The Potential Impact of Earthquakes on Firefighting Water Supply in Everett, Washington

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Certification Statement

I hereby certify that my responses on this submission constitute my own product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions, or writings of another.

Signed:

[Signature]
Abstract

The problem was the Everett Fire Department had not made adequate plans for providing alternative water supplies after earthquakes to provide continued fire protection. The purpose of this paper was to identify the risk of earthquake damage to Everett, Washington, and its water system and describe strategies to provide alternative supply for the support of continued firefighting operations. The descriptive method was used to describe the risk and likelihood of earthquake damage to Everett, Washington, and its water system, and describe strategies that might be used to ensure water supply. Everett Fire Department drivers were surveyed about their experience with operating from static sources, and neighboring departments were surveyed about their state of preparation and ability to provide mutual aid. The research questions were: 1) What are the fault lines that threaten Everett? 2) What are ways that earthquakes damage water systems, and what methods are used to protect them? 3) What is the current state of the Everett water system? 4) What methods of ensuring alternative water supply have been employed by other departments? Surveys found that necessary equipment and preplanning for alternative supply were unavailable or incomplete in the surveyed jurisdictions. The surveys also found a lack of regular training in drafting. This research recommended that hard suction be available in all stations, training be provided annually and that each department pre-designate static water sources and ensure that information is disseminated. Long term recommendations are installation of dry hydrants and development of a Portable Water Supply System (PWSS).
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Introduction

The coastal areas which surround the Pacific Ocean are a seismically active region where the movement of tectonic plates creates large numbers of earthquakes. As part of this region, the Pacific Coast of the United States, the State of Washington and the City of Everett are vulnerable to potentially devastating earthquakes. The State of Washington averages over 1,000 earthquakes per year, but only 15 to 20 are felt each year (Cascadia Regional Earthquake Workgroup [CREW], 2012, para. 7).

In addition to the damage created by the tremors, historically there have been large losses of property associated with fires after earthquakes in this Pacific coastal region including the San Francisco fire and earthquake of 1906, (“PNSN,” 2012, para. 2), and Kobe, Japan in 1995 (“PNSN,” 2012, para. 3). The water supply of a community can be quite vulnerable to the movement of the ground during an earthquake, and maintaining that supply or providing for alternative water supply to extinguish post-earthquake fires is vital to the continued economic vitality of the community and the safety of its residents.

The problem is that Everett, Washington is located in a seismically active region, and the Everett Fire Department has not made adequate plans for providing alternative water supplies after an earthquake in order to continue to provide fire protection to the city.

The purpose of this research is to identify the risk and likelihood of earthquake damage to Everett, Washington, and its water supply system and to look at strategies to provide for alternative water supplies for the support of continued firefighting operations in the event of potential earthquakes.
The descriptive method will be used to complete this research. First, it will be used to describe the current water system in Everett, its vulnerabilities and efforts already in place to protect the water supply. Second, it will be used to identify water supply vulnerabilities and successes discovered during recent seismic events, and to apply those lessons learned to the water system in Everett, Washington. Then the broader county population areas which also rely on water supplied by the Everett Municipal Water System will be identified and matched with their corresponding fire agencies. These fire agencies identified as dependent on the Everett Municipal System for firefighting water supply will be examined to determine their capabilities for maintaining post-earthquake water supply.

The research questions are:

- What are the known fault lines that threaten Everett, Washington and what is the likelihood of earthquake occurrence and potential for causing damage to the city?
- What are the ways that earthquakes can damage water systems, and what methods are being used to protect water systems?
- What is the current state of the municipal water system in Everett, Washington, and what are its vulnerabilities to earthquakes?
- What methods of ensuring alternative water supply have been employed by other departments to provide for post-earthquake fire suppression?

**Background and Significance**

The city of Everett, Washington is both the county seat and largest city of Snohomish County, Washington. Everett had an estimated population of 110,079 as of July 1, 2017, according to the US census bureau (US Census Bureau Website, 2017, table 1). Founded in 1893, and situated on the shores of Puget Sound, Everett is the economic center for the entire
county, and has transitioned from a traditional fishing, shipping, and lumber products economy to a manufacturing economy with the assembly lines for multiple Boeing passenger aircraft located within the city limits (Community Profile, 2012, p. 13). The city of Everett contains 33.45 square miles of land and an additional 15.03 square miles of water (usa.com, 2011, table 1).

The Everett Fire Department was founded in 1892, and it provides all hazards protection to the city from six stations with five full time engine companies, one ladder company, one cross-manned engine and ladder company, three medic (ALS) units, two aid (BLS) units, and one battalion chief. The department is staffed with 175 uniformed personnel and 11 non-uniformed administrative personnel (2017 Annual Report, 2018, p. 1). For the calendar year of 2017, the department responded to 23,934 calls for service of which 109 were structure fires (2017 Annual Report, 2018, p. 3).

The Pacific coast of the United States is a seismically active region, and as part of this region, the state of Washington and the city of Everett are vulnerable to damage from earthquakes. It has been predicted that there is in the Puget Sound area, “an 84% chance of a magnitude 6.5 or greater deep earthquake striking within 50 years” (“Cascadia Regional Earthquake Workgroup,” 2016, para. 3). “Washington has a history of large earthquakes. Due to increased population, new construction and infrastructure development in this state, we can expect the next large earthquake to result in loss of human life with significant economic impact” (Emergency Management Division - State of Washington [EMDWA], 2011, p. 1). “While not widely perceived today by the public or even many professionals in the earthquake or fire service fields, fire following earthquake is recognized by professionals specializing in this field as continuing to pose a very substantial threat” (Scawthorn, 2011, p. 2).
With regard to fire following earthquakes (FFE), “These ignitions occur at the same time that damaged water supply systems impair fire suppression capabilities, damaged communication networks hinder coordination, constricted and damaged roads restrict access, passive fire defenses are degraded (e.g., breached firewalls), and fire service personnel are injured or otherwise overwhelmed by the demand for their service. The result can occasionally be conflagrations that cause substantial damage, sometimes even more than the earthquake ground shaking itself (Lee, 2009, p. 20). With the vulnerability of the City of Everett to earthquakes and the association of fires with those earthquakes, the Everett Fire Department needs to have preparations made for alternative water supply in order to support post-earthquake firefighting requirements.

This paper was suggested by and continues from the Executive Fire Officer (EFO) third year course, “Executive Analysis of Fire Service Operations in Emergency Management” (EAFSOEM). During the course, unit 8 “Incident Analysis – Earthquakes” had the enabling objective for students of 8.1 to “Examine emergency response considerations and issues common to earthquake incidents,” and enabling objective 8.2 to “Examine cascading events common to earthquake incidents” (EAFSOEM - Student manual, 2016, p. 8-1). Additionally, the goals of this paper coincide with the published goals of the United States Fire Administration (USFA), where goal number three of the strategic initiatives for the fiscal years 2014 to 2018 is to “enhance the fire and emergency services’ capability for response to and recovery from all hazards” (United States Fire Administration [USFA], 2014, p. 12).

**Literature Review**

The Puget Sound region in general and therefore Everett itself is vulnerable to three types of earthquakes (Seattle Emergency Management Website, 2010, para. 2):
1. Crustal or Shallow Quakes that occur in the North American plate at depths between 0-30 km (0-18.6 miles) below the surface. Intense shaking and accompanying localized damage occur near the epicenter but usually diminishes quickly with distance relative to the other earthquake types. Shallow quakes are the type expected on the Seattle Fault and the South Whidbey Island Fault, which is the primary but not only source for shallow quakes in the vicinity of Everett (Seattle Emergency Management Website, 2010, para. 3).

2. Intraplate or Deep Quakes occur at depths of 30-70 km (18.6-43.5 miles) below the earth’s surface in the oceanic crust as it dives under lighter continental crust. Because of the depth, even buildings located right above them are far enough away that ground motions are diminished. The 2001 Nisqually Earthquake that struck the Puget Sound areas was an example of a deep quake (Seattle Emergency Management Website, 2010, para. 4).

3. Subduction Zone or Megathrust Quakes occur on the interface between the North American plate and the San Juan de Fuca plate, a small plate extending from northern California to British Columbia. These are the largest type of earthquakes in the world (Seattle Emergency Management Website, 2010, para. 5).

Shallow or crustal earthquakes have the potential for greater, but more localized damage, and tend to be more infrequent. For example, the Seattle Fault, which has been more extensively studied, has ruptured three times in the past 3,000 years. Deep quakes are the most common type of earthquake in the Puget Sound region, with examples occurring in 1909, 1939, 1946, 1949, 1965, and 2001 that were greater than 6.0 in magnitude. The mega-thrust earthquake is considered the greatest risk to the region in general with a predicted magnitude of 9.0 or greater.
The affected area could stretch from Northern California to British Columbia, Canada. Historically, these quakes have occurred approximately every 500 years (Seattle Emergency Management Website, 2010, p. 1).

The South Whidbey Island Fault (SWIF) is a shallow crustal fault that crosses Puget Sound from Whidbey Island and “projects onto the mainland near Everett and continues to the southeast” (“SWIF scenario,” 2012, para. 5). The occurrence of a shallow quake that would have the greatest potential effect on the City of Everett is the SWIF. Evidence shows that “earthquakes on the SWIF probably caused at least three episodes of strong ground shaking and one tsunami in the last 1200 years” (“SWIF scenario,” 2012, para. 4). The evidence of tsunami activity comes from sand deposits found along the Snohomish River delta, which is a northern part of the city of Everett.

Based on the previous history of the SWIF and other similar faults, it is estimated that rupture of this fault may generate an earthquake up to magnitude 7.5 (Fiege, 2009, para. 1). The probability of occurrence of a shallow earthquake in the Puget Sound region is estimated to be
15% in the next 50 years for all shallow quakes, not just the SWIF (Cascadia Regional Earthquake Workgroup [CREW], 2009, p. 8). In 2012, the potential damage to the Everett area from a magnitude 7.4 SWIF earthquake was modelled using the HAZUS (Hazards US) Earthquake loss estimation method from FEMA (Federal Emergency Management Agency). This scenario modelled 7.4 magnitude earthquake was determined to potentially result in approximately “97800 buildings (~5% of the inventory) at least moderately damaged, with 6% of these damaged beyond repair. A handful of bridges will be destroyed completely, significant fractions of the utility system will be only partially functional in the first day after the earthquake but mostly fixed within a week. However, more than 100,000 households will be without potable water or power on the first day and tens of thousands still without both after a week. Almost 14,000 households will be displaced, and 58% of these will require public sheltering. Fatality estimate range from 90 to 432 depending on the time of day the earthquake strikes. Economic losses will be in the range of many billions of dollars” (“SWIF scenario,” 2012, para. 9).

Deep earthquakes in the Cascadia Region are the most common type that can potentially damage Everett. Due to their occurrence in the subducted plate, they may occur anywhere in the region, and the location is difficult to predict. Due to the unpredictability in the location of these types of earthquakes, there are no damage scenarios available on the potential effect on Everett. These types of earthquakes typically are not accompanied by aftershocks and are believed to have a maximum magnitude of less than 7.5. Damaging deep earthquakes occur every 10 to 30 years in the Puget Sound region, and “there is an 84% chance of a deep earthquake greater than 6.5 in magnitude occurring in the next 50 years” (Cascadia Regional Earthquake Workgroup [CREW], 2008, p. 1).
“The world’s largest quakes occur along subduction zones. Dubbed great earthquakes, the magnitude of these events ranges from 8.0 to 9.0+ (the largest recorded was a magnitude 9.5 quake off the coast of Chile in 1960). Their characteristics include prolonged ground shaking, large tsunamis, and numerous aftershocks. Because the magnitude scale is logarithmic, each increase of one unit signifies that the waves radiated by the earthquake are 10-times larger and 32-times more energetic: This means that a M9.0 quake releases 1,995 times more energy than a M6.8” (“Cascadia Subduction Zone,” 2013, p. 8).

The Juan de Fuca plate is located just off the Pacific coast of North America and is subducted or pushed underneath the North American plate along a roughly 700-mile long zone that stretches from Northern California north past Oregon and Washington State to Vancouver Island in British Columbia, Canada. The Juan de Fuca plate is continually growing and pushing eastward at a rate of 3 to 40 millimeters per year. Unfortunately, the plates do not smoothly glide past each other and when the plates are locked together energy is stored in these interfaces (“Cascadia Subduction Zone,” 2013). When the plates finally slip free, the stored energy will be released as an earthquake. The Cascadia subduction zone last produced a full-length rupture earthquake in 1700, with an estimated magnitude of 9.0 and produced a significant tsunami (“Cascadia Subduction Zone,” 2013, p. 5). On average there is a full rupture of the Cascadia Subduction Zone every 500 years, but the actual interval has varied considerably and “have been separated by as many as 1,000 years and as few as 200” (“Cascadia Subduction Zone,” 2013, p. 8). “Reduced to simple odds, the chances that an earthquake as large as magnitude 9.0 will occur along the zone within the next 50 years are about one in ten” (“Cascadia Subduction Zone,” 2013, p. 8).
It is difficult to describe the regional damage that would result from a full rupture Cascadia Subduction Zone earthquake, but predictions can be made from the experiences of the 2010 Maule Subduction Zone earthquake in Chile that measured 9.0, and the Great Tohoku Subduction Zone earthquake in Japan in 2011. Each of these earthquakes was accompanied by multiple aftershocks as large as 7.9 in magnitude ("Cascadia Subduction Zone," 2013, p. 9). The aftershocks are likely to destroy buildings and infrastructure already weakened by the main earthquake. There would also be a likely tsunami that would strike the Pacific coast along the subduction zone and combined with the earthquake the death toll regionally is greater than 10,000 ("Cascadia Subduction Zone," 2013, p. 8).

"Modeling shows that the supply of drinking water is very likely to be interrupted as a result of earthquake damage. As with other utilities, the time it takes to restore some level of functionality will depend on location: Estimates range from three weeks to seven months, and perhaps much longer in areas near the coast. Complete restoration of some damaged systems could take several years. Disruption of water systems is especially problematic because broken natural gas connections and fallen power lines frequently start fires in the aftermath of big
earthquakes. In the 1989 Loma Prieta earthquake, for instance, a fire broke out in San Francisco’s Marina District after liquefaction caused underground gas lines to fail. Typically, the same water system that supplies drinking water is used by firefighters to put out fires, so quake damage to the system will seriously hamper their efforts” (“Cascadia Subduction Zone,” 2013, p. 12).

“In 2012, the Water Research Foundation looked at the damage to water infrastructure from four different earthquakes:

- 2010 Chili earthquake (magnitude 8.8)
- 2010 Christchurch, New Zealand, earthquake (magnitude 7.3)
- 2011 Christchurch, New Zealand, earthquake (magnitude 6.1)
- 2011 Tohoku earthquake (magnitude 9.0)

They found that the bulk of the total earthquake damage to water systems, and the resulting water outages to customers, was due to the failure of hundreds to thousands of smaller diameter distribution pipes in zones of infirm ground. They also found that existing buried pipe infrastructure remains highly susceptible to damage due to earthquake-caused ground failures (liquefaction, landslide, surface faulting and other effects)” (Stanley, 2015, p. 2).

The energy released when an earthquake occurs, through the slipping of a fault, damages water distribution pipelines through two major mechanisms. The first of these mechanisms is termed a Transient Ground Deformation (TGD) and refers to the shaking or movement of the ground that occurs during the release of energy in an earthquake. During TGD the ground moves in proportion to the intensity of the event, but it returns to the position of origin and is therefore transient or temporary. The intensity of the TGD is affected by distance to the epicenter, the intensity of the earthquake, the duration of the earthquake, and the soil conditions at the location
(O’Rourke, Jung, & Argyrou, 2016). The damage that may occur can be due to the inability of the material of the pipe or effected joints to resist the movement, stretching or twisting in the ground. The damage that occurs to the pipeline is also highly dependent on the construction of the pipe itself, including the material it is made of, and the soil conditions of installation and location (Sherson, Nayyerloo, & Hospool, 2015). The second type of movement is termed a Permanent Ground Deformation (PGD), where the shaking or movement of the ground is of sufficient intensity to make permanent changes in the ground topography, stability or ability to support the weight. Three types of PGD that particularly effect pipelines are liquefaction, fault line displacements, and landslides.

Liquefaction is “a type of ground failure that occurs when shaking during an earthquake causes water-saturated sand, silt, or gravel layers underground to behave like a liquid rather than a solid. Soils that are prone to this are frequently found along natural waterways and in areas where the ground consists of artificial fill (Washington State Emergency Management Council: Seismic Safety Committee [Washington EMC], 2012, p. 27). Fault line displacements are permanent movements of the ground related to the slippage of the fault itself during a seismic event when the pipeline crosses the fault. These movements are often seen in news pictures of roads and railroad tracks that are no longer continuous. These fault line displacements can be horizontal or vertical and may result in pipes being in different planes and unable to maintain integrity. Landslides may also be triggered by earthquakes when the TGD leads to decreased hillside stability in a vulnerable area. These landslides, defined as “gravity-driven movements of earth materials downslope,” (Tromans, 2004, p. 42), may occur in naturally occurring slopes or man-made slopes.
The vulnerability of the distribution system piping is highly dependent on the materials used in the construction of the pipes and the design of any connections present. The well-studied 1995 earthquake in Kobe, Japan highlighted the differential vulnerability of different piping materials during seismic events:

Table 1

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Ductile Iron (DI)</th>
<th>Cast Iron (CI)</th>
<th>PVC</th>
<th>Steel</th>
<th>Asbestos Cement (AC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe failures per km</td>
<td>0.47</td>
<td>1.49</td>
<td>1.39</td>
<td>0.43</td>
<td>1.73</td>
</tr>
</tbody>
</table>

(Regional Water Suppliers Consortium [RWSC], 2013, p. 15)

The chart summarizes the performance of several types of pipe within this water system during the 1995 earthquake. The older types of pipe still in use, such as asbestos cement (AC) and cast iron (CI), showed a much higher frequency of breaks than other types. “Pipelines having poor earthquake resistance generally include old pipes and those susceptible to corrosion. Cast iron pipes exist in many modern water systems but are known to be one of the most vulnerable to earthquake damage. Replacing old and vulnerable pipes with more seismically resistant and corrosion resistant pipes reduces damage and can improve post-earthquake network performance. Inadequate maintenance reduces integrity and increases a facilities' vulnerability to earthquake damage. Therefore, providing adequate and continued maintenance for pipelines and other facilities helps safeguard against seismic damage. Designing pipeline connections to structures, and incorporating flexible joint connections, also reduces earthquake damage “(Davis, 2010, p. 3).
After the 2010 earthquake in Christchurch New Zealand, the water utility replaced 2.5 km of damaged pipe with HDPE (high density polyethylene) pipe as a test and while replacing the rest of the pipes with a conventional type of pipe. When another earthquake struck in 2011, the conventional pipe was damaged as expected according to the type of material of the pipe, but there was no damage to the HDPE pipe. While that doesn’t mean that HDPE cannot be damaged by an earthquake, the HDPE performance was much better than expected. The real-world success of HDPE in New Zealand has led to introduction and usage in the US (Purdue University, 2013). The increased use of HDPE pipe has the potential to greatly improve the resilience of water distribution systems during seismic events.

In addition to the damage from the ground movement on the pipe and transmission lines, water distribution systems are vulnerable to the loss of electrical power to run pumps, physical damage to treatment plants and pump stations and damage to reservoirs and dams. Utilities are working towards protecting their systems through seismic hardening of treatment plants and pump stations, providing seismically protected electrical back-up generators, and protecting reservoirs and dams.

An additional issue is that when the system is damaged and water leaks from the damaged pipes, the back up water supplies in undamaged reservoirs and behind dams can be subject to loss from the pipe leaks. Seismically activated valves in these locations prevent the stored water supply from leaking out through the broken pipes until the system can be inspected (Zschau & Kuppers, 2003, p. 682).

Kobe, Japan has made large investments in improving the resiliency of their water infrastructure after the disastrous magnitude 6.9 Great Hanshin Earthquake of 1995 in which more than 6,000 people died and subsequently led to 148 separate fires which destroyed 6,513
buildings (Woodruff, 2015, para. 1). After the introduction of flexible pipes, reinforced connectors and shut-off valves on reservoirs, the management of Kobe City Water Bureau confidently expects “zero interruption” to water distribution during the next seismic event (Banse, 2017, para. 6).

One of the greatest difficulties faced by most public water utilities is the costs associated with the replacement of aging and earthquake vulnerable pipes. Although the resistant types pipes have been identified, the replacement costs are beyond the budgets of most utilities. For perspective, the Los Angeles Department of Water and Power (DWP) has an ambitious plan to replace 435 miles of the total of 6,730 miles of pipeline over the next ten years at the cost of 1.35 billion dollars (Poston & Stevens, 2015, table 2). “But difficult questions remain about how the agency will find the money, how much it will inconvenience commuters and whether the utility can ever catch up with its aging infrastructure” (Poston & Stevens, 2015, para. 5).

The water system in Everett, Washington, Everett Public Works (EPW) provides water not only to the city of Everett and its residents and businesses but has grown to a regional provider that supplies a population of about 615,000 people (Everett population 110,079) and 75% of the businesses and population of Snohomish County (“Everett Water System,” n.d., para. 1). The major components of the Everett water system include two large water storage reservoirs, Spada Lake with a 50 billion gallon capacity and Lake Chaplain with a 5.2 billion gallon capacity). The system also has a water filtration plant, which can treat up to 141 million gallons per day (MGD), four large water transmission pipelines that can carry up to 200 MGD of treated water to Everett, a distribution system of pumps and water mains that would measure more than 410 miles if laid end-to-end, and fifteen storage facilities (tanks and reservoirs) ranging from 100,000 gallons to 24 million gallons in capacity (“Everett Water System,” n.d., para. 2).
The Everett water system is also responsible for supplying and maintaining the approximately 3,300 fire hydrants throughout the city (Nasr & Peterson, 2014, para. 8.4), and reports that “Fighting a fire is the single largest demand that a water system will experience. Large volumes of water at high flow rates are required at point locations, resulting in high flow velocities, large head losses, and extreme pressure drops. To mitigate these system impacts and provide the necessary fire flows, the water distribution network can be upgraded with a combination of supply, storage, and pipe sizing improvements. Fire flow requirements are set by the City of Everett fire department depending upon the type of development (residential or commercial) and particular construction details (e.g., whether a structure has a built-in sprinkler or other fire suppression system)” (Nasr & Peterson, 2014, p. 4.8). The water system has identified needed upgrades through computer modelling to provide for adequate fire flow in all areas of the city during maximum daily demand periods (Nasr & Peterson, 2014, p. 4.9).

The Everett water system has budgeted large amounts of money to capital improvements with $107,840,000 budgeted for 2015 through 2020, and an additional $49,390,000 budgeted from 2021 through 2035 (Nasr & Peterson, 2014, p. ES-11). Even so, “Everett’s full list of seismic upgrades could take 20 years to complete” (Banse, 2017, para. 11).

When examining the types of pipe being used within Everett, there have been significant upgrades made in the type of pipe used and a larger amount of more resilient pipe in use (City of Everett, 2007, p. 9.3). Ductile iron (DI) accounts for more than half of the pipe in use (53.5%), and there is some HDPE installed. There does remain a significant amount of Cast Iron (CI) and small amounts of galvanized iron and asbestos cement (AC) (Nasr & Peterson, 2014, p. 1-35). The CI and AC are each much more susceptible to damage during a seismic event.
Table 2

*Everett Public Works water system pipes by material*

<table>
<thead>
<tr>
<th>Everett Water System Pipe Type</th>
<th>Feet in Everett system</th>
<th>Percent of Total</th>
</tr>
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<tbody>
<tr>
<td>Total pipe in system</td>
<td>2,166,734</td>
<td>100%</td>
</tr>
<tr>
<td>Asbestos Cement (AC)</td>
<td>42,220</td>
<td>1.9%</td>
</tr>
<tr>
<td>Concrete Cylinder</td>
<td>18,836</td>
<td>0.9%</td>
</tr>
<tr>
<td>Cast Iron (CI)</td>
<td>764,754</td>
<td>35.3%</td>
</tr>
<tr>
<td>Concrete</td>
<td>556</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Copper</td>
<td>1475</td>
<td>0.1%</td>
</tr>
<tr>
<td>Ductile Iron (DI)</td>
<td>1,159,428</td>
<td>53.5%</td>
</tr>
<tr>
<td>Galvanized Iron (GI)</td>
<td>1552</td>
<td>0.1%</td>
</tr>
<tr>
<td>HDPE</td>
<td>21,246</td>
<td>1.0%</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>68,165</td>
<td>3.1%</td>
</tr>
<tr>
<td>PVC</td>
<td>481</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Steel</td>
<td>85,646</td>
<td>4%</td>
</tr>
<tr>
<td>Unknown</td>
<td>1,905</td>
<td>0.1%</td>
</tr>
</tbody>
</table>


The water supply to Everett also faces significant risk from liquefaction. The transmission lines that supply Everett and by extension a large part of Snohomish County come across the Snohomish River valley to the east of the city. This area is identified as at risk for liquefaction (Everett Liquefaction Map (City of Everett Website, 2006, figure 1)) and poses potential damage to these transmission lines which would limit the water supply in Everett to
that stored in local reservoirs. Additional local risks for liquefaction exist around the Snohomish River delta to the north and the bayside area of Puget Sound where liquefaction could damage local water mains and interfere with water supply in those areas. These areas of liquefaction potential are also the areas where there is currently easier access to static water sources, and the fire department might attempt to access to provide alternative water supply for firefighting needs.

The Water Supply Forum (WSF) is a regional Puget Sound area group representing the local governments and water supply systems that addresses issues including resiliency of the public water supplies (Water Supply Forum Website, 2016, para. 1). The WSF has modelled the effect of some possible regional earthquakes on the largest regional water suppliers and presented its recovery scenarios for the Everett Public Works (EPW) water system. The standard used by the WSF for system recovery and restoration of water supply is when water is provided to greater than 90% of its customers. Providing for firefighting water supply may not be complete at the point of 90% customer restoration dependent on the location of firefighting needs. The WSF predicts the following restoration periods for Everett Public Works in which less than 90% of customers would be provided with water:

- Cascadia Subduction Zone earthquake would result in a seven-day restoration period.
- South Whidbey Island Fault earthquake would result in a thirty-day restoration period.
- Seattle Fault earthquake may result in some damage to the system but would not result in a restoration period.

(WSF, 2016, table 1)
The WSF additionally predicts damage to the EPW system during the Cascadia Subduction Zone scenario with “complete damage to Reservoir #2” and “approximately 15 transmission system breaks/leaks” (WSF, 2016, p. 9).

During a 7.0 magnitude Seattle quake scenario, the WSF predicts that the EPW system would have “slight damage to its facilities and approximately six transmission pipeline breaks/leaks” (WSF, 2016, p. 9).

The WSF report predicts heavier damage during a potential 7.5 magnitude South Whidbey Island Fault (SWIF) earthquake where the EPW system “could have complete damage to Reservoir 2, extensive damage to several key facilities, and approximately 50 transmission pipeline breaks/leaks” (WSF, 2016, p. 9). The WSF estimates that during a SWIF scenario, the distribution systems in the three-county area that includes Everett would have “as many as 4,000 additional failures” (WSF, 2016, p. 10).

When the water system fails due to an earthquake, the alternative methods that fire departments have used or are planning to use to provide firefighting water can be divided into three general areas. First, the department or municipality may construct in advance a secondary in-ground water supply system such as San Francisco’s Alternative Water Supply System (AWSS) or Vancouver, Canada’s Dedicated Fire Protection System (DFPS). Second, the fire department can be supplied with water by an above-ground temporary water system like that in Oakland or San Francisco’s Portable Water Supply System (PWSS). The final way that fire departments may supply water is through tender and drafting operations much like many rural departments do regularly. These drafting operations may be supported in urban areas through the construction of underground cisterns such as are in place in San Francisco, Vancouver, and Kobe.
The AWSS of San Francisco and the DFPS of Vancouver are second hydrant systems which were constructed independently from the regular water system with separate sources, higher pressure, and earthquake-resistant design. The drawbacks to this type of system are two-fold, financial and structural. In 2003 the city of Vancouver, Canada completed their Dedicated Fire Protection System (DFPS) modelled after the San Francisco AWSS. It consists of two pumping stations, 10,000 meters of 24-inch welded pipe and 70 hydrants installed at the cost of $52 million. It is designed to withstand earthquakes up to 8.3 in magnitude (Poulos, 2014, para. 4). For reference, the maximum magnitude associated with a Cascadia Subduction earthquake is 9.0 (“Cascadia Subduction Zone,” 2013). The $52 million-dollar price on the DFPS in 2003 would rise to nearly $71 million in 2018 dollars (https://www.saving.org/inflation/).

Unfortunately, while these systems appear to provide a robust alternative supply model, a project of this expense and scope are outside of the possibilities for most cities and fire departments.

Due to the alternate water supply systems being installed in the same ground as the regular water supply system, they are also subject to the same possibility of damage as the regular water system despite their more robust design. During the 1989 Loma Prieta earthquake in San Francisco, the AWSS pipes in the South of Market area suffered a major leak that drained the reservoir in 30 to 45 minutes and rendered the system inoperable (Eguchi & Seligson, 1994, p. 148). The higher pressure and volumes of these systems do give them additional utility for larger non-earthquake fires and high-rise demands during non-earthquake incidents.

The PWSS found in Oakland and San Francisco consists of long lengths of large diameter hose (LDH), portable hydrants and powerful pumps to supply them. If available, fire boats are an ideal platform for pumping the PWSS due to proximity to and location on the water source and the ability to avoid any land-based debris, traffic or road blockages. After examining the cost
associated with building their own AWSS and finding a lack of resources and political will towards accomplishment, the City of Berkeley, California instead developed a PWSS and purchased 12 miles of 12-inch hose and a large pump that will send salt water to any part of the city (Cherney, 2015, para. 3). These systems can be set up where needed, are not vulnerable to the same TGD as the primary water system and the AWSS. “Every fire department in the state of California should have it, or something like it,” warned Charles Scawthorn, a UC Berkeley researcher and principal at the disaster-response consultancy SPA Risk who has been modeling quakes for 40 years. “The state should develop a standardized system for cities of more than 50,000. They would be linked together and be able to work together in the event of a catastrophe” (Cherney, 2015, para. 4). The recommendations for this system could also be applied to other localities with seismic risk to their water supply system outside of California. The PWSS also has the additional advantage of providing a large water supply for the use in urban interface areas where the water supply infrastructure might be inadequate or undeveloped.

Finally, fire departments may look to supply water through relay pumping, water tender operations and drafting from static sources. These operations are common in the day to day tactics of rural departments across the United States that don’t have access to a system of hydrants. Relay pumping may provide a temporary solution to water supply, but UC researcher Scawthorn believes that this will not be useful after a massive quake because when the engines are being used as a stationary pump, they will be unavailable when needed for fighting other fires (Cherney, 2015, para. 12). Water tender operations may also be of limited use with “one single 2,500-gallon tanker truck…that is enough water to power one handline for only 10 minutes…essentially just enough water to combat a blazing single-family home. Although it takes only seven minutes to refill the tanker, which can theoretically be from any source, it
would likely take too much time to move around to be very useful in a large-scale conflagration” (Cherney, 2015, p. 18).

To provide for effective drafting operations, a department needs to have a plan in place to identify and prioritize locations in each area that can be used to provide water (Zaitz, 2015). Drafting can additionally be improved and made more effective by the installation of dry hydrants (Jakubowski, 2012, p. 1) that “can provide a simple, cost-effective solution to the need for access to water sources without delay. A dry hydrant consists of an arrangement of piping with one end in the water and the other end extending to dry land and available for connection to a pumper” (NFPA Website, 2016, para. 5).

Some major cities have installed a firefighting cistern system to provide water supply to drafting operations in the event of water system failure. These cisterns can also be vulnerable to the same TGD and PGD that affect the primary water system, and debris may limit access to them. During the 1995 Kobe quake many of “the 971 underground cisterns located throughout the city that were meant to be used for emergency firefighting operations were either blocked by debris, preventing firefighting apparatus from reaching them, or they were damaged and lost all their water through leakage” (National Fire Protection Association [NFPA], n.d., p. 2). Drafting itself might be a problem as a Captain Homer Robertson commented, “In most urban departments drafting is a lost art” (Robertson, 2014, para. 1).

**Procedures**

To try and predict damage to the EPW system in the event of an earthquake, it might be useful to evaluate the damage suffered in other earthquakes. The well-studied 1995 earthquake in Kobe provides real-world performance data for several different types of pipe used in water systems and the damage caused by an actual earthquake. It needs to be viewed with caution in
that each earthquake is different and therefore the TGD and possible PGD will be different in each scenario.

The available data for pipe performance in Kobe during the 1995 earthquake is for five types of pipes and reports their performance in the format of pipe failures per kilometer (km) installed. These failure rates are presented in Table 1 of this paper and are 0.47 failures per km for ductile iron (DI), 1.49 failures per km for cast iron (CI), 1.39 failures per km for PVC, 0.43 failures per km for steel, and 1.73 failures per km for asbestos cement.

This data set does not provide for information on all the types of pipe used in the EPW system (converted to km) but can only be used to extrapolate the potential damage on the same five types of pipe in the EPW system.

Table 3

Length of Pipe in Everett by Material

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Ductile Iron (DI)</th>
<th>Cast Iron (CI)</th>
<th>PVC</th>
<th>Steel</th>
<th>Asbestos Cement (AC)</th>
<th>Total Everett Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everett (feet)</td>
<td>1,159,428</td>
<td>764,754</td>
<td>481</td>
<td>85,646</td>
<td>42,220</td>
<td>2,166,734</td>
</tr>
<tr>
<td>Everett (km)</td>
<td>353.4</td>
<td>233.1</td>
<td>0.15</td>
<td>26.1</td>
<td>12.87</td>
<td>660.42</td>
</tr>
<tr>
<td>feet/3280.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Everett pipe (km) in this data set – 625.62

Percent of Everett pipe in this data set – 625.62/660.42 = 94.7%
Table 4

*Predicted Number of Pipe Failures in Everett (current)*

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Ductile Iron (DI)</th>
<th>Cast Iron (CI)</th>
<th>PVC</th>
<th>Steel</th>
<th>Asbestos Cement (AC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everett (km)</td>
<td>353.4</td>
<td>233.1</td>
<td>0.15</td>
<td>26.1</td>
<td>12.87</td>
</tr>
<tr>
<td>Failures per km (Kobe)</td>
<td>0.47</td>
<td>1.49</td>
<td>1.39</td>
<td>0.43</td>
<td>1.73</td>
</tr>
<tr>
<td>Total Failures</td>
<td>166</td>
<td>347</td>
<td>Less than 1</td>
<td>11</td>
<td>22</td>
</tr>
</tbody>
</table>

Total predicted pipe failures in Everett – 546

In the evaluated 625.62 km or 94.7% of pipes present

Table 5

*Predicted Pipe Failures after Replacement of CI and AC with DI*

<table>
<thead>
<tr>
<th></th>
<th>Cast Iron (CI)</th>
<th>Asbestos Cement (AC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everett (km)</td>
<td>233.1</td>
<td>12.87</td>
</tr>
<tr>
<td>Failures (Table 5)</td>
<td>347</td>
<td>22</td>
</tr>
<tr>
<td>Failure per km using DI</td>
<td>0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>Failures after DI replacement</td>
<td>109</td>
<td>6</td>
</tr>
<tr>
<td>Failure Difference with DI</td>
<td>-238</td>
<td>-16</td>
</tr>
</tbody>
</table>

Predicted Pipe Failures in Everett from table 5 – 546

Difference with DI replacement – (-238) + (-16) = (-254)

Predicted Pipe Failures with DI replacement - 292
To assess the Everett Fire Department’s current state of preparation to provide for alternative water supply, a survey was sent to each of the Drivers in the department and additionally to each of any Acting Drivers through surveymonkey.com. The Driver position at the Everett Fire Department is a tested civil service promotional position. The survey (Appendix A) consisted of seven questions designed to anonymously measure each Driver’s comfort and recency with the tasks of drafting and relay pumping, ability to find the necessary hard suction hoses and to determine whether hard suction was available in each station. The survey was emailed to each person with a personal invitation to participate in the survey (Appendix B).

To assess the capability of Snohomish County departments and potential Mutual Aid partners in the event of a disaster, a survey was sent to officers from the larger departments that were identified as dependent on EPW water supplies. The seven departments surveyed serve a combined 645,548 residents (see Appendix E) and due to some water system overlaps, represent slightly more residents than the total served by the extended EPW system. The survey (Appendix C) consisted of seven questions designed to measure the training levels of the driver/engineers, the level of preparation the department has achieved, and the ability of each department to assist other jurisdictions outside of its boundaries. The survey was sent with a personal invitation to participate (Appendix D).

**Results**

The data that collected from the 1995 Kobe earthquake of the performance of various materials used in water pipes were in the format of the number of failures per kilometer. The WSF (Water Supply Forum) estimates that the three-county area that includes Everett would have “as many as 4,000” water main failures during a SWIF earthquake scenario (WSF, 2016, p. 10), but does not provide any specific numbers for Everett itself.
To estimate the scope of the main failures in Everett and the effect of an earthquake on the EPW system, the failure rate from Kobe was multiplied by the length of these pipe materials in the EPW system. The total number of failures determined by these equations is presented in Table 5.

*Current system predicted pipe failures in Everett = 546*

The number of pipe failures, when combined with the number of transmission line failures and loss of reservoir 2, allow an estimation of the potential effect of a SWIF earthquake on the EPW system as it is currently configured.

The decrease in pipeline failures if the older CI and AC pipes were to be replaced with the commonly used and more earthquake resistant DI pipe is presented in Table 6.

*Predicted pipe failure decrease due to pipeline replacement = 254*

The reduction of 254 failures out of a predicted 546 failures is a reduction of 46.5% in the total predicted failures for the city (254/546 x 100). The predicted failures of distribution pipes in the Everett drops from 546 to 292 with the replacement of CI and AC pipe with a more earthquake resistant DI pipe. This 46.5% reduction in the number of failures would correspond directly to a 46.5% reduction in the number of repairs required and lead to equivalent greater resiliency. This calculation clearly shows the value of replacing the older pipe with more earthquake resistant pipe. The potential increases in system resiliency may be even greater when newer types of pipe such as HDPE are integrated into the system.

An invitation for “The Alternative Water Supply for EFD Drivers” survey was emailed to each of 31 drivers and 6 acting drivers in the Everett Fire Department. Of these 37 invitees, 29 surveys were completed for a 78.4% response (29/37 x 100). A sample of this invitation is in Appendix B.
Table 6

*EFD Drivers Survey Question 1*

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, without searching</td>
<td>34.48%</td>
<td>10</td>
</tr>
<tr>
<td>Yes, but I had to search</td>
<td>6.90%</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>58.62%</td>
<td>17</td>
</tr>
</tbody>
</table>

Question 1, “Are you able to locate sections of hard suction in your assigned station?” was answered by all 29 respondents. Seventeen of the twenty-nine drivers (58.62%) who took the survey were unable to locate any sections of hard suction. Ten of the drivers were able to locate the sections without searching, and another two were able to locate with searching.

Table 7

*EFD Drivers Survey Question 2*

<table>
<thead>
<tr>
<th>EFD Fire Stations</th>
<th>Number of Drivers reporting hard suction found in station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station 1</td>
<td>4</td>
</tr>
<tr>
<td>Station 2</td>
<td>1</td>
</tr>
<tr>
<td>Station 4</td>
<td>1</td>
</tr>
<tr>
<td>Station 5</td>
<td>3</td>
</tr>
<tr>
<td>Station 6</td>
<td>2</td>
</tr>
<tr>
<td>Station 7</td>
<td>1</td>
</tr>
<tr>
<td>N/A or “Don’t know”</td>
<td>3</td>
</tr>
</tbody>
</table>
Question 2, “If you are able to locate sections of hard suction, what is your assigned station?” was answered by 17 of the respondents and skipped by 12. The responses collected were in the form of a dialogue box allowing any answer which leads to a variety of answers with the same meaning, for example, Station 1 and Sta. 1. Additional answers including “N/A” and “Don’t know” stem from the lack of clarity in the question. There are acting drivers and one floating driver per shift that do not have an assigned station as asked in the question. At least one driver reported being able to locate a section of hard suction in each station according to the survey (there is no Station 3).

Table 8

EFD Drivers Survey Question 3

<table>
<thead>
<tr>
<th>EFD Fire Stations</th>
<th>Number of Drivers reporting no hard suction found</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station 1</td>
<td>3</td>
</tr>
<tr>
<td>Station 2</td>
<td>5</td>
</tr>
<tr>
<td>Station 4</td>
<td>2</td>
</tr>
<tr>
<td>Station 5</td>
<td>1</td>
</tr>
<tr>
<td>Station 6</td>
<td>2</td>
</tr>
<tr>
<td>Station 7</td>
<td>4</td>
</tr>
<tr>
<td>N/A or “Don’t know”</td>
<td>3</td>
</tr>
</tbody>
</table>

Question 3, “If you are unable to locate hard suction, what is your assigned station?” was answered by 20 and skipped by 9. The answers were also collected in a dialogue box as in
Question 2, so there are equivalent variances in the answers provided here as well. This question is also complicated by the lack of clarity due to acting positions and floating positions. Drivers in each station reported being unable to locate any sections of hard suction.

Table 9

*EFD Drivers Survey Question 4*

<table>
<thead>
<tr>
<th>How many sections of hard suction are in your assigned station?</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>53.57%</td>
<td>15</td>
</tr>
<tr>
<td>One</td>
<td>28.57%</td>
<td>8</td>
</tr>
<tr>
<td>Two</td>
<td>17.86%</td>
<td>5</td>
</tr>
<tr>
<td>Three</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Four</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Five</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>More than five</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Question 4, “How many sections of hard suction are in your station?”’, was answered by 28 and skipped by one person. Fifteen of the drivers reported that there were no sections of hard suction in their station and thirteen reported that there were one or two sections. No one reported more than two sections present.
Table 10

**EFD Drivers Survey Question 5**

“Are you comfortable in your ability to draft water from a static source?”

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am comfortable with my ability</td>
<td>41.38%</td>
<td>12</td>
</tr>
<tr>
<td>I have some comfort but could use some</td>
<td>55.17%</td>
<td>16</td>
</tr>
<tr>
<td>refresher training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am not comfortable with this task</td>
<td>3.45%</td>
<td>1</td>
</tr>
</tbody>
</table>

Question 5, “Are you comfortable in your ability to draft water from a static source?” was answered by all 29 of those who took the survey. Twelve drivers reported they were comfortable in their ability to complete the task, another 16 reported that they “have some comfort, but could use some refresher training” and one reported that they were “not comfortable.”

Table 11

**EFD Driver Survey Question 6**

“When was the last time you drafted water from a static source?”

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within the past year</td>
<td>24.14%</td>
<td>7</td>
</tr>
<tr>
<td>Within the past three years</td>
<td>31.03%</td>
<td>9</td>
</tr>
<tr>
<td>Within the past five years</td>
<td>24.14%</td>
<td>7</td>
</tr>
<tr>
<td>Within the past ten years</td>
<td>6.90%</td>
<td>2</td>
</tr>
<tr>
<td>More than ten years</td>
<td>13.79%</td>
<td>4</td>
</tr>
<tr>
<td>Never</td>
<td>0%</td>
<td>0</td>
</tr>
</tbody>
</table>
Question 6, “When was the last time you drafted water from a static source?” was answered by all 29 of those who took the survey. Seven had drafted in the past year, nine more had drafted in the past three years, and seven more had drafted in the past five years. Two of the drivers had drafted in the past ten years, and four had not drafted in the past ten years.

Table 12

**EFD Driver Survey Question 7**

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within the past year</td>
<td>37.93%</td>
<td>11</td>
</tr>
<tr>
<td>Within the past three years</td>
<td>27.59%</td>
<td>8</td>
</tr>
<tr>
<td>Within the past five years</td>
<td>10.34%</td>
<td>3</td>
</tr>
<tr>
<td>Within the past ten years</td>
<td>6.90%</td>
<td>2</td>
</tr>
<tr>
<td>More than ten years</td>
<td>3.14%</td>
<td>1</td>
</tr>
<tr>
<td>Never</td>
<td>13.79%</td>
<td>4</td>
</tr>
</tbody>
</table>

Question 7, “When was the last time you relay pumped?” was answered by all 29 of those who responded to the survey. Eleven drivers have relay pumped in the past year, eight have in the past three years, and three drivers have in the past five years. Two drivers have relay pumped in the past ten years, one has in the past ten years, and four have never relay pumped.

The EFD drivers survey clarified some points about the preparedness of the department for alternative means of water supply while simultaneously confusing others. The current lack of any other preparation indicates that any disruption of water supply will need to be mitigated by reliance on drafting from static sources as a means of supply. The perceived confidence and
experience reported by drivers in relay pumping and drafting indicate that there are some familiarity and comfort with the skills involved, but that there is room for regular training, practice and increased comfort with the skills with greater than half (58.62%) needing a refresher or not having comfort with the skill. The answers reported on the locations of the necessary hard suction sections is problematic. The surveyed drivers reported that the hard suction was available in every station, while at the same time other drivers reported that the hard suction was unavailable in every station. This uncertainty leaves the availability of this required equipment in doubt and requires follow-up.

The survey “Snohomish County Departmental Alternative Water Supply” (County Departmental Survey) was sent to officers at the seven largest departments in Snohomish County. These departments were chosen for their at least partial reliance on water supplied by Everett Public Works and the size of their combined populations served. The total population served by these departments is greater than the population dependent on EPW water due to mergers of non-EPW customers into EPW dependent fire departments, but still represents a large majority of EPW dependent residents. Seven officers representing these seven larger departments were invited to participate in this survey and with additional follow-up, seven responses were received for a completion rate of 100%.
Table 13

*County Departmental Survey, Question 1*

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, all companies carry hard suction</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Some companies carry hard suction</td>
<td>14.29%</td>
<td>1</td>
</tr>
<tr>
<td>Hard suction is not carried in the engines but is available in the stations</td>
<td>42.86%</td>
<td>3</td>
</tr>
<tr>
<td>Hard suction is not carried on the engines, and it is not available in the stations</td>
<td>42.86%</td>
<td>3</td>
</tr>
</tbody>
</table>

The results for question 1 of the County Departmental Survey, “Do your engine companies carry hard suction hose?” were that none of the surveyed departments had hard suction on each of their engine companies, and one department reported some of their companies with hard suction. Of the remaining departments, three had hard suction sections in station, and three departments had no hard suction on the engines and no hard suction available in station.

Table 14

*County Departmental Survey, Question 2*

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>14.29%</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>85.71%</td>
<td>6</td>
</tr>
</tbody>
</table>
Of the seven departments surveyed, for question 2 of the county survey, “Does your department have a written post-earthquake alternative water supply procedure?”, only one department reported having a written plan. The remaining six departments reported that they did not have a written plan.

Table 15

*County Departmental Survey, Question 3*

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, at least annually</td>
<td>42.86%</td>
<td>3</td>
</tr>
<tr>
<td>Yes, but less frequently than annually</td>
<td>14.29%</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>42.86%</td>
<td>3</td>
</tr>
</tbody>
</table>

The results for the County Departmental Survey question 3, “Are your driver/engineers trained in drafting from a static water source on a regular basis?”, were that three of the departments trained annually, one department trained less frequently than annually, and three departments had no regular training of their driver/engineers in drafting.

Table 16

*County Departmental Survey, Question 4*

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>28.57%</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>71.43%</td>
<td>5</td>
</tr>
</tbody>
</table>
The results of question 4 of the County Departmental Survey, “Have you designated static water sources within your service area that can be accessed in the event of an earthquake interrupting your primary water supply?” were that two departments had pre-designated these sources, while the other five had not designated any sources.

Table 17

*County Departmental Survey, Question 5*

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>We have designated static sources, and the information is distributed to the stations in a printed format</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>We have designated static water sources, and they are available to companies in a digital format</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>We have designated static sources, but the information has not been distributed</td>
<td>28.57%</td>
<td>2</td>
</tr>
<tr>
<td>We have not designated static water sources</td>
<td>71.43%</td>
<td>5</td>
</tr>
</tbody>
</table>

When surveyed as to the storage of information on designated static water sources in question 5, none of the departments that were surveyed had the information available to companies in the field in either a printed or digital format. Five of the departments were unable to provide that plan because they had no written plan, while the other two departments had a written plan for designated static water sources (see question 4 of the County Departmental Survey), but these plans were not made available or shared with stations.
Table 18

*County Departmental Survey, Question 6*

“Is your department prepared to supply its own firefighting water after any potential disruption to the primary water system due to an earthquake?”

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>28.57%</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>71.43%</td>
<td>5</td>
</tr>
</tbody>
</table>

In question 6 of the County Departmental Survey, two of the departments surveyed reported that they were prepared to provide for their own firefighting water in the event of a disruption, while the other five departments reported that they were not prepared to provide their own water in the event of a disruption.

Table 19

*County Departmental Survey, Question 7*

“In the event of an earthquake-based disruption to the primary water supply for large portions of the county, will your department have the ability to assist in alternative water supply to neighboring jurisdictions?”

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Response (%)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, we will have sufficient resources to assist other jurisdictions</td>
<td>28.57%</td>
<td>2</td>
</tr>
<tr>
<td>No, we will only have resources to support our own water supply</td>
<td>42.86%</td>
<td>3</td>
</tr>
<tr>
<td>No, our resources are insufficient to supply our own water</td>
<td>28.57%</td>
<td>2</td>
</tr>
</tbody>
</table>
In question 7 of the County Departmental Survey, two of the seven departments surveyed report that they will have sufficient resources to assist other jurisdictions. Three of the surveyed departments report that they will only have the resources to support their own water supply needs, and the remaining two departments report that their resources are insufficient to supply their own needs.

The County Departmental Survey was intended to evaluate the preparation of the larger departments in Snohomish County for providing for alternative water supply in the event of disruption to their primary water supply. None of the surveyed departments carry hard suction hose on all their engine companies, and three of the seven largest departments do not have hard suction available even in their stations. Three departments have regular annual training of their drivers in drafting, while three of the departments have no regular training at all in drafting.

Among these seven departments, there are a total of eight tenders to provide for shuttle operations, and there are none assigned in the urban areas of the county (C. Holmgren, personal communication, November 20, 2018).

From a perspective of departmental preparation, the surveyed departments responded that only one of the departments had written post-earthquake water supply plans in place and only two of the seven surveyed departments had pre-designated any static water sources. Of all seven of the departments surveyed, none had the information stored in a way that could be accessed by companies in the field in the event of a disaster.

Finally, the survey looked at the ability of the departments to provide for their own water supply and to potentially provide mutual aid resources to neighboring departments for alternative water supply. Two of the seven departments reported that they would be able to provide for their own water supply needs, while the remaining five departments reported that they were not
prepared to supply their own needs. When surveyed as to their ability to provide resources to neighboring jurisdictions, two reported that they would be capable of assisting other jurisdictions, three departments reported that they would only be able to support their own needs, and two of the departments reported that they would not even have the resources to support their own needs. When looking at the answers to the final questions, it is important to realize that the officers reporting their departmental capabilities may have different ideas of what a potential earthquake’s effect might be on the region. The strength and support of these mutual relationships between Snohomish County departments are such that it is likely that these departments will assist each other if the requests are possible, and damage to their own infrastructure allows it.

**Discussion**

The problem is that Everett, Washington’s location in a seismically active region, requires that the Everett Fire Department make adequate plans for providing alternative water supplies after an earthquake to continue to provide fire protection to the city. Intra-agency groups recognize that the region is vulnerable to several types of earthquakes and the chance of occurrence over the next 50 years ranges from 15% for shallow crustal earthquake such as a South Whidbey Island Fault (SWIF) earthquake (CREW, 2009), 10% for Cascadia Subduction Fault Quake (“Cascadia Subduction Zone,” 2013), or 84% for a deep earthquake in the general region (CREW, 2008). The Water Supply Forum has estimated potential damage to the EPW system from the SWIF and Cascadia Subduction earthquakes that this research paper supports through the application of the Kobe damage assessments (Table 1) applied to the current state of the EPW system (Table 2). The Kobe damage assessment applied to the potential future state of the EPW system through replacement of vulnerable pipe materials also supports the reporting of
Davis (2010) and others regarding the replacement of aging and vulnerable pipe leading to increased resiliency and greater earthquake resistance.

The preparation of departments in Snohomish County for continued operations after a seismic event was evaluated and found to be inadequate in most cases. Presently, with no other options in place, the departments of Snohomish County, including the Everett Fire Department, have by default chosen to rely on drafting and static water sources for their supply in the event of an earthquake-based disruption. In contrast to the recommendations of Zaitz (2015) and Jakubowski (2012) for drafting water supplies, pre-planning of water sources has not been completed nor shared with field personnel. The pre-designation of these sources and the sharing of this information with responding companies in advance is critical to the success of these operations during initial periods.

In surveying larger departments in California, Scawthorn (2011) found that hard suction was becoming less common on urban engine companies and that the location of static water sources was poorly documented and infrequently drilled on (Scawthorn, 2011, p. 47). The survey results paint a similar picture being present in Snohomish County. The survey results tend to agree with Robertson (2014) when he stated: “In most urban departments drafting is a lost art.” While not lost completely, the capability of drafting is decreasing.

The current state of the county is that some departments are not equipped, trained or prepared to supply water through drafting even to their own jurisdictions and that relying on mutual aid for these capabilities would be overly optimistic.

The survey results presented in this research paper are only a snapshot of current conditions present in Everett and Snohomish County. Several of the departmental improvements have the possibility of being implemented immediately and would dramatically change the
preparation levels of these departments. Further research into the preparation levels of these departments and written procedures that need to be in place are other opportunities for future study.

**Recommendations**

To prepare the Everett Fire Department to provide for post-earthquake alternative water supply, several things can and should be done immediately. First, the location of hard suction hose needs to be standardized and known, and the access needs to be readily available. With no sections available on the engines, there should be readily accessible (not hidden) sections available in each station and all personnel should be aware of their location. Taking this action may become especially critical when positions are filled during shift trades or overtime. Secondly, each company should have training opportunities at least annually to practice drafting and increase their comfort levels and competence. Finally, written procedures for alternative water supply and lists of potential static water sources and their locations must be written and distributed to the companies that need to access them. This information should be in a printed format that is readily accessible in stations in the event of any post-earthquake communication and power failures. Having this information will allow companies to become competent with any procedures and familiar with locations and access for static water supply in their areas.

Everett Public Works (EPW) is working through a comprehensive and long-term plan of seismic upgrades and increasing resilience to the water system in the City of Everett that will pay dividends for the city and the rest of Snohomish County. The Everett Fire Department should continue to support these upgrades and maintain the communication pathways to ensure that EPW continues to support the department’s needs and requirements going forward.
The longer-term recommendations are that the city and department develop a network of dry hydrants to provide for easier access to any pre-designated static water sources at both natural locations and larger pools in the city. The possibility of adding requirements to the municipal code for the addition of dry hydrants to new construction projects at these locations in the city should also be considered.

Everett should also consider the benefits of having a tender available in the city. The possibility of partnering with EPW on the specification and ordering of any future investment, so that mutually beneficial needs are met and further explored.

Everett should also consider the possibility of developing a PWSS (Portable Water Supply System) like those of San Francisco, Oakland, and Berkeley, California. There may be several possibilities for pumping a PWSS through existing, hardened EPW facilities, a future fireboat, or US Navy resources stationed at Naval Station Everett in addition to or as a cost-effective replacement for a dedicated high-capacity pump. The challenge will be the lack of sufficient large diameter hose and the lack of ability to deliver that hose where needed. A first step in the development of a PWSS should be the identification and stockpiling of appropriate hose along with a transport and deployment plan for the hose that might piggyback onto existing proposals for deployment pods for technical rescue or Hazmat. Additionally, to defray the potential costs of a system, the department should investigate partnerships with the new Paine Field Commercial Airport and Naval Station Everett to see if their needs and capabilities for alternative water supply might overlap with those of the Everett Fire Department in developing a PWSS.
References


City of Everett. (2007). *City of Everett comprehensive water plan 2007*. Everett, Washington:

City of Everett, Washington.


*Community Profile*. (2012). Retrieved from Everett, WA Website:

https://everettwa.gov/DocumentCenter/View/548/2012-Community-Profile-PDF


https://www.iitk.ac.in/nicee/wcee/article/14_S21-015.PDF


https://www.epa.gov/dwsixyearreview/drinking-water-distribution-systems

Earthquake hazards: Fire. (2012). Retrieved from

https://pnsn.org/outreach/earthquakehazards/fire


https://www.nap.edu/read/2269/chapter/7


Everett Water System Fact Sheet. (n.d.). Retrieved from

https://everettwa.gov/DocumentCenter/View/17002/Water-System-PDF
Executive analysis of fire service operations in emergency management - Student manual.  


Retrieved from https://ecommons.cornell.edu/handle/1813/13588


comprehensive water plan. Retrieved from Everett, Washington Website:  


Conference on Earthquake Engineering. Retrieved from


Southern Whidbey Island Fault M7.4 earthquake scenario. (2012). Retrieved from
https://earthweb.ess.washington.edu/gomberg/ShakeMap/ShakeMapGeologicSummaries.html


https://www.census.gov/quickfacts/fact/table/everettcitywashington/POP060210


Appendix A

Alternative Water Supply Survey for Everett Fire Department Drivers

(1) Are you able to locate sections of hard suction at your assigned EFD station?

■ Yes, without searching
■ Yes, but I had to search
■ No

(2) If you are able to locate hard suction, what is your assigned station?

_________________

(3) If you are unable to locate hard suction, what is your assigned station?

_________________

(4) How many sections of hard suction are in your station?

■ Zero
■ One
■ Two
■ Three
■ Four
■ Five
■ More than five

(5) Are you comfortable in your ability to draft water from a static source?

■ I am comfortable in my ability to complete this task
■ I have some comfort, but I could use some refresher training
■ I am not comfortable with this task
(6) When was the last time you drafted water from a static source?

- Within the past year
- Within the past three years
- Within the past five years
- Within the past ten years
- More than ten years
- Never

(7) When was the last time you relay pumped?

- Within the past year
- Within the past three years
- Within the past five years
- Within the past ten years
- More than ten years
- Never
Sample of Invitation Email for Survey Participation

(Insert Name Here),

In order to generate data for my EFO paper, I am conducting a survey of Drivers and acting drivers at the EFD. I would appreciate you taking the time to complete it. The link is attached below:

https://www.surveymonkey.com/r/ZF7SQMW

I am trying to get an accurate feel as to our capabilities, so please answer honestly – your answers are anonymous.

Thanks,

Mike
Appendix C

Snohomish County Departmental Alternative Water Supply

(1) Do your engine companies carry hard suction hose?

- Yes, all companies carry hard suction
- Some companies carry hard suction
- Hard suction is not carried, but it is available in the station
- Hard suction is not carried and is not available in stations

(2) Does your department have a written post-earthquake alternative water supply procedure?

- Yes
- No

(3) Are your driver/engineers trained in drafting water from a static source on a regular basis?

- Yes, at least annually
- Yes, but less frequently than annually
- No

(4) Have you designated static water sources within your service area that can be accessed in the event of an earthquake interrupting the primary water supply?

- Yes
- No
(5) If you have designated static water sources, how is the information on them being stored?

- We have designated static water sources, and the information is distributed to the stations in a printed format
- We have designated static water sources, and they are available to companies in a digital format
- We have designated static water sources, but the information has not been distributed
- We have not designated static water sources

(6) Is your department prepared to supply its own firefighting water after any potential disruption to the primary water system due to an earthquake?

- Yes
- No

(7) In the event of an earthquake-based disruption to the primary water supply for large portions of the county, will your department have the ability to assist in alternative water supply to neighboring jurisdictions?

- Yes, we will have sufficient resources to assist other jurisdictions
- No, we will only have resources to support our own water supply
- No, our resources are insufficient to supply our own water
Appendix D

Sample of Invitation Email for Snohomish County Departments Survey

Good evening!

I’m writing a paper for my EFO program regarding post-earthquake water supply in Snohomish County. I would like to include input from (add the name of department). I estimate that the survey will take approximately two minutes to complete.

https://www.surveymonkey.com/r/Z6KFL22

Please feel free to contact me with any questions or clarifications.

Thanks in advance for your participation and time!

Michael Calvert

Everett Fire Department
### Appendix E

Population served of Seven Largest Snohomish County Fire Departments

<table>
<thead>
<tr>
<th>Fire Agency</th>
<th>Population Served</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Snohomish County Fire &amp; Rescue</td>
<td>250,000 (South Snohomish County Fire Website, 2017, para. 1)</td>
</tr>
<tr>
<td>Snohomish County Fire District 7</td>
<td>116,000 (Sno 7 FD Website, 2017, para. 8)</td>
</tr>
<tr>
<td>Everett Fire Department</td>
<td>110,079 (US Census Bureau Website, 2017, p. 1)</td>
</tr>
<tr>
<td>Marysville Fire District</td>
<td>80,000 (Marysville FD Website, 2011, para. 4)</td>
</tr>
<tr>
<td>Lake Stevens Fire Department</td>
<td>50,000 (LS Fire Website, 2017, p. 1)</td>
</tr>
<tr>
<td>Mukilteo Fire Department</td>
<td>21,469 (US Census Bureau Website, 2017, p. 1)</td>
</tr>
<tr>
<td>Arlington Fire Department</td>
<td>18,000 (Arlington FD Website, 2012, p. 1)</td>
</tr>
<tr>
<td>Total Population Served</td>
<td>645,548</td>
</tr>
</tbody>
</table>