Recognize the role that Cascade's Lake Tapps resource could play in augmenting regional drinking water supplies. Full development and use of this resource for municipal supply could help to mitigate climate change effects on other drinking water supplies and/or effects on local streamflows and aquatic ecosystems in the watersheds of other major drinking water supplies.
4. **Regulatory flexibility.** Convene a discussion with the Washington State Departments of Ecology and Health regarding regulatory revisions that could reduce obstacles for utilities seeking to respond to climate change. For example, more flexibility may be needed to enable transfers of production capacity between surface- and ground water supplies.

7.2.2 Resiliency Funding

1. **Advocate with state and federal decision-makers for funding to support resiliency improvements.** Communicate with the State Legislature, federal Congress, and agency managers regarding the consequences of major risk events that would affect large populations within the central Puget Sound region. Advocate for increased funding and prioritizing of preparation and mitigation capabilities, in state and federal funding programs for water utilities. Jointly seek funding for specific initiatives. Also partner with national organizations such as the Association of Metropolitan Water Agencies, the Water Research Foundation, and American Water Works Association to highlight the value of funding and research to improve resiliency.

7.3 Short-Term Actions for Individual Water Systems

7.3.1 Emergency Water Supplies

1. **Water for life-support and public health purposes.** Review the short-term, emergency water supply options discussed in Appendices D and J. Determine how these approaches could be used locally to improve public access to water for critical safety and health purposes following an emergency event. Also consider how these supplies relate to emergency shelters and critical facilities, including hospitals and other facilities housing vulnerable populations. Then identify and implement the actions needed to make the selected practices operational, including provision for funding and periodic testing of the emergency supplies.
2. **Water for firefighting.** In conjunction with local fire authorities, review the short-term, emergency water supply options discussed in Appendix J. Determine how these approaches could be used locally to improve resiliency of water supplies, including non-potable sources, for emergency firefighting. Then identify and implement the actions needed to make the selected practices operational, including provision for funding and periodic testing of the emergency supplies.
3. **Coordinate with local emergency managers on roles and responsibilities**. As a follow-up to the recommended Forum workshop with federal, State and local agencies and non-governmental organizations on supplying water to public shelters or at other sites, convene a similar workshop at the sub-county level, to include city governments and local utilities. Share information from the regional workshop, and use the local workshop to identify further actions at the local level that may be needed to assure effective post-event coordination and communication. This may include periodic update workshops and/or consideration of this issue in table-top and other emergency exercises and preparation drills.

7.3.2 Coordination with “lifeline sector” organizations

1. **Maintain and expand coordination protocols.** Maintain regular and proactive communications with “lifeline sector” organizations, including periodic meetings and/or exercises to communicate and rehearse emergency protocols. Appendix M discusses existing relationships each of the regional water systems maintains with private utilities or public agencies responsible for: 1) regional and local roadways, 2) electrical power, and 3) fuel supplies, including both diesel fuel and gasoline. The lifeline sector agencies are themselves engaged in ongoing efforts to improve the speed and effectiveness of service-restoration following an emergency event, particularly earthquakes. Utilities should give special attention to arrangements with fuel suppliers and water-treatment chemical suppliers, as these areas appear less developed than transportation and electrical power responses.

7.3.3 Mitigation for Earthquake Damage to Water Distribution Systems

1. **Characterize specific risks to local distribution systems.** Evaluate the vulnerability of water systems to large seismic events, including specific consideration of how shaking, liquefaction, and landslides at the local scale would interact with existing water distribution reservoirs, pump stations, pressure-reducing valves, and piping networks. Estimate potential pipeline damage using seismic hazard maps overlain on pipeline network maps. SPU, Tacoma Water and EPW each have undertaken assessments of seismic risks to their water distribution systems and the City of Bellevue is currently engaged in a similar effort.
2. **Earthquake-resistant pipes.** Assess opportunities to replace the water supply and distribution system "backbone" with earthquake resistant pipe through ongoing renewal and replacement programs.
3. **Maintain Access to Personnel with Specialized Skills.** Assess and implement strategies to maintain availability of specialized skills necessary for rapid restoration of water-supply systems. Appendix C discusses specialized skills that will be needed for rapid restoration of water-supply systems. These include dam-safety specialists, structural engineers, and welders capable of making repairs to large-diameter water transmission lines. Strategies to assure these skills are available when needed include internal staff training, and maintenance of relationships and/or contracts with public agencies and private companies. Utilities should assess how these strategies can be applied most effectively in the context of their specific needs, in-house capabilities, and existing contractual relationships with service providers.
4. **Evaluate and apply emerging tools from USGS**. Evaluate use of emerging tools produced by the U.S. Geological Survey such as ShakeMap/ShakeCast and the ShakeAlert Early Warning System. For details, see Appendix E.
5. **Determine need for repair materials.** Improve estimates of expected repair materials for earthquake scenarios and take stock of repair materials available. Consider how each utility's post-event stockpiles of transmission and distribution pipe repair materials could be rapidly replenished to support recovery, through joint arrangements led by the Forum (see Section 7.1.3).

7.3.4 Mitigation for Threats to Water Quality

1. **Operations and capital projects.** Review the risk categories and the associated types of mitigation actions and capital improvements discussed in Appendix F for applicability to the utility's own drinking water supply system. Evaluate these actions and improvements to determine whether they should be built into the utility's near-term operations programs and/or longer-term capital improvement plans.
2. **Template for post-event restoration of potability.** Adapt the template provided in Appendix G for application to the specific water system. Train key staff in how the template should be applied to restore potability following a large scale depressurization of regional water transmission lines. Also adapt the template as needed for application to local water distribution mains.
3. **Template for public communications following restoration of potability.** Adapt the template provided in Appendix H for application to the specific water system. Train key staff in how the template should be applied to communicate with the public regarding restoration of potability following a large scale depressurization of regional water transmission lines. Also adapt the template as needed for application to local water distribution mains.

7.3.5 Climate Change

1. **Use best available climate science in appropriate ways.** Be a savvy consumer of climate change information – putting information in context and applying models and tools that are most appropriate for the decisions being evaluated. Update resource planning in response to revelations and advancements in climate science. NCAR's Dos and Don'ts guidelines provide suggestions on how to do this - see Section 4.0 for details.

7.4 Long-Term Actions for Individual Water Systems

7.4.1 Post-Event Level-of-Service (PE-LOS)

1. **Utility-specific capital plans.** Starting with the 50-year PE-LOS goals and associated utility-specific assessments of capital project requirements described in Appendix A, develop a utility-specific, long-term capital plan aimed at achieving the goals. This could include development of 10- and 20-year project lists to be incorporated in the utility's adopted capital improvement plan, along with evaluation of how far these improvements would advance the utility's expected PE-LOS towards the desired 50-year goals. Re-assess progress towards the PE-LOS goals periodically. For example, this could be done using hydraulic modeling evaluations in conjunction with seismic breakage projections, each time the utility's water system plan is updated. Also see Section 7.4.2.
2. **Groundwater supplies.** Assess how development of new groundwater supplies or augmentation of existing groundwater supplies could improve drought resiliency and offset some of the challenges posed by climate change. Also assess how groundwater sources could be used to improve earthquake resiliency. Depending on the results of these assessments, consider including groundwater-supply projects in the utility's capital improvement plan on an appropriate time scale. However, include consideration of how ground water interactions with surface streams will affect access to groundwater supplies, as climate change may exacerbate existing challenges related to instream flows and the health of aquatic ecosystems.

7.4.2 Altering Distribution Systems to Isolate Reservoirs

1. **Evaluate strategies for isolating distribution-system storage reservoirs.** Appendix E outlines approaches that can be used to design pipe networks for isolation of storage reservoirs from piping networks when an earthquake occurs. Individual utilities should consider how these approaches could be applied within their water distribution systems. This evaluation may identify opportunities to reconfigure piping/valve/reservoir systems to prevent draining of reservoirs during an earthquake. This in turn would contribute to the capital improvement plan discussed in the PE-LOS category of this action plan. While there may be some short-term opportunities in this category, substantial changes to distribution system configuration may be better viewed as a long-term program in conjunction with other asset replacement and renewal programs. (Also see Section 7.4.1).

7.4.3 Regional Interties

1. **Periodically Re-assess Value of Interties.** The Resiliency Project has shown that large interties to connect the regional water supply systems of Everett, Seattle and Tacoma would improve resiliency mainly for risk events that have localized effects instead of regional effects. Major droughts, volcanic eruptions, and Cascadia Subduction Zone earthquakes would likely compromise water supply systems throughout the region, and interties would offer little benefit in terms of sharing water resources during these incidents. Interties would offer greater value for mitigating localized incidents such as a major wildfire or crustal fault earthquake affecting one system more severely than others. Given the complexity and cost associated with major, regional interties, and a long list of other

mitigation actions that are either lower cost or more effective at achieving specific resiliency goals, Forum members concluded that developing regional interties is not a priority at this time for purposes of improving resiliency. However, the regional water utilities should revisit this question periodically as their circumstances and needs change over time and as ongoing growth and development brings water piping networks closer together.

Smaller interties connecting local systems within the region can offer benefits across a wide spectrum of emergency events that have different effects on systems situated close together. Therefore local utilities should continue to assess the costs and benefits of smaller interties with their neighboring water systems.

7.4.4 Climate Change

1. **Monitoring aquifer conditions.** To the extent that groundwater serves as an important resource to small and mid-size communities, and remains a supplemental source for select regional systems, consider establishing a program of long-range monitoring of aquifer recharge and water levels as affected by climate change, salinity from sea-water intrusion (also connected to climate change), or other long-term trends affecting the viability of aquifers in the central Puget Sound region. Since aquifer storage can supplement surface storage, work with State agencies and/or local planning jurisdictions to understand the interactions between land development practices and recharge of aquifers used for drinking water supplies.
2. **Monitoring developments in climate science.** Designate staff to monitor ongoing developments in climate forecasting and associated water resource conditions in the Pacific Northwest. Apply this information to resource planning, customer communications and system adaptation.

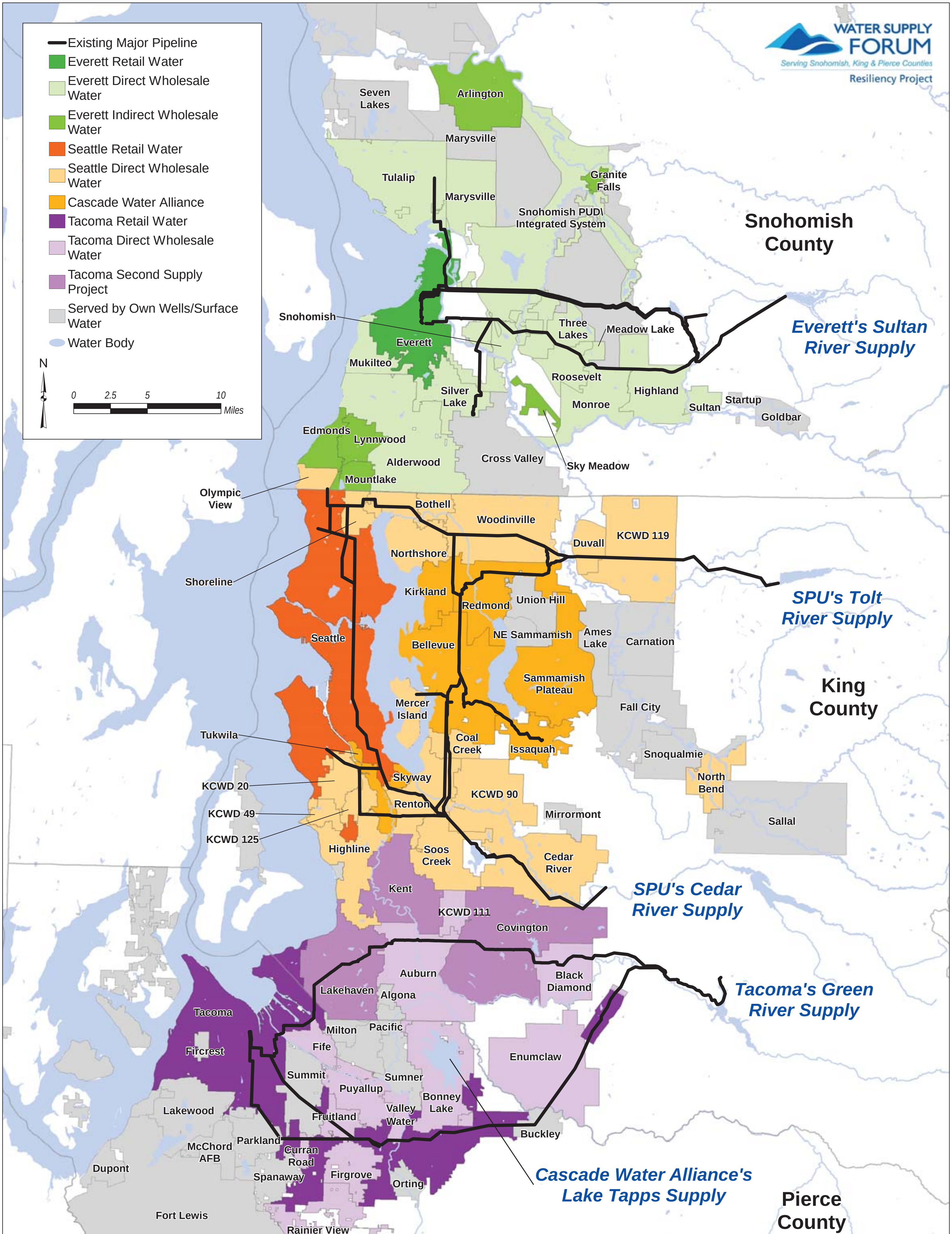

Figure 1 Water Supply Systems in the Three County Area

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APPENDICES

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