Appendix F.
"Break the System" Analysis

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Water Supply Forum

Regional Water Supply Resiliency Project

“Break the System” Analysis Technical Memorandum (Task 302)

Snohomish, King, and Pierce Counties, Washington

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

MAY, 2018

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Abbreviations

DBP	disinfection byproducts
DOC	Dissolved Organic Carbon
DOH	Washington Department of Health
LOS	level of service
MCL	Maximum Contaminant Level
NTU	Nephelometric Turbidity Unit
pH	A measure of acidity or alkalinity
SCADA	supervisory control and data acquisition
SMCL	Secondary Maximum Contaminant Level
SRF	State Revolving Fund
TOC	total organic carbon
TM	technical memorandum
USEPA	United States Environmental Protection Agency
WAC	Washington Administrative Code
WRF	Water Research Foundation

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1.0 Introduction

The Water Supply Forum (Forum) is a voluntary organization with representatives from public water systems and local governments from King, Pierce, and Snohomish Counties in Washington State. Forum membership represents most, but not all, of the water systems in the three-county area and most of the population served and water supplied. The Forum's members represent a diverse group of public water utilities, ranging from large municipally owned systems to water and sewer districts and regional water associations. The Forum is comprised of: Seattle Public Utilities, Everett Public Works, Tacoma Water, Cascade Water Alliance, Alderwood Water & Wastewater District, and other water utilities in the region. In total, Forum members serve approximately 2.3 million people over 1,200 square miles. The region served includes approximately 60 cities/water districts, a major metropolitan area, three ports, and international businesses including Weyerhaeuser, Starbucks, Amazon, Microsoft, and Boeing.

The Water Supply Forum is conducting a water system resiliency project to evaluate risks to regional drinking water systems and measures to improve resiliency against those risks. The work specifically addresses water system resiliency in the Central Puget Sound area, including King, Pierce, and Snohomish Counties. The project was split among four resiliency topics: earthquakes, climate change, drought, and water quality.

This technical memorandum (TM) describes the resiliency assessment for water quality. Specifically, this TM builds upon the water quality work completed in Phase 1 and summarizes the analysis to identify the limits that could completely compromise water treatment or quality in the region from wildfire, volcanic eruption, resource supply chain failure, severe adverse weather, and accidental contamination. In addition, the results of the Phase 1 earthquake scenarios will be used to assess the impacts on water quality in the region.

2.0 Background

Water utilities in the Central Puget Sound region are susceptible to a variety of risk events both natural, such as earthquakes, volcanos, wildfires, severe storms, and drought, and anthropogenic, such as disruptions to the resource supply chain and accidental contamination. These risk events have the potential to disrupt individual as well as multiple utilities and limit or prevent the delivery of safe and reliable water to customers. To plan for these events, the Water Supply Forum came together to determine how utilities could continue providing essential water service during a crisis.

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 achieved and the impacts on public health and safety and the economy are minimized. The objective of this Resiliency Project is to help the water utilities of King, Pierce, and Snohomish counties take proactive steps in evaluating and enhancing this region's water supply system resiliency across and between individual utility service area boundaries. Project evaluations will contribute to public education on regional water system risks and resiliency plans. Without the drivers of actual crises or mandated efforts, the Forum member utilities have worked across jurisdictional boundaries and brought together staff with expertise in engineering, planning and the sciences to evaluate the water supply system risks facing the central Puget Sound region and identify opportunities to jointly improve the region's resiliency to these risks.

Although the region's water utilities currently manage their own systems for a variety of risks, the Water Supply Forum recognized the importance of leveraging regional resources to better prepare for potentially major water supply disruptions.

The goal of this analysis is to specifically identify the point at which a utility's, or utilities', processes are no longer resilient enough to maintain an adequate LOS in terms of water quality. In other words, this analysis seeks to qualitatively identify the magnitude of an event that will "break a system" and cause a utility to cease delivering drinking water that is fully compliant with all United States Environmental Protection Agency (USEPA) and Washington Department of Health (DOH) regulatory requirements. This analysis focuses solely on water quality and does not consider water supply as a utility may be able to continue delivering non-potable water to meet non-potable system demands, such as firefighting or toilet flushing.

3.0 Basis of Analysis

This analysis starts by identifying a typical small, medium-sized, and large water utility to encompass the breadth of facilities present in the study area. This analysis assumes the utilities each have their own water supply. Consecutive systems without their own supplies were not specifically considered for this analysis, but much of the information remains applicable. In addition, this analysis only considers Group A systems regulated under Washington Administrative Code (WAC) 246-290. The smaller Group B systems were excluded because their facilities and capabilities are much more limited than Group A systems and their service populations are considerably smaller. The categories of water supply, treatment capabilities, storage, distribution network, staffing, financial capacity, and monitoring capabilities define each size of the identified typical utility (see Table 1).

Each of these utilities were assessed against several water quality-related risk events. These risk events were first identified in the Forum's Phase 1 efforts as those that would (1) affect many small, medium, and large-sized utilities in the tri-county area; (2) have common mitigation measures that can be readily identified and developed for all utilities to use; and/or (3) not necessarily already covered by readily available published literature or current utility planning and operating procedures. Based on this prioritization process, the Forum Water Quality Committee selected six risk events from Phase 1 for further evaluation in this Phase 2 effort: wildfires, volcanic eruptions, resource supply chain disruption, accidental contamination, severe adverse weather, and earthquakes. These six risk events have a low likelihood of occurrence, but the consequence of an occurrence would be a severe, negative impact on a utility's ability to provide safe drinking water. Specific implications for the three-county area include the following:

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

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

The analysis then quantitatively identifies a severe risk event that could occur to generate the water quality failure. The quantitative standards that define water quality failure are:

1. Contaminant concentrations reaching above maximum contaminant limits (MCLs) and secondary MCLs (SMCLs) established by the DOH and USEPA,
2. Inability to achieve primary disinfection at the system point of entry and/or the inability to consistently maintain secondary disinfection in the distribution system.
3. Turbidity measurements above regulatory limits, which is 0.3 NTU for filtered systems and 5.0 NTU for unfiltered systems.

Most risk events can be mitigated by running treatment facilities at lower production rates to adequately treat the water. For example, a conventional treatment facility rated for 10 MGD can still produce drinking water even if a landslide in the watershed causes turbidities to exceed 10,000 NTU by operating at 1 to 2 MGD. The lower production rate allows the elevated raw water solids to be adequately removed by the existing sedimentation equipment and avoids having the filters blinded. Alternatively, some chemical contaminants can be adequately destroyed using higher oxidant dosages and oxidant contact times achieved by operating the facility at lower production rates. Finally, reduced chemical supplies (either due to regional shortages and/or inability to transport available regional supplies to a specific facility) would be adequate as long as the production rates are also correspondingly reduced. Given this continuum of operations related to water quality conditions, causing a treatment facility to completely stop producing water quality-compliant water can be difficult. To bracket the analysis in this report, a treatment facility is considered broken when it is no longer able treat water at the facility's rated capacity.

Finally, this analysis assumes that risk events are not avoided by shutting down the treatment facility and meeting system water demands by drawing from other supplies. The treatment facility will continue drawing from the affected water supply, and therefore shutting down is one mitigation strategy to the risk event.

The following sections discuss the magnitude of the risk events that could lead to these conditions while section 10presents a summary. In the context of this analysis, the "Water Supply" column in the table refers only to surface water supply; groundwater was not in the scope of this analysis.

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Table 1. Utility Categories

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 1 (continued)

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.

Table 2. Water Quality Risk Events

Risk Event	Event Description
Wildfire	Significant area of the watershed has burned. Large amounts of debris and increased sediment transport to surface water supply. Increased concentrations of total nitrogen, organic nitrogen, ammonium, potassium, magnesium, iron, calcium, total organic carbon (TOC) and other cations that form carbonates would all increase significantly in runoff events and enter the watershed. Potential for firefighting chemical contamination.
Volcanic Eruption	Mount Rainier would erupt similar to the Mount St. Helens eruption in 1980. Debris, avalanches, mudflow (lahar), and ash fall will cover surrounding areas. Ash and lahar will extend up to 60 miles from Mount Rainier. Increased turbidity, acidity and heavy metals concentrations that will shift source water quality.
Resource Supply Chain	Essential treatment chemicals such as coagulants and disinfectants cannot be delivered due to supplier issues and/or road blockages due to other catastrophic events. Treatment systems would not be able to properly disinfect water and are unable to meet water quality standards.
Severe Adverse Weather	Large snow and/or ice storm hits the tri-county region making road travel difficult or impossible. Access to the facility by employees, chemical trucks, and fuel trucks is hindered by bad road conditions and fallen trees. Power outage that lasts approximately one week or more.
Accidental contamination	A large release of chemicals occurs in the surface water supply. Such a release would be a vehicle landing/falling into the reservoir. A worst-case situation could be either a firefighting plane releasing upwards of 4,000 gallons of fire retardant along with several tens of thousand gallons of jet fuel, a commercial passenger plane carrying 65,000 gallons of jet fuel, a train derailment of multiple 34,500-gallon tanker cars spilling, or a tanker truck carrying 9,000 gallons of gasoline. The end result, regardless of the type of vehicle, is that chemicals and/or fuel enter the treatment facility and the facility processes are unable to adequately remove the contamination.
Earthquake	Any one of the earthquake events identified in Phase I may occur. Distribution pipe breaks cause debris to enter the system.

4.0 Wildfire

The wildfire risk event considers a situation where a significant amount of the watershed contributing to a surface water supply has burned. In addition, the burn area is located near the supply, either directly adjacent to the river or reservoir, or close to the streams and rivers feeding the point of withdrawal along the river or in the reservoir. Large amounts of ash, debris and sediment are transported into the water supply during the fire and with each subsequent precipitation event. Increased concentrations of total nitrogen, organic nitrogen, ammonium, potassium, magnesium, iron, calcium, TOC and other contaminants would be found in the water during runoff events. Finally, contamination from the firefighting chemicals used to stop the wildfire event is likely.

These significant water quality changes will have an immediate, major, and persistent impact on drinking water treatment systems. These impacts are cumulative as a result of pollutants mobilized by the fire, chemicals used to fight the fire, and landscape disturbance from the post-fire response actions. The primary water quality-related changes after a wildfire are:

- Increased turbidity and total solids from the debris and sediment, including black ash, from burned vegetation. This material results in higher solids loading into treatment facilities.
    - For conventional treatment facilities, higher chemical consumption for turbidity removal (which further increases the solids loading) can occur at the water filtration facilities along with shorter filter runs and lower production efficiencies (a failure condition per this analysis).
    - Direct filtration facilities, with their lack of pre-filtration solids removal, will likely be overwhelmed by the high turbidity and result in reduced production and turbidity levels exceeding limits in the filtered water.
    - For the unfiltered water systems, the turbidity could cause water quality violations and the shut-off of supplies until the raw water turbidity decreases.
- Turbidity and total solids released into the water would also increase from forest clearing and clear-cutting activities as firefighters make fire breaks to contain the wildfires and from the ruts caused by vehicle traffic across forested areas.
- Increased ammonia, nitrite, nitrate, and phosphate and pH fluctuations from burned vegetation and sediment transport.
- Increases in nitrogen and phosphorous concentrations after the elevated turbidity subsides also may lead to algal blooms in downstream water impoundments resulting in filter clogging problems and extreme fluctuations in pH and dissolved oxygen concentrations that affect treatment operations. Also, these nutrients may result in a series of distribution system impacts such as increased potential for biofilm formation leading to elevated heterotrophic plate counts, coliform detections and problems, lower and fluctuating chlorine residuals coupled with higher and unstable chlorine demands, higher disinfection byproducts (DBP) formation potential, and pH instability.
- The introduction of radionuclides and metals from ash, soils, and geologic sources within the burned area, causing potential compliance issues for these regulated inorganic compounds.
- The introduction of fire retardant chemicals that directly enter into waterbodies or fall onto soils that would enter into the water after subsequent rain events. Fire retardants typically contain large amounts of ammonia, which would cause increased chlorine demands, difficulty in maintaining free chlorine residuals, and the potential taste and odor issues if they enter a water intake. In addition, retardants contain several compounds for which there is sparse information on human health effects and no regulatory limits. This uncertainty could also pose an issue.

The potential regional impacts could be significant as the vast majority of the tri-county area's drinking water comes from surface water resources. Specifically, the major drinking water supplies in the central Puget Sound region are in heavily forested watersheds and/or adjacent to large tracts of forested land. Figure 1 illustrates the reservoirs most likely to be impacted by wildfire in the region.

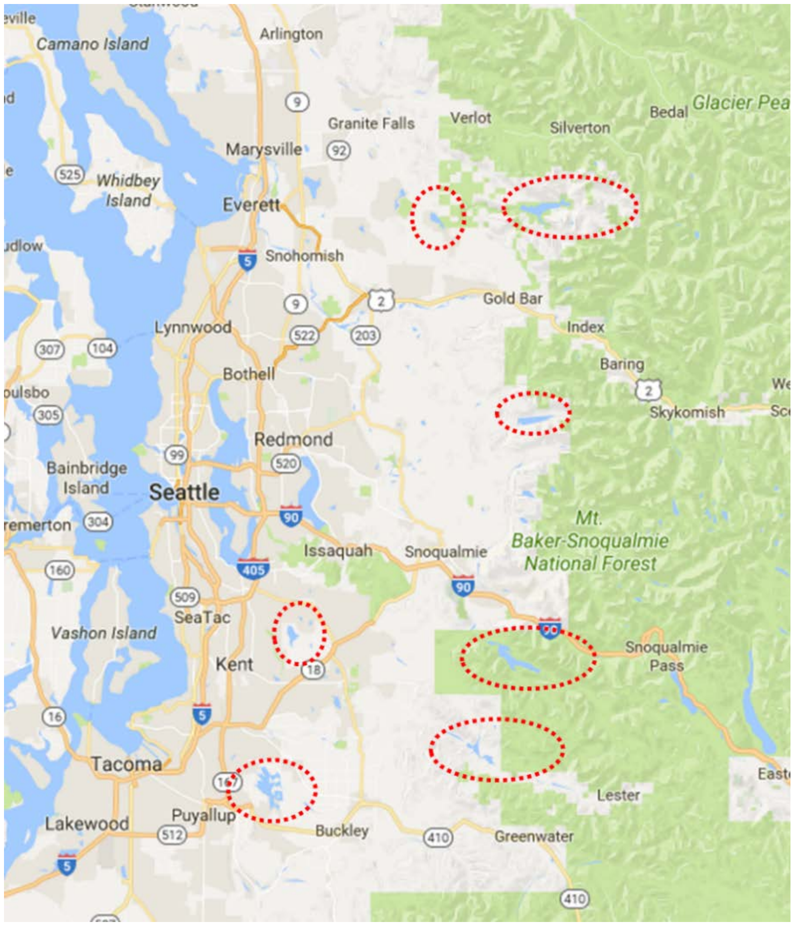

Figure 1. Potential Wildfire Impact Areas in Regional Supply Watersheds

The magnitude of the water quality effects vary widely and are affected by the area of the burn, the intensity of the burn, the proximity of the burned area to the river or lake supply, the amount of fuel in the burn area, the amount and type of fire suppression activities taken, and the installed water treatment system. The wide variability of environmental conditions means there is no correlation between acreage burned and a treatment facility failure. The Water Research Foundation (WRF) report “Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation” (Sham et. al, 2013) indicates wildfires as small as 300 acres affected the surveyed water utilities, though extent of the impacts were not listed. A known point of reference is the Fourmile Canyon Fire in Colorado. This fire burned 23 percent of the watershed (6,425 acres) and the resulting water quality impacts forced treatment plants drawing off of the river to reduce production or shut down, which represent failure conditions per this analysis. An equivalent burn for the Tolt and Green River Watersheds, the smallest and largest of the regional watersheds, would be 2,875 acres and 33,900 acres respectively. Table 3 summarizes the potential impacts of a wildfire for the typical water utility analyzed in this report. Given the wide variability of impacts, this “Break the System Analysis” assumes a burn of several thousand acres close to the reservoir/river that causes immediate and sustained changes to the raw water quality. This analysis assumes firefighting efforts would not create additional water quality impacts. Precipitation is assumed be negligible as major wildfires in the Central Puget Sound would most likely occur in the dry summer period.

Table 3. Wildfire Impacts to Typical Drinking Water Utilities

Utility Type	Water Supply	Treatment Facilities	Distribution Water Quality	Public Health and Other Customer Impacts
Small	Surface water supply cannot be used for long period of time until initial debris flow washes out. Supply to customers is compromised, especially if purchased regional water can not be distributed throughout system.	Facility unable to cope with turbidity and solids loads. Processes upset as filters blinding off too rapidly. Limited instrumentation means turbidity and other contaminants are passing through treatment facility.	Potential for turbidity and inorganic chemical violations due to contaminants breaking through filters. Turbidity breakthrough and ineffective Dissolved Organic Carbon (DOC) removal can cause chlorine residual violations. Attempts to increase chlorine dosages can cause higher DBPs.	Turbidity and chlorine residual violations can result in boiled water advisories. If inorganic contaminants are found to exceed MCLs, then “Do Not Drink” order likely issued. Increased microbial issues, especially with unchlorinated systems
Medium	Surface water supply cannot be used for long period of time until initial debris flow washes out. Treatment facilities fail again with subsequent larger events. Heavy reliance on groundwater, taxing aquifers. Available supply unlikely to be able to met system demand.	Facility can cope but at very limited production as much of produced water is used for filter backwashing. More extensive instrumentation means turbidity not likely passing through filters but inorganic contaminants likely passing through filters.	Potential for inorganic chemical violations due to contaminants breaking through filters. Ineffective DOC removal can cause chlorine residual violations. Attempts to increase chlorine dosages can cause higher DBPs.	Chlorine residual violations can result in boiled water advisories. If inorganic contaminants are found to exceed MCLs, then “Do Not Drink” order likely issued. Taste-and-odor ad color issues may be reported. Increased microbial issues. Increased microbial issues, especially with unfiltered systems.

Large	Surface water supply cannot be used until initial debris flow washes out. Available supply unlikely to be able to meet system demand.	Conventional filtration facilities, can operate but with limited production in subsequent precipitation events. Direct filtration plant likely clog so rapidly as to provide no to very limited net production. Unfiltered water systems , due to the lack of turbidity removal can continue to operate with heavy debris build up. However, disinfection processes likely overwhelmed.	Filtered Systems: Potential for inorganic chemical violations due to contaminants breaking through filters. Ineffective DOC removal can cause chlorine residual violations. Attempts to increase chlorine dosages can cause higher DBPs. Unfiltered systems: Immediate turbidity violations and potential for inorganic chemical violations. Multiple violations for primary disinfection and chlorine residuals Attempts to increase chlorine dosages can cause higher DBPs.	Chlorine residual violations can result in boiled water advisories. If inorganic contaminants are found to exceed MCLs, then “Do Not Drink” order likely issued. Unlined cast iron pipes or pipes with heavy scale deposits, may release constituents of concern and/or create taste-and-odor and color (red/discolored water) issues to be reported. Increased microbial issues, especially with unfiltered systems.

Table 3 (continued)

Utility Type	Staffing	Financial Capability	Monitoring Ability
Small	Much if not all of the utility staff would be troubleshooting the water treatment plant and monitoring conditions, leaving little staff available to support other water utility needs.	The unplanned regional water purchases would likely quickly deplete the utility operating fund and leave utility in a difficult financial position.	Likely no impact; system is too limited (online monitoring) to detect and report issues other than turbidity without field sampling/monitoring activities

Medium	Multiple field crews would be diverted to watershed and treatment operations. Critical utility functions (ex. main repairs) would continue but non-critical activities (ex. service renewals and meter replacements) temporarily curtailed.	Cash reserves would be depleted with additional labor and chemical purchase, leaving no cushion for any other emergencies.	Existing system instrumentation would need to be supplemented with extensive field monitoring to track raw water supply and distribution water quality.
Large	Existing highly skilled staff may draw upon some additional staff to provide temporary labor. All other utility activities continue with little to no impacts.	For filtered systems, the impact to finances would be small compared to the overall budget. For unfiltered systems, the budget may be impacted due to large unplanned water purchases to meet regional demands while the facility is shutdown.	Existing instrumentation would help identify areas with issues, but areas may be large. Extensive field monitoring to understand specific impacts would be required.

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.

5.0 Volcanic Eruption

The volcanic risk event considers a situation where a volcano erupts near a region which includes supply watersheds and transmission, distribution, and treatment facilities. Specific volcanic hazards which pose the greatest threat to water systems include ash fall, tephra fall (large rock fragments ejected during an eruption), and lahar flows (debris flows resulting from pyroclastic materials mixing with snow). These hazards can be highly variable in both spatial distribution and magnitude of effect, though there is predictability surrounding which regions are most vulnerable to each specific hazard. There are no preventative measures that can reduce the possibility of volcanic eruptions, and response measures generally do not include addition of chemicals into the environment (e.g. fire suppression chemicals); thus, impacts from volcanic hazards are generally acute and would not be compounded by response efforts.

Volcanic hazards can result in a range of negative impacts on water quality, including:

- Turbidity: Introduction of ash and debris into water supplies can increase turbidity, creating abnormal treatment conditions and clogging filters. Turbidity can persist for extended periods of time due to re-suspension mechanisms such as wind and rainfall.
- Acidity/Alkalinity: Ash is known to be highly acidic and can readily reduce the source water pH. Water treatment operations are designed to work within a specific pH range. Water acidified by excessive ash loading, once brought into a treatment facility, could result in abnormal coagulation conditions that may reduce coagulation, sedimentation, and filtration effectiveness, leading to non-compliance with quality standards.
- Metals: Ash can contain high concentrations of various metals which could impact treatment processes and raise concentrations of various regulated inorganic contaminants above allowable levels.
- Debris flows: Lahars have been observed to extend up to 60 miles away from an eruption and destroy infrastructure in their paths. Any water system infrastructure in the path of a lahar (i.e. supply, intake, treatment, transmission, and distribution) is vulnerable to severe damage, which could lead to inundation of debris and sediments into multiple parts of a system.

The volcanic eruption event is particularly significant due to its potentially severe negative effects on source water and surface reservoirs, as well as its extensive spatial reach. Areas at the highest risk for water quality impact are those directly in the path of a lahar flow, those nearest to the volcano (susceptible to heavier debris falls), and systems downwind from the eruption (ash will be carried primarily in the direction of the prevailing winds). Any surface water resources within those regions are potentially at risk.

Mount Baker, Mount Adams, Glacier Peak, Mount Rainier, and Mount St. Helens are all active volcanoes in Washington State, and each volcano differs in the severity and extent of hazards they could potentially produce. Only two volcanoes in the region would directly impact the Central Puget Sound area: Mount Rainier and Glacier Peak. Figures 2 and 3 illustrate the locations of highest risk to the region from Mount Rainier and Glacier Peak for lahars, lava flow, and tephra fall. However, these maps exclude ash fall, which from the experience of Mount St. Helens is known to affect areas several orders of magnitude greater than all the other risks combined. The result is that though Mount Rainier is at the southern end of the Central Puget Sound Forum study area, ashfall could readily impact those utilities in Snohomish County, while ash from Glacier Peak in the north could fall in Tacoma, Puyallup, and Lake Tapps. The specific area of impact will depend on the direction of the prevailing winds at the time of eruption. Prevailing winds generally flow from west to east, meaning under typical conditions, the heaviest of ashfall would be east of the study area. However, even light ashfall can affect utility water quality operations.

Large suburban areas of Pierce County, and to a lesser degree, southern King County, would be affected by lahars, ash/tephra falls, or both resulting from a Mount Rainier eruption. Lahars directly threaten the Puyallup, Nisqually, Cowlitz, Carbon, and White River valleys, which include densely populated areas. The lahars would destroy many water system facilities in their paths, and those facilities not destroyed would likely be contaminated and require cleaning and disinfection prior to returning to service.

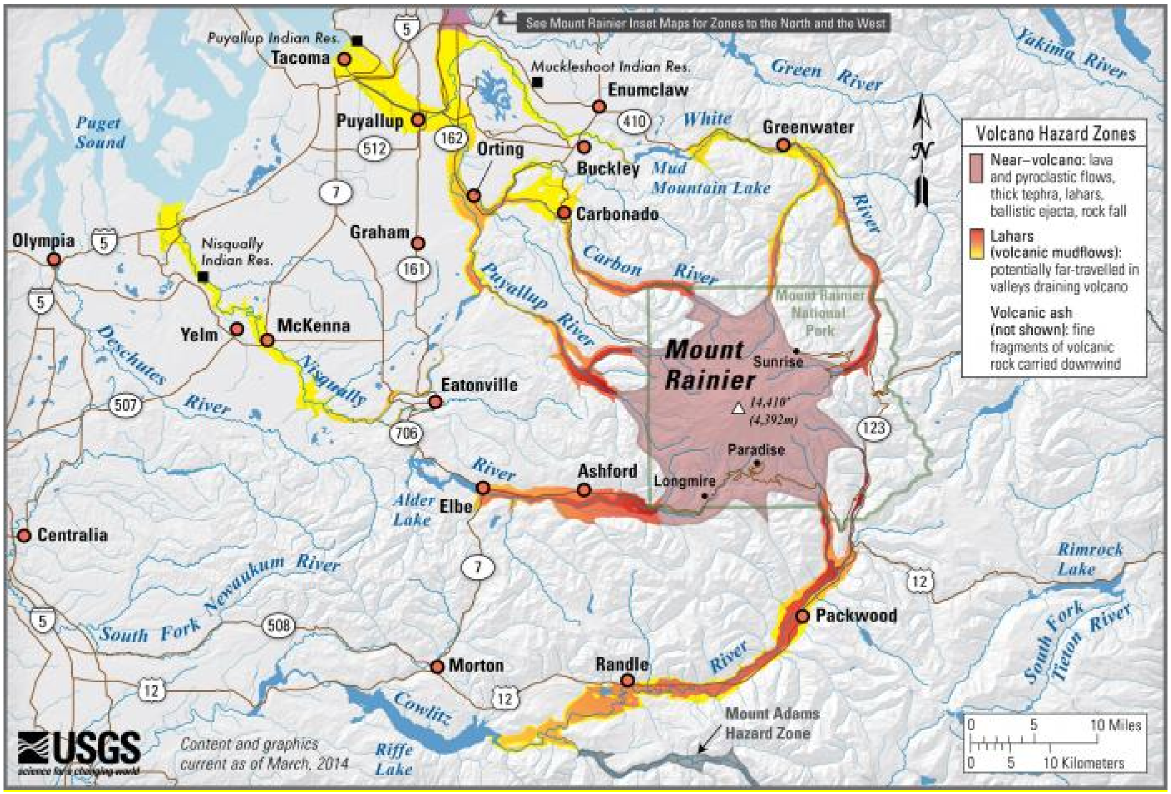

Figure 2. Mount Rainer Volcanic Eruption Hazard Zones

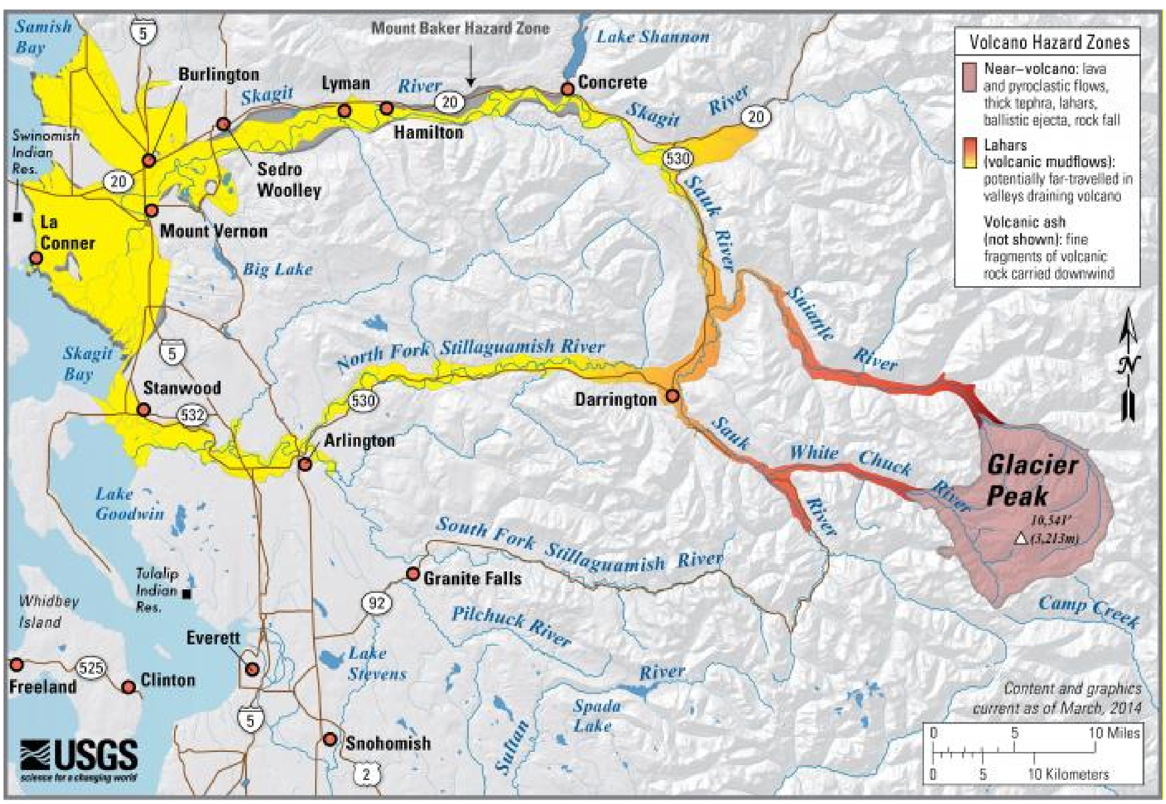

Figure 3. Glacier Peak Volcanic Eruption Hazard Zones

Past eruptions of Glacier Peak have severely affected river valleys that begin on the volcano. The Suiattle, White Chuck, Sauk, and Skagit River valleys are all at risk from lahar inundation. These effects will be most frequent in the White Chuck and Upper Suiattle River valleys. They will be less frequent, but potentially more damaging due to greater population and infrastructure, in the Sauk and Skagit River valleys. Still less likely would be lahars in the Stillagumish River valley, which would occur only if the Sauk River became choked with enough debris to be diverted west into the Stillaguamish River valley.

In river valleys downstream of both volcanoes, lahars could block transportation routes, destroy and bury structures in mud, cover roads with debris, choke river channels and intakes, and disrupt raw water quality for years or decades after the eruptions stop. Considering the analysis above, the volcanic eruption scenarios that could “break the system” are if Mount Rainier or Glacier Peak has an eruption similar to the 1980 Mount St. Helens eruption. Debris, avalanches, mudflow, and lahar flows extending up to 60 miles from the source, with ashfall blanketing the region for hours to depths totaling several inches of ash accumulation.

As for water quality impacts, many of the impacts were short-lived. Bonelli et. al (1982) determined that water pH and anion concentrations (such as sulfate and chloride) in the rivers and creeks surrounding Mount St. Helens returned to pre-eruption values in two to three days after the eruption ended. The greater change is the long-term increase in total and dissolved carbon caused by the mass die-off of vegetation in the affected areas.

Table 4 summarizes the impacts of volcanic eruptions for the typical water utilities described.

Table 4. Volcano Impacts to Typical Drinking Water Utilities

Utility Type	Water Supply	Treatment Facilities	Distribution Water Quality	Public Health and Other Customer Impacts
Small	Surface supplies, as well as wholesale purchases from larger utilities, may become unavailable, causing the utility to lose all water sources. Surface water supplies may be lost if the river has shifted away from the intake.	Physical damage is a low risk unless directly in the path of a lahar. Ashfall/turbidity will likely repeatedly shutdown the facility until the water supply clears up due to impaired finished water quality or physical clogging of systems. In addition, ashfall can intrude into motors and gears to cause premature equipment failures.	Potential for turbidity and inorganic chemical violations due to contaminants breaking through filters. Turbidity breakthrough can cause chlorine residual violations. Attempts to increase chlorine dosages can cause higher DBPs. Varying water pH can result in distribution system and premise plumbing corrosion and color issues.	Taste-and-odor and color issues can occur. At a minimum, boiled water advisories would be issued. “Do Not Drink” orders may be issued for inorganic contamination or corrosion issues.
Medium	Surface supplies, as well as wholesale purchases from larger utilities, may become unavailable, causing the utility to lose all water sources. Surface water supplies may be lost if the river has shifted away from the intake. Heavy reliance on groundwater may tax aquifers.	Similar impacts to a small utility. Treatment plant will likely have to dedicate a larger portion of resources to water treatment than normal for the duration of ash and increased sediment intake. Extreme situations may require facility to shut down.	Similar impacts to a small utility.	Similar impacts to a small utility.

Utility Type	Water Supply	Treatment Facilities	Distribution Water Quality	Public Health and Other Customer Impacts
Large	Surface supplies, as well as wholesale purchases from larger utilities, may become unavailable, causing the utility to lose all water sources. Surface water supplies may be lost if the river has shifted away from the intake. Heavy reliance on groundwater may tax aquifers.	Unless in the path of a lahar, filter facilities can continue operations but production varies depending on raw water quality. Direct filtration facilities will have turbidity exceedences as solids loading exceeding filtration capabilities. No additional staffing required but higher chemical usage or additional chemicals required, especially for coagulation and pH adjustments. Unfiltered water systems likely to exceed regulations and require a boil water advisory. Heavy deposition of solids in basins and piping.	Filtered Systems: Similar impacts to a small utility except that pH issues may be limited as all large facilities have pH adjustment systems. Unfiltered systems: Immediate turbidity violations and potential for inorganic chemical violations. Multiple violations for primary disinfection and chlorine residuals	Similar impacts to a small utility.

Table 4 (continued)

Utility Type	Staffing	Financial Capability	Monitoring Ability
Small	The extent of the impacts will readily overwhelm available staff.	Unplanned regional water purchases would likely quickly deplete the utility operating fund and leave utility in a difficult financial position. Outside assistance would be needed to fund repairs.	Likely no impact as system is too limited to detect and report issues other than turbidity.
Medium	Multiple field crews would be diverted to treatment and emergency repair operations. Non-critical activities (ex. service renewals and meter replacements) temporarily curtailed.	If the impact is just ashfall, a utility would have higher-than-budgeted operational costs but the overall impact would be manageable. Physical damage to infrastructure could deplete cash reserves and potentially affect the overall utility budget.	Existing system instrumentation would need to be supplemented with extensive field monitoring to track raw water supply and distribution water quality. Field monitoring may be difficult, as areas may become inaccessible.
Large	Dedicated in-house staff will focus on treatment operations while other utility staff would be diverted to infrastructure repairs. Non-critical activities (ex. service renewals and meter replacements) temporarily curtailed.	If the impact is just ashfall, a utility would have higher-than-budgeted operational costs but the overall impact would be manageable. Physical damage to infrastructure could deplete cash reserves and potentially affect the overall utility budget.	Existing instrumentation would help identify areas with issues, but areas may be large. Extensive field monitoring to understand specific impacts would be required. Any monitoring equipment in the path of a lahar is likely to be destroyed.

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.

A non-capital programmatic activity that could improve response to volcanic eruption would be for the Forum to 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. This may also be applicable to some impacts from large wildfires.

6.0 Resource Supply Chain

The resource supply chain risk event represents an inability to get needed chemicals, staff, fuel, or equipment to maintain proper water quality operations at various facilities. This study focused on treatment chemicals to bracket this water quality analysis. Staffing, fuel, and equipment supply impacts would impact all sizes of utilities equally, assuming that utilities are operating efficiently with little to no spare labor resources, for all of the utility areas (i.e. supply, treatment, distribution, storage, etc.).

A chemical supply chain disruption could inhibit a facility’s ability to properly treat the water and carry out general water treatment activities, leading to violations of water quality standards. This analysis is only concerned with supply chain disruptions as they relate to resources necessary for maintaining water quality and does not include resources for maintaining water supply, transmission, or distribution systems.

The primary chemical supplies of concern are coagulants, pH adjusters like soda ash, and chlorine. The most common water quality-related impacts due to supply chain issues are:

- Surface water turbidity violation: Coagulants are used to remove suspended solids from solution for filtration or settling. A lack of coagulant would leave solids in the water, reducing turbidity treatment effectiveness, potentially leading to turbidity violations.
- Groundwater treatment violation: Groundwater treatment systems uses many chemicals or products to remove various contaminants, such as coagulants for arsenic coagulation/filtration, chlorine and/or permanganate for manganese removal with greensand or pyrolusite filters, granular activated carbon for volatile/synthetic organic compounds and per- and polyfluoroalkyl substances, and sodium hydroxide for corrosion control.
- Decreased disinfection capacity: chlorine is often used in the disinfection process due to its efficiency and affordability. Without sufficient chlorination throughout treatment and resulting chlorine residuals, live pathogens, biofilms, and other unsafe bacteria would pass through the treatment process and into storage and the distribution system, potentially causing a public health risk.

Resource supply chain disruptions can have multiple causes. One cause is issues at the source of supply: a chemical supplier may become unable to supply sufficient chemical quantities in a timely manner or the chemicals they supply suffer a decline in quality. Another cause is transportation issues caused by delivery delays by rail, adverse weather or earthquakes. Chemical supply contracts are often fulfilled by companies with out-of-region warehouses/storage yards, with deliveries by tanker trucks overland to each water treatment facility. These delivery routes may be heavily impacted on the east by snowstorms closing mountain passes, flooding in the southern region of the Puget Sound closing roads, or earthquakes causing extensive transportation infrastructure damage across the region. See the "Severe Adverse Weather" and "Earthquake" sections for more detailed analyses of those risks.

Regardless of cause, the magnitude of a supply chain disruption that can "break the system" is dependent on event duration. This is different from many other risks, where the magnitude of impact is dependent on a regional position relative to the risk event. A typical water treatment facility is designed to have 28- to 30-days of average day demand chemical available when fully stocked. Some utilities may not have the full 30-day stock at the time of a supply chain disruption and high demand conditions during hot weather may require a utility to use higher quantities of chemicals. Within the 30-day time period, all utility sizes would be affected equally by supply chain disruption due to their similar design of chemical stockpile; small utilities will have fewer chemicals on hand, but this lower quantity may still carry them through a 30 day disruption. Facilities will typically draw down half their supply before ordering more chemicals. In the very short term, no calculable water quality impact may be observed due to this stockpiling.

Based on the above analysis, a 30-day supply disruption event is considered sufficient to break the system. It is also reasonable to assume that there will be fluctuations in day demand and pre-event chemical stock, leading some utilities to a broken system condition before 30 days have passed. Table 5 summarizes the impacts to each utility size following a supply chain disruption event.

Table 5. Resource Supply Chain Impacts to Typical Drinking Water Utilities

Utility Type	Water Supply	Treatment	Distribution Water Quality	Public Health and Other Customer Impacts
Small	There is no impact to the water supply.	Loss or reduced use of coagulant or polymer feed results in turbidity breakthrough from filters while reduced use or loss of oxidants causes failure of primary disinfection, or loss of removal capacity (for greensand filters).	Reduced chlorine means possible inadequate disinfection in many parts of the system. In addition, turbidity breakthrough can also mean bacteria or other pathogens entering and persisting in the distribution system.	Boiled Water Advisory required until all chemical dosages restored to normal operating levels and the distribution system is purged of un/under-treated water.
Medium	There is no impact to the water supply.	Similar to a small utility.	Similar to a small utility.	Similar to a small utility.
Large	There is no impact to the water supply.	Similar to a small utility.	Similar to a small utility.	Similar to a small utility.

Table 5 (continued)

Utility Type	Staffing	Financial Capability	Monitoring Ability
Small	No direct impact.	Purchasing chemicals off-contract can be expensive and puts a significant drain on finances.	No direct impact
Medium	Same as small.	Same as small.	No direct impact
Large	Increased labor for water quality sampling and monitoring.	Same as small.	No direct impact

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.

7.0 Severe Adverse Weather

The severe adverse weather risk event considers a short-term (up to a week) intense weather event of such magnitude that it disrupts regular water system performance. This event is defined as short-term to differentiate it from long-term weather events like seasonal anomalies or climate change. Severe adverse weather can result in treatment facility failure, equipment damage, communication loss, SCADA loss, supply chain disruptions, and inability of employees to access water system facilities. These impacts can significantly compromise a water system’s operations, putting water quality directly at risk. Severe adverse weather is assumed to be spatially large and covers most parts of the Central Puget Sound area.

The primary water quality-related changes due to severe weather events are:

- Infrastructure damage: High winds, ice storms, and flood events following heavy rainfall all pose a direct threat to infrastructure, particularly above-ground. If treatment infrastructure is damaged, treatment procedures may be halted, leading to sub-standard water passing through the treatment facility. Distribution system components could also be broken or damaged, especially during very cold weather conditions.

- Source water quality: flooding and landslides can increase sediment loads into supply sources, potentially surpassing the standard treatment conditions a water treatment plant is designed to handle, leading to compromised water quality. Flood events generally will only happen in the low-land regions; upper watersheds will drain quickly and multiple dams/reservoirs act as flood control mechanisms. In extreme flood events, treatment and wellhead facilities may be inundated. The main impacts of flooding will be along river corridors and poorly drained urban areas. Landslides can occur anywhere with variable topography. Landslides have been observed to drive rivers to extremely high levels of turbidity that are effectively untreatable to standards.
- Power loss: High winds can take down power lines, damage power generation infrastructure, and power delivery mechanisms to facilities. Back-up power will be engaged when they are available.

Note this risk event pertains solely to water quality facilities and does not evaluate the risk of running out of fuel (similar to a resource supply chain disruption) at booster pump stations and other supply facilities.

Table 6 summarizes how severe adverse weather events affect each utility size. Two adverse weather scenarios that formally break the system, as developed from the above analysis, were considered:

1. An ice/wind storm hits the entire region making road travel difficult to impossible and causing power outages of up to one week.
2. A large snowstorm with up to two feet of snowfall occurs, similarly limiting road travel.

Such events occur regularly in the Central Puget Sound region, with the last major snowstorm occurring in February 2017. For both scenarios, the storms also cause debris to wash into the surface water supply (runoff), or causing a surface supply river to scour or reservoirs to swirl, causing elevated water turbidities in the source water. These water quality impacts are specific to surface water as groundwater would have no impact from this risk event.

Table 6. Severe Adverse Weather Impacts to Typical Drinking Water Utilities

Utility Type	Water Supply	Treatment	Distribution Water Quality	Public Health and Other Customer Impacts
Small	Supply may be compromised if raw water pumps and wells lose power or are flooded.	Treatment operations may need to stop due to lack of operator access or facility is physically damaged. Even if treatment continues, surface water operations likely disrupted due to cold water temperatures and storm-driven elevated turbidities. There are no impacts to groundwater treatment.	Water quality may vary to reflect disrupted operations.	The very cold water may also increase the number of water main breaks.
Medium	Same as small.	Same as small.	Same as small.	Same as small.
Large	Same as small.	The greater level of automation allows treatment operations to continue. Facility damage will limit production but larger size and greater number of redundancies means facility will not likely be completely offline (but which is still a failed system per the definition in Section 3.0).	Same as small.	Same as small.

Table 6 (continued)

Utility Type	Staffing	Financial Capability	Monitoring Ability
Small	Staff will be unable to commute to water system facilities, resulting in delayed response. May need assistance (local enforcement, national guard, etc.) getting staff to work.	Smaller projects can be self funded. Emergency funds would likely be depleted by larger projects, and grants would likely be necessary for full recovery.	Already limited monitoring ability likely to be taken offline by adverse weather and power outage.
Medium	Same as small.	Same as small	Likely extensive damage to monitoring infrastructure. Monitoring may have to be supplemented by manual field and facility monitoring due to outages and damaged equipment.
Large	Water control centers already have provisions for adverse weather would remain staffed to monitor water system operations. Treatment facilities will also be staffed but access will be slow and result in extended work shifts. Field water quality staffing will be curtailed to limit unsafe driving. Movement may need assistance (local enforcement, national guard, etc.) to get around.	Would likely have the capability to self-fund repairs required following a severe weather event. Extensive damage may significantly impact financial reserves, but unlikely to deplete them.	Some monitoring infrastructure, whether in-system or in a source region, is likely to be damaged. Additional field monitoring would be required to properly assess damage, leading to possible information gaps where damage may have occurred.

8.0 Accidental Contamination

An accidental contamination risk event is defined as when a fuel, oil, or any hazardous material that can contaminate a utility's water supply is accidentally introduced, creating unsafe drinking water conditions. This can occur from chemical spills during transport (by road or rail) or a plane landing in a source watershed or an open-air storage reservoir. Introduction of uncommon contaminants in source water presents both short and long term impacts as chemicals may be environmentally persistent, can bypass regular treatment operations, and require abnormal operations to clean up. If a utility exposed to this event lacks an alternative water source (e.g. groundwater, wholesale purchases), the option to close off their treatment facilities may not be feasible and contaminants may reach the distribution system, putting consumers at risk. Naturally occurring contamination or internal chemical overdosing are not included in this analysis.

The primary water quality-related risks of an accidental contamination event include:

- Environmental contamination: Some contaminants are persistent and could remain in the source watershed or aquifers for extended periods of time, posing a long-term habitat and water quality threat.
- Treatment interruption: Normal treatment operations may not be effective in the face of a chemical spill, requiring reallocation of resources to contamination remediation, leaving less resources available for normal treatment processes. This could consequentially lead to other water quality violations beyond the chemical contaminants.

The focus of accidental contamination is at the supply prior to reaching the intake or well/wellfield. An event such as a train or plane crash is discreet, meaning only specific supplies and utilities would be affected by a single event. The utilities in the tri-county area all draw from different watersheds and aquifers, and there is no single river, stream, or aquifer in Central Puget Sound serving multiple, large water systems, such as would be found in other parts of the state like the Columbia River basin.

To approach the type of contamination event that would break the system, consider a plane or tanker truck crashing into a source watershed or surface reservoir. The reservoir's ability to dilute fuel from a plane or tanker truck crash is quite high, meaning with good mixing and dilution, there is effectively no accidental contamination risk. Also, the buoyant properties of fuels mean they will float to the surface of a reservoir, which can then more readily be cleaned up by emergency responders. Thus, in order for a crash into a reservoir to represent a direct accidental contamination threat, the vehicle (plane or tanker truck) would need to spill very close to an intake point. The contaminant would also need to reach the intake quickly enough to minimize dilution.

Given the considerations above, the following specific "break the system" scenarios were developed for this analysis (scenarios assume an accident very close to the water treatment intake):

1. A firefighting plane crashes into a reservoir and contaminates water with 4,000 gallons of fire retardant along with fuel.
2. A larger passenger plane carrying 250,000 liters of fuel crashes into reservoir.
3. a train derailment with multiple 34,500-gallon tanker cars spilling their cargo.
4. A double tanker truck carrying approximately 9,000 gallons of oil/gasoline spills in the watershed due to an accident.

The prior analysis is specific to surface water supplies. Groundwater contamination from these scenarios may not impact a utility for a long period of time due to hydraulic times of travel, or at all if the contamination occurs in a surface aquifer while the wells draw from lower, protected aquifers.

Fuel/hydrocarbon removal from water typically uses a flotation process, such as induced gas floatation or dissolved air flotation, adsorption onto powder activated carbon particles added to flocculation tanks, adsorption in granular activated carbon vessels, or air-stripping. Other than air-stripping, these processes are very rare in the Central Puget Sound region utilities, and air-stripping is only installed in groundwater supplies, not surface water supplies. Metal salt coagulation, media or membrane filtration, and oxidation with ozone have little to no impact on hydrocarbons. Ozonation may degrade the hydrocarbons into shorter-chain molecules that could be adsorbed by a downstream biological filter; the effectiveness depends on the ozonation contact time, biological activity of the filter, and the specific compound but published results indicate removals above 90 percent in laboratory experiments (Health Canada, 2014).

Table 7 describes the impacts an accidental contamination event may have on each utility type and service area.

Table 7. Accidental Contamination Impacts to Typical Drinking Water Utilities

Utility Type	Water Supply (Surface only)	Treatment	Distribution Water Quality	Public Health and Other Customer Impacts
Small	Surface supply is small so the benefit of dilution and river flushing is much less. Contaminants would enter a treatment facility at higher concentrations. Likely response is to purchase more regional water.	Treatment systems unlikely able to effectively remove the contaminants, leading to immediate treatment shut down once the contamination is detected.	The lack of instrumentation means that fuel has entered the distribution system for the period of time between the incident and detection.	Public health may be compromised in the period betwee the incident and detection. Subsequent detection will result in a Do Not Drink order until the contamination is purged from the system.
Medium	Surface supply is larger so the benefit of dilution and river flushing is greater. Contaminants would enter a treatment facility at lower concentrations than for a small utility.	Treatment systems may not able to effectively remove the contaminants, leading to immediate treatment shut down once the contamination is detected. Temporary systems could be installed to provide additional removal.	Same as a small utility but the period of time may be short with the improved instrumentation and staffing.	Same as a small utility.

Utility Type	Water Supply (Surface only)	Treatment	Distribution Water Quality	Public Health and Other Customer Impacts
Large	Surface supplies are among the largest in the area so there is significant of dilution and flushing. Contaminants may enter a treatment facility at concentrations already below issue.	Facilities using ozone and biological filtration will likely able to effective remove the contaminant, albeit with increased chemical consumption and monitoring. For all other facilities, little to no contaminant removal occurs until detection occurs, which would occur quickly given level of instrumentation and staffing.	No impact if treatment is ozone/ biofiltration, or if detection occurs prior to water entering the distribution system.	Same as a small utility if the contamination is not removed or detected prior to reaching the distribution system.

Table 7 (continued)

Utility Type	Staffing	Financial Capability	Monitoring Ability
Small	Utility may not have staff with specialty expertise in contaminants of concern. In that case, staff would require aid from an external contaminant expert to guide recovery.	If a wholesale supplier's water quality is compromised, utility would have to dramatically change their operations, likely leading to significant draining of financial reserves.	Highly limited ability to monitor for uncommon contaminants in the system.
Medium	Could need to reallocate staffing to concentrate on this issue. Other staff may continue to operate without change.	Similar to small, but with more standard operational flexibility, providing a safety net for financial reserves.	Similar to small, but with better distribution and treatment system monitoring ability.
Large	Specialized staff may be available (or temporarily hired) to work specifically with an accidental contamination event. Most utility activities would continue uninterrupted.	Large operations budget may allow for remediation measures, including water purchases, without significant reallocation or damage to the utility budget.	Similar to a medium utility but with even greater monitoring capabilities

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.
- The Forum could 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.

9.0 Earthquake

The earthquake risk event considers a significant earthquake occurring in the region of a water system's infrastructure and/or supply source. All parts of water systems are susceptible to damage from earthquakes due to their spatial extent and above and below ground components. Earthquakes may damage infrastructure, spawn tsunami events that inundate low-elevation areas, lead to supply chain disruptions, cause major landslides, and potentially damage or disrupt groundwater supplies, all nearly simultaneously. The combination of all these impacts may lead to increased turbidity in the water supply, contamination from damaged water mains and reservoirs; and inability of staff to travel to water system facilities due to damaged roads.

The primary water quality-related risks from an earthquake event include:

- Turbidity: For surface water facilities, earthquakes of high magnitude can cause significant landslides in source watersheds, leading to increased sediment loads, untreatable by a non-filtered facility and potentially overwhelming a facility with filters. The impacts to wells will likely result in turbidity coming from the disturbed surrounding aquifer and from gravel pack in each well.
- Facility contamination: Intense shaking caused by a high-magnitude earthquake is likely to expose and break transmission, treatment, and distribution infrastructure, rendering the systems highly vulnerable to inundation by contaminants. Once non-treated or contaminated water enters into exposed pipes, the water cannot be treated and the system may require significant operational procedures such as flushing to remove contaminants and clean out before distribution is safe again.
- Inadequate treatment: A regional earthquake can cause supply chain disruptions by destroying transportation infrastructure by which the chemicals and supplies used by water treatment facilities are transported. Treatment chemicals would likely be used at a higher rate during the recovery stages of an earthquake due to possible compromised source water quality, leading to a rapid reduction of chemical stockpile quantities and inadequate water treatment even after systems are back online until the supply chain is revived.

Results from Phase 1 suggested that for each earthquake scenario, at least one of the major water suppliers (Seattle Public Utilities, Everett Public Works, Tacoma Water) in the three-county area could take up to 60 days to restore water at average winter day demand to at least 90 percent of customers' taps after a major seismic event, effectively "breaking the system". The Phase 1 analysis was focused on the larger water systems; similar major impacts could occur on smaller systems in the same regions. Any water system near the epicenter of an earthquake, regardless of size or urban/rural location, is vulnerable to major impacts. Table 8 describes the impacts an earthquake event will have on each size water system in the event region.

Table 8. Earthquake Impacts to Typical Drinking Water Utilities

Utility Type	Supply	Treatment	Distribution Water Quality	Public Health and Other Customer Impacts
Small	Turbidity from landslides will compromise surface water quality. Water from wholesale providers may also be compromised in the same way, leaving few alternatives for clean surface water supply. Turbidity from groundwater supplies will increase immediately after the event but will be cleared out if continued pumping occurs.	Extensive damage to treatment facilities could stop treatment operations immediately following an earthquake.	Multiple breaks means severely compromised water quality due to intrusion and depressurization.	A Boil Water Order throughout system is issued for all water, once non-potable water is restored. Rescinding the order will occur for the entire system at once.
Medium	Same as small except for those utilities using groundwater.	Same as small.	Same as small but there are more and larger reservoirs, meaning that some areas could still have potable water available at the reservoirs.	Same as small but Boil Water Order may be rescinded on a block-by-block basis.
Large	Same as medium.	Same as small.	Same as medium	Same as medium.

Table 8 (continued)

Utility Type	Staffing	Financial Capability	Monitoring Ability
Small	Limited staff will be entirely dedicated to post-event remediation and would need external support to accomplish all recovery tasks. No availability for day-to-day facility function. Damaged transportation infrastructure would hinder staff from reaching water system facilities.	Extremely limited capability to rebuild infrastructure following an earthquake, would very likely drain capital reserves and require emergency funds.	Basic monitoring systems could be damaged or destroyed. Staff would not have availability to dedicate to field monitoring post-event.
Medium	Most staff will be dedicated to recovery efforts. Select few specialty staff may look towards post-event procedures and return to normal methods. Damaged transportation infrastructure would hinder staff from reaching water system facilities.	Large scale emergency projects are likely to deplete any financial reserves, and SRF loans and bonds would likely be required to fully conduct the recovery effort.	Monitoring infrastructure in all parts of the system could be damaged, leading to reduced data about system wide effects.
Large	Most staff will be dedicated to recovery efforts. 24-hour staff may already be onsite to begin post-event recovery. Damaged transportation infrastructure would hinder staff from reaching water system facilities.	The massive undertaking of repairing infrastructure of a large system would likely drain its financial reserve. Federal aid would be required on top of current emergency funds to fully repair the system.	Same as medium

The capital improvements to protect water quality facilities from a seismic event are centered on making the facilities and the systems within the facilities more resilient. A few of the improvements include:

- Allowing piping to have a range of movement without failure.
- Anchoring equipment to floors and walls.
- Strengthening basin walls and floors.

A list of other capital recommended facility improvements can be found in the references from the Phase 1 Resiliency project documents.

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 system to protect these assets from damage.

10.0 Additional Recommended Actions

Additional actions that could be taken to mitigate multiple risk events discussed in the prior sections include:

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.

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.

11.0 Summary

This report analyzed how six water quality risk events, originally defined in Phase 1, could “break a system,” leading to compromised water quality. Impacts from each risk event exist on a continuum, dependent on the magnitude of the event. Specific “break the system” scenarios developed in this tech memo represent events of very extreme magnitude, but remain within the bounds of real possibility. These extreme scenarios, though unlikely, are important to consider when risk planning.

Each utility faces their own challenges and questions regarding water quality risks, as 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 this technical memorandum, utilities can conduct self assessments and address questions of how to best address risk in the context of their own systems. The Forum can act as a guide and collaborative toolbox from which to draw ideas and plans from, but the utilities themselves must tailor plans to their own needs.

12.0 References

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