Appendix J.
Short-term Emergency Supply Options Following an Earthquake

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Technical Memorandum

To: Overarching Risk Team, Water Supply Forum Resiliency Project

From: Dan Graves and Andrew Graham, HDR

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Subject: Task 102 –Short-term Emergency Supply Options Following an Earthquake

Introduction

As part of the Water Supply Forum (Forum) Resiliency Project, HDR conducted a review of case studies and assessments of emergency water supply sources and delivery methods that can be provided in the immediate aftermath of an earthquake. The review included:

- Distinguishing different categories of essential, life-sustaining services that will require water supply post-earthquake that will not have access to their regular supplies.
- Inventory of alternate means for delivering water supplies that could be made available within 72 hours following an earthquake.
- Characterizing constraints and practical considerations affecting different supply sources.
- Matching the different sources to the identified categories of water needs, accounting for conditions in the Forum region.

This analysis supports the Forum and its members in determining how to improve their resiliency to major seismic events in the region. While this review focuses on earthquake events, much of the discussion is also relevant to other types of risk events that could disrupt water supply. Compared with a seismic event, considerations such as prevalence of fires and damage to transportation infrastructure would presumably be less problematic in the aftermath of the other types of risk events studied as part of the Resiliency Project.

Methods

HDR conducted a literature review to gather information about how cities and their water utilities provided emergency water supplies following major earthquakes in North America and abroad in recent decades. This included searching literature available from the Water Research Foundation and the American Water Works Association, and a broader internet search for other literature.

Case studies of major earthquakes reviewed included: Christchurch, New Zealand; Northridge, California; Kobe, Japan; and the 2011 East Japan Earthquakes. The case studies and articles included information about the extent of damage to the water system, restoration times, and methods of distributing water to the public in the hours and days immediately following each earthquake.

The challenges posed by these earthquakes have prompted analysis and planning efforts in other seismically vulnerable regions besides the Pacific Northwest. HDR reviewed materials related to those assessments as well.

Results from these reviews are summarized in the following sections of this technical memorandum.

Categories of Essential Water Services

This technical memorandum subdivides water needs in the immediate aftermath of an earthquake into four distinct categories. These categories have differing characteristics that have implications for the source(s) of supply that can best meet the needs. The four categories represent essential, life-sustaining services only.

Fire Flows

Fires resulting from earthquakes are a common occurrence, and have been the "single most destructive seismic agent of damage in the twentieth century" (Scawthorn, 2011). Fires result from earthquake damage to electrical systems and natural gas lines. Fires can be large and widespread, and a large volume of water (magnitude of hundreds to thousands of gallons per minute) will be required to effectively control fires. While fires would be hazardous in any part of the Forum utilities' service areas, the most severe effects on public safety would be in the most densely developed areas where large populations are concentrated and structures are close together.

Typically, water for firefighting comes directly from the distribution system through a fire hydrant in large quantities under high pressure. Water transmission and distribution systems are likely to be compromised, such that water necessary to carry out firefighting efforts may not be available, even in undamaged parts of the distribution system.

A paradox in resiliency planning affects water systems. Water systems may equip large reservoirs (tanks) with earthquake valves that shut off automatically in the event of an earthquake. This is important for water retention, but results in preventing flow into the undamaged parts of the system for firefighting.

Firefighting water does not need to be potable, and this creates opportunities that are not applicable to the other essential uses of water considered in this technical memorandum.

Hospitals

Hospitals are a high priority for emergency supply and would face severe impacts from water supply interruption. Hospitals require water that is sanitary and comes in moderate volumes greater than the per capita needs of the general public. Clean water is necessary for drinking water for patients and essential hospital staff, personal hygiene, sanitation of medical equipment, and cooking. High purity water is required for dialysis and similar procedures. Other water uses in hospitals include HVAC, laundry, and custodial services, and water for these uses doesn't need to be potable but still needs to be sanitary.

Large hospitals in the region include (but are not limited to):

- Tacoma General Hospital (Tacoma)
- St. Joseph Hospital (Tacoma)
- Swedish Hospital (Seattle and suburban campuses)
- Harborview Medical Center (Seattle)
- Virginia Mason Medical Center (Seattle)
- Seattle Children's Hospital (Seattle)
- Overlake Medical Center (Bellevue)
- Evergreen Healthcare (Kirkland)
- Providence Regional Medical Center (Everett)
- Veterans Administration (Seattle and Lakewood)

As described in the task 202.4 technical memorandum about tanker truck delivery requirements, total water deliveries to all hospitals throughout the Forum region would require hundreds of thousands of gallons per day, even when operating at lower than normal volumes.

Immediacy of water delivery following an earthquake is more critical for hospitals than for the other categories discussed in this technical memorandum. Health-compromised patients have greater immediate needs than a healthy citizen, and hospital emergency room visits will spike very quickly, resulting in an immediate need for water supplies to maintain effective operations.

Multiple forms of hydration besides water are also used in hospitals, especially for critically ill patients and surgical patients. However, this technical memorandum is limited to provision of water supply.

Vulnerable Populations Outside Hospitals

Vulnerable populations are groups of people that, during the post-earthquake emergency response period, cannot actively procure their own water. This technical memorandum focuses on those residing in shelters or institutional facilities during the emergency response period.

Emergency Shelters

Activation of emergency shelters to house people displaced from their homes will house diverse groups of people of varying age, income levels, and health conditions. This may include severely health-compromised persons and/or those with mental disabilities, together with healthy citizens from the general population. There are facilities in the region, large and small, that could act as shelters such as public schools and universities, stadiums such as CenturyLink Field, Key Arena, and the Tacoma Dome, and large events centers. While these facilities have physical capacity to hold large numbers of citizens, their drinking water and sanitary facilities may be overwhelmed due to the damaged water distribution network and sewer collection systems.

Senior Centers

Residents in senior centers often live there due to health factors such as decreased mobility or a need for frequent medical attention. Many (though not all) senior citizens will not be in good enough health condition to autonomously attend to their own water needs or to venture out to water distribution centers.

Prisons and Detention Centers

Prisons throughout the region include multiple State Department of Corrections facilities in and around Seattle, the Monroe Correctional Complex to the northeast, and the Tacoma Northwest Immigration Detention Center in the Tacoma area. Prisons and other detention centers must continue their operations under secure conditions. Inmates and detainees will not be able to autonomously access water, and onsite plumbing systems may be damaged. Therefore at some facilities, water will need to be delivered directly to inmates.

All of these vulnerable populations have similar needs. Potable water needs include drinking, personal hygiene, and cooking. An important use that does not require potability is toilet flushing, though this will depend on whether wastewater collection systems remain functional. For drinking purposes, the CDC and FEMA recommend, at a bare minimum, 1 GPD per person (FEMA, 2004). Similar figures are suggested by the City of Wellington, New Zealand, and suggest that as much as 5 GPD may be necessary in certain circumstances (Shaw and McCarthy, 2012).

Domestic Needs (General Public Outside Shelters)

Many citizens may be able to stay in their homes after an earthquake, but will not have regular water service. Domestic water needs are similar to those of vulnerable populations (i.e. drinking water, toilet flushing, cooking, and hygiene). Their mobility may be limited due to damaged roadways throughout the region.

Potential Supplies During Emergency Conditions

The literature reviewed by HDR describes a range of water-supply approaches that can meet at least a portion of the needs described above. This section describes these approaches, and the following section discusses which supplies can best serve the different categories of water needs. For purposes of this discussion, any means of delivering water to the public is considered a "supply."

Hardened, dedicated infrastructure: Select reservoirs, pipelines, pump stations, or other elements of water distribution infrastructure can be designed and constructed to be earthquake resistant and dedicated to high-priority uses. This type of solution could be highly effective as long as stored water remains available or these features are connected to a source of supply that remains functional. However hardening existing infrastructure would be costly and may be disruptive to construct in a heavily urbanized setting.

Water that customers store routinely on-site: Water systems in the Pacific Northwest encourage all citizens to keep food and water supplies in their homes in case of an emergency. Recommendations have recently been shifting towards quantities sufficient for up to 2 weeks. This could apply to a broad range of customers including residences, businesses, schools, and other institutions. To the extent that citizens store water on site, the demand on public-sector delivery of emergency water supplies can be reduced.

Bottled water purchased/trucked/flown in: Bottled water is commonly sold in grocery stores, convenience stores, and gas stations. However, supplies on hand sell out very quickly following emergencies. Emergency supplies of bottled water can also be delivered to the region by truck, airplane, or helicopter following the seismic event.

Public and private wells: Some water systems in the Forum maintain supply wells, as do some private citizens, businesses and institutions. Wells could supply water for individuals who drive/walk to them, or for filling large tankers if the wells can produce water at high volumes quickly. Wells may be potable or non-potable. Wells run by electric pumps may not have their primary energy supply available, requiring a back-up power supply. As with other infrastructure features, wells can be damaged by the effects of a seismic event.

Tanker trucked water or flexible bladder tanks: Large tanker trucks with capacities on the scale of thousands of gallons can physically bring water to distribution points. Tankers may be subject to State Department of Health regulations for water quality if transporting potable water, which may delay the response. More information on tanker truck emergency water supply regulations can be accessed through the Washington Department of Health. In addition, any plans involving tanker truck deliveries must take damaged roadways into consideration. Coordination with transportation officials to improve resiliency of select roadways integrated with shelter planning would be valuable. In addition, communications with transportation authorities and law enforcement during emergency planning exercises could be used to communicate the importance of tanker truck deliveries during emergency traffic control. Water tanker trucks should be a high priority for traffic management, just below the priority levels assigned to emergency vehicles and law enforcement.

Portable bladder tanks designed for potable water can also be delivered by truck, effectively converting any flatbed truck into a water distribution truck. These tanks can also be airlifted by helicopter. Care should be taken to ensure any regulatory requirements are met when planning or requisitioning bladder tanks.

Public utility reservoir/tank: Large public utility reservoirs (hundreds of thousands to millions of gallons) could be made accessible as points of distribution for emergency water, and for filling tanker trucks or portable bladder tanks. Some reservoirs have earthquake outflow valves which can be closed by a seismic trigger, preserving the water supply in the event of water main breaks in the distribution system. (As noted previously, seismic valves to shut down reservoir outflows actually cut against the need for maintaining fire flows immediately following an earthquake.)

Another possibility is that utility crews may be able to obtain water "stored" in the regional transmission lines, even if the source of supply has been cut off. Water could potentially be accessed at blow-off valves. The utility would need to take into account whether the water within the transmission line remains potable. There may be other considerations to determine whether this approach is viable, how to transport the water to locations suitable for public access, and whether it justifies diverting utility crews from other response activities.

Large on-site tanks: Public buildings and institutions could maintain large water tanks at their facilities. In the event of a distribution system failure, the tank could be isolated and used for emergency supply. The tanks would need to be integrated into the facilities' normal water systems to ensure continuous cycling to maintain potability. There may be significant maintenance requirements above and beyond simply installing such tanks.

Rivers, lakes, seawater: There are numerous water bodies in the Forum region that could serve as water sources for non-potable uses including firefighting and bathing. These are limited to locations with suitable proximity to surface water bodies.

Truck- or ship-mounted filtration "plant": Small portable treatment facilities can be built inside vehicles and driven to distribution points. The systems can filter water at rates of a few thousand gallons per hour, depending on the sophistication of the system. The treatment facilities require a constant water supply source, such as a well or lake, thus have a limited range of operations, unless storage facilities are built into the vehicle as well. Ship-based treatment plants are commonly used in U.S. Navy relief efforts, but these commonly require at least a week before they arrive from far-away ports and can produce only limited quantities of potable water.

Rainwater: Households and facilities may install simple facilities for capturing rainwater from their roofs which can be stored in a barrel or small cistern. Collected rain water generally will be non-potable though rain water can be stored for extended period of time depending on the intended use. While it may also be feasible for citizens to assemble collection systems on their roof downspouts "on-the-fly", this type of rainwater harvesting would depend on rainfall immediately after an earthquake, and therefore would not be considered reliable.

Matching Supplies to Essential Services

Fire Flows

Fire flows are the most problematic of the needs discussed previously, because fire locations are unpredictable, large volumes of water may be needed immediately after the seismic event. Even undamaged areas of a distribution system may lack water, either because of problems "upstream"; or due to the earthquake valve/fire-flow paradox discussed previously. Each utility will need to consider how to balance these conflicting needs, given, local conditions and system facilities. However, there are some potential solutions.

Auxiliary Water Supply System

The City of San Francisco, in response to the 1906 earthquake, installed a high-pressure water supply dedicated for fire flows, named the Auxiliary Water Supply System (AWSS). An AWSS is a hardened infrastructure option, reinforced to withstand earthquake forces and with numerous components such as pump stations, large gravity-fed reservoirs, and dispersed urban cisterns that make it highly resilient. This system is considered to be reliable and would act as an uninterrupted fire flow supply. A similar solution could conceivably be developed in select portions of the Forum' utilities' service areas, either as a retrofit or during redevelopment projects. However, the effort to install an AWSS would be extremely capital intensive, and would be highly disruptive during construction.

Fireboats

San Francisco also has a fireboat, which can link up to the system and fight fires immediately adjacent to San Francisco bay. This solution could be applicable to the downtown harbor areas in Tacoma, Seattle and Everett; as well as on Lakes Washington and Union in Seattle.

Portable Supply System

Another option is a portable water supply system (PWSS). A PWSS uses portable pumps and hose tenders to pull water from smaller, spatially diverse sources which could include tanker trucks or local ponds/pools/lakes. One potential action to take would be for Forum water systems to discuss with local fire stations the various public accessible water sources that could be tapped by a PWSS, and plan additional firefighting resources, such as tanker truck placement, around those sources.

Surface Water Drafting

The City of Bellevue currently maintains operational procedures for drafting water from surface sources for firefighting. Fire engines can pump drafted water 1,000 to 2,000 feet away from the source for localized firefighting. For fires further away, the system can be used to fill the tank on the fire engine, which can drive to the site of the fire. Salt water in the Puget Sound is acceptable for firefighting, but is corrosive and may lead to equipment maintenance/replacement costs. Other utilities in the WSF region, particularly those with large urban centers adjacent to large water bodies, could develop surface water drafting plans that prioritize sources and cover the widest range possible.

Hospitals

Hospitals should maintain emergency water supply plans (EWSP) (CDC and AWWA, 2012). These plans should list supply sources and organize procedures to take in the event of a water supply emergency. This review did not include research on individual hospitals' EWSPs in the Forum region.

As previously described, hospitals require immediate water deliveries to avoid life-compromising interruptions of service. Water supply should be able to reach all floors in multi-level hospital buildings, so resiliency of on-site plumbing is also an important consideration.

A solution that can provide uninterrupted, high-volume service is hardened infrastructure; a dedicated supply line designed with earthquake-resistant materials.

On-site groundwater wells owned by the hospital are also viable alternatives (quickly accessible and can produce in high volumes), though they may require on-site water treatment if the wells do not produce potable water (Tanaka, 2008).

Hospitals can keep a small volume of stored water on-site. Large, on-site storage tanks are also an option.

Hospital buildings outfitted with an external plumbing connection that tanker trucks can serve would also help to provide service. This solution would not meet the immediacy requirement described previously, so may be best viewed as part of a multi-layered approach to meeting hospital needs.

Hospitals throughout the region should individually determine which of these options are feasible and best suited to their needs, operational capabilities, and investment priorities.

Other Vulnerable Populations

Emergency Shelters

Large shelters could house significantly larger volumes of people than other vulnerable population housing facilities. Water utilities in the Forum should determine which sites in their service areas could act as large shelters and contact facility management and local units of government charged with emergency response to discuss plans.

Large shelters could be well served by trucked water, as well as water bladders or bottled water delivery, including by helicopter. If a shelter is able to generate daily estimates of water needs and can communicate with disaster relief agencies supplying emergency water, appropriate deliveries of water could be brought to the shelter and distributed accordingly.

Smaller facilities that are expected to become shelters in a post-earthquake emergency scenario could be outfitted with large on-site reservoirs. These reservoirs could be integrated into a given facility's regular water system, and could store enough water to serve a small shelter population for at least a few days before other emergency supplies arrive (JFE Engineering, 2014). Small shelters would also be well served by bottled water trucked in, water bladders, or by tanker trucks.

Senior Centers

Senior centers could rely on supplies similar to small shelters, since the needs and relative populations will be similar. However, senior centers could also benefit from water already stored on-site. These facilities serve a predictable population at any given time, and thus can accurately calculate how much water should be stored to meet their needs.

Prisons and Other Detention Centers

The prison situation is unique because inmates do not have the freedom to get water for themselves, so water needs to be brought directly to them. On-site wells and/or large on-site reservoirs could be beneficial at prisons.

Another option for efficient delivery installation is to have plumbing within the facility designed such that a tanker truck (or other bulk supply source) can hook into the system from the outside (CHA, 2011). An advantage of this type of system is that water can still go directly to various locations in the building through pipes, reducing the burden on staff to transport the water. However, infrastructure damage is always possible during an earthquake and the plumbing system may not withstand earthquake forces; both the building and plumbing system would have to be designed such that both are likely not to fail. Also, water utilities would have to be in contact with many facilities to maintain records of this special type of plumbing, which could be a cumbersome task.

Domestic Uses (General Public Outside Shelters)

An important emergency supply source for domestic use is previously stored water maintained on-site. Local governments and disaster preparedness organizations recommend households in earthquake-prone areas store at least 3 days' (ideally 1 to 2 weeks) worth of food and water supplies in case of a supply disruption. Most disaster relief efforts will need to primarily focus on large

shelters and infrastructure rehabilitation within the first 3 days of an emergency; it would be inefficient to focus on individual households in the immediate aftermath, and the on-site storage buffer would reduce the burden on disaster recovery operations.

Stored rainwater could be an effective source for non-potable uses such as toilet flushing or bathing. (Toilet flushing will depend on whether wastewater collection systems remain functional.)

It should be expected that not all residents will store on-site emergency water supplies, and that disruptions in some areas could last longer than residents' stored supplies. Distribution points of multiple types would be beneficial to domestic uses, such as tanker trucks, public utility reservoirs, and local wells. One consideration for this solution is the reasonable walking distance to reach a public distribution point (e.g. 1.0 to 1.5 miles). Within that area, many residents or "good Samaritan" neighbors and volunteers could be expected to walk to the reservoir. Large tanks situated in parks could also be part of the solution, as discussed previously for vulnerable populations.

Conclusion

The literature review identified several different types of water supplies and shows how they must be matched appropriately with the water service needs of different types of uses and populations following an earthquake event. Rather than relying on a single solution, water utilities, emergency managers, administrators at hospitals, prisons and other institutions, and even the general public should probably use multiple, overlapping strategies.

Further work is needed to determine cost-effectiveness and practicality of alternate approaches in each community.

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