Homeland Security

EXTENDED WATER OUTAGE INFRASTRUCTURE SYSTEM OVERVIEW

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SCOPE

The Department of Homeland Security's Office of Cyber and Infrastructure Analysis (DHS/OCIA)[1] produces Infrastructure System Overviews to provide a synopsis of how particular infrastructure systems operate. Infrastructure System Overviews are not intended to describe threats, vulnerabilities, or consequences of any aspect of the infrastructure system. This Infrastructure System Overview is intended to provide information about the functioning of critical infrastructure systems during an extended water outage and is one of a series of products produced by OCIA on the Water and Wastewater Systems Sector.

This Infrastructure System Overview was coordinated with the Federal Emergency Management Agency (FEMA), DHS Office of Infrastructure Protection, the District of Columbia Water and Sewer Authority (DC Water), and the National Infrastructure Simulation and Analysis Center. A draft of this version was shared with the Environmental Protection Agency.

INTRODUCTION

The availability of potable water and the ability to move wastewater are essential for most critical infrastructure sectors, the population, and the economy of major metropolitan areas. Critical infrastructure owner-operators may have varying ability to store water for use during water outages or rationing; however, the lack of water may force companies to curtail operations. For example, two-thirds of companies in Silicon Valley, California, estimated that they would have to shut down operations completely if water was curtailed for 30 days or longer.[2]

Potable water availability can be disrupted in a number of different ways, with the ability to affect major metropolitan areas. Water main breaks are a major cause of water disruptions. The American Society of Civil Engineers reports that there are about 240,000 water main breaks per year in the United States.[3] Los Angeles' Department of Water and Power reports three to four water main breaks per day.[4] Regions of the country that experience sub-zero weather can face numerous water main breaks during the winter caused by the weakening of pipes from expansion and contraction of pipe material.[5, 6]

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[1] In February 2014, NPPD created the Office of Cyber and Infrastructure Analysis by integrating analytic resources from across NPPD including the Homeland Infrastructure Threat and Risk Analysis Center (HITRAC) and the National Infrastructure Simulation and Analysis Center (NISAC).
[2] Silicon Valley Manufacturing Group (2002), Water reliability survey, San Jose, California.
[3] American Society of Civil Engineers, "Drinking Water D," at http://www.infrastructurereportcard.org/drinking-water/, accessed November 12, 2014.
[4] San Jose Mercury News, "UCLA chancellor says damages from water pipe break in the tens of millions of dollars," at http://www.mercurynews.com/drought/ci_26250267/ucla-chancellor-says-damages-from-water-pipe-break, accessed February 2, 2015.
[5] UCLA flooding is latest black eye for L.A.'s aging water system, http://www.latimes.com/local/lanow/la-me-ln-ucla-flooding-aging-la-water-system-20140729-story.html, accessed August 5, 2014.
[6] District of Columbia Water and Sewer Authority, Life Cycle of a Water Main Break," http://www.dcwater.com/wastewater/watermain_break.cfm, accessed August 7, 2014.

While it is unusual for a large metropolitan area to experience broad water outages, these types of events have occurred. After Hurricane Katrina in 2005, portions of New Orleans went without water for about 2 months.[7] Drought, flooding, heavy precipitation, contamination, earthquakes, and infrastructure failures are examples of events that can lead to water disruptions.

Drought can cause water supplies to dry up leaving regions without water or can cause water quality concerns in surface water systems.

- In 2007, an exceptional drought in the Southeast resulted in Lake Lanier, the primary water source for Atlanta, being 90 to 121 days away from drying up.[8]
- The 2011 drought in Texas led to a number of towns losing ready access to water or caused the water to have high levels of dissolved solids rendering the water bad tasting or undrinkable.[9,10]

Flooding can result in the inability to treat and deliver drinking water for a prolonged period of time. This can be caused by direct physical damage to water infrastructure, resulting in structural and electrical damage. Floods can also reduce water supply capacity through erosion and sedimentation processes. The ability to recover in a timely manner depends on the availability of repair or replacement parts.

- Heavy flooding in Colorado in 2013 resulted in significant sediment deposition, water main breaks, and damage to water treatment facilities.[11]
- Heavy precipitation events can also result in high turbidity (sedimentation) in surface water systems. Treatment plants may be unable to remove sufficient particulates and microbial content to meet regulations. Therefore, water utility operators may issue advisories both to reduce water consumption and boil water.

Contamination of potable water sources can render the water unusable.

- In February 2014, a methylcyclohexane methanol spill led to a do-not-use water order for 300,000 people in the Charleston, West Virginia, area.[12]
- In December 2014, residents in a section of Washington, D.C., were warned not to drink or use tap water because of contamination from an unknown petroleum product.[13]

Eutrophication (excessive plant and algae growth) and cyanobacteria blooms can be caused by agricultural run-off or sewage treatment plant discharge resulting in do-not-drink orders, particularly during periods of low water levels.[14,15]

- Toxic algae blooms from Lake Erie entered the Toledo, Ohio water system in the summer of 2014 and resulted in a do-not-use water order for more than 400,000 people.[16]

Water distribution systems generally are dependent on electric power for treatment and pumping of water.[17] Disruptions in the electric power system often lead to water distribution service disruptions in the absence of backup power. Backup power is common for critical components such as treatment plants and large pumping stations, but generators require refueling and significant maintenance to operate continuously. Even then, the

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[7] Brozovic, Nicholas, David Sunding, and David Zilberman, "Estimating Business and Residential Water Supply Interruption Losses from Catastrophic Events," Water Resources Research 43:1-14.
[8] Goodman, B., "Drought-Stricken South Facing Tough Choices," The New York Times, October 15, 2007, www.nytimes.com/2007/10/16/us/16drought.html?_r=0.
[9] Texas Monthly, "Drought Raises Concerns about Texas Water Quality," on November 1, 2011 at https://www.texastribune.org/2011/11/01/drought-comes-water-quality-issues/, accessed January 14, 2015.
[10] Reuters, "Life in Drought: Parched Texas Town Seeks Emergency Fix," on October 29, 2011 at http://www.reuters.com/article/2011/10/30/us-weather-drought-texas-idUSTRE79S2RF20111030, accessed January 14, 2015.
[11] The Denver Post, "Colorado Floods: Water-Treatment Plants Struggle to Keep Up," September 14, 2013, http://www.denverpost.com/news/ci_24093109/floods-stressing-water-treatment-issues-could-still-loom, accessed August 11, 2014.
[12] CNN, "West Virginia Asks Feds to Study Possible Health Effects of Chemical Spill," February 20, 2014, http://www.cnn.com/2014/02/19/health/west virginia water/, accessed August 1, 2014.
[13] D.C. Water, "Frequently Asked Questions – DC Water's Do Not Drink Advisory", December 19, 2014 http://www.dcwater.com/news/factsheet/pdfs/DoNotDrink_FAQ.pdf, accessed December 30, 2014.
[14] National Oceanic and Atmospheric Administration/National Ocean Service, "Why do Harmful Algal Blooms Occur?", at http://oceanservice.noaa.gov/facts/why_habs.html, accessed January 7, 2015.
[15] Carnegie Science, "Drought Led to Massive 'Dead Zone' in Lake Erie," on January 6, 2015 at https://carnegiescience.edu/news/drought_led_massive_%E2%80%9Cdead_zone%E2%80%9D_lake_erie, accessed January 7, 2015.
[16] Wall Street Journal, "Algae Blooms Making Toledo Water Undrinkable Are Thriving" August 3, 2014 at http://online.wsj.com/articles/algae-blooms-making-toledo-water-undrinkable-are-thriving-1407107871, accessed October 3, 2014.
[17] In some cases, the distribution of potable water occurs by gravity and does not require electric power.

generators may fail.[18] Refueling during extreme weather events can be challenged by damage to supporting infrastructure, such as Transportation and Energy Sector infrastructure, and the large amount of fuel needed to run generators. These issues can be further exacerbated by limited fuel supplies and reduced workforce to deliver the fuel.[19]

- As an example, during Hurricane Sandy in 2012, some parts of Long Island, New York, lost their water supply due to a loss of electric power. Emergency generators provided power to the majority of the water system on Long Island.[20]

Earthquakes can wreak havoc on water systems by damaging both underground and above ground infrastructure, including pipes, storage tanks, pump stations, and treatment plants. For example, a 7.2-magnitude earthquake in Baja, California, damaged two water treatment plants due to the water oscillating in storage tanks. Parts of the California water system were also damaged.[21]

- During the 1994 Northridge earthquake in southern California, three major transmission systems, which provide over three-quarters of the water to the City of Los Angeles, were disrupted as a result of pipe damage in more than 1,000 locations.[22]

Failing infrastructure due to a combination of age, material, and environmental conditions (including seasonal variation) will result in disruptions to water distribution systems across the United States. East Coast cities have the oldest water systems in the United States, with many built in the late 1800s. The American Society of Civil Engineers has given drinking water infrastructure a failing grade, largely due to the age of infrastructure and lack of funds to replace the infrastructure.[23] The average age of water main pipes in the Washington, D.C., system is more than 77 years old.[24]

TIME-RELATED IMPACTS OF WATER OUTAGES

The following are expected outcomes from complete loss of water and wastewater in a densely populated city. The outcomes are further defined as immediate and long term, in addition to recovery concerns. The impacts of water outages can be assessed in terms of immediate (up to 24 hours) and longer-term effects (up to 1 week). The cause of the outage impacts which effects may be experienced and how to respond. For instance, boiling water during minor events (e.g., elevated turbidity, low pressure, and backwater risks) will make the water drinkable; boiling water in the case of a chemical spill may increase the potency of the polluting chemical making consuming the water even more toxic than before. In all cases, owner-operators of critical infrastructure, the public, and others should follow the direction of the water authorities and appropriate officials.

IMMEDIATE EFFECTS (UP TO 24 HOURS)

- Utility managers are likely to issue water restrictions immediately. These measures often include:
  - No outdoor water use;
  - Water only for drinking and cooking purposes;
  - Reduction in commercial, industrial, and institutional water uses; and
  - Boil water alerts.

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[18] See, OCIA, "Infrastructure System Overview: Extended Electric Outages," June 2, 2014.
[19] 2,000 gallons per hour may be required to operate a pump and 6,000 gallons per hour for a treatment facility.
[20] Suffolk County Water Authority, "SCWA Assures Customers Their Water is Safe and Fine to Drink," October 31, 2012, http://www.scwa.com/scwa_assures_customers_their_water_is_safe_and_fine_to_drink/, accessed August 11, 2014.
[21] California Governor's Office of Emergency Services, "Baja Earthquake Exec Summary," http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=2&cad=rja&uact=8&ved=0CCYQFjAB&url=http%3A%2F%2Fwww.calema.ca.gov%2Fplanningandpreparedness%2Fdocuments%2Fbaja%2520earthquake%2520exec%2520summary.docx&ei=5bzoU83IJa_esATd_YDQDg&usg=AFQjCNHetgY3hH1xoYAdMaP75fkkHQvLTQ&bvm=bv.72676100,d.cWc, accessed August 11, 2014.
[22] Jeon, S., O'Rourke, T. (2005). "Northridge Earthquake Effects on Pipelines and Residential Buildings." *Bulletin of the Seismological Society of America*, 95(1), 294-318.
[23] American Society of Civil Engineers (2013). "2013 Report Card for America's Infrastructure." Available at http://www.infrastructurereportcard.org/drinking-water/.
[24] DC WASA, 2011. "Across the country, cold weather, aging water infrastructure cause more breaks." Available at http://www.dcwater.com/news/listings/press_release529.cfm.

- Water is generally available in distributed storage (e.g., water tanks) for a few minutes to days depending on the storage capacity within pressure zones. Customers at lower elevations have better access to distributed storage due to gravity. Depending on the mechanical configuration within a building, high-rise customers may not have any water available in the absence of electric power, regardless of pressure at the base of the building.
- Short-term water service disruptions can result in pressure drops throughout a water system. Pressure drops will create challenges relative to fire suppression and could result in building evacuations due to inability to provide adequate fire protection. Building evacuation decisions are often made by the local Fire Marshal.[25]
- Without adequate supply of water, hospitals may not be able to treat patients and will likely cancel all non-essential surgeries. Hospitals will identify total water needs, obtain 24 hours' worth of bottled water, if not already on hand, identify alternative hospitals for patients, and implement procedures for curtailing a drop in water pressure for essential equipment that requires water pressure or cooling.[26]
- The inability to treat wastewater or store untreated wastewater will likely result in the spillage of untreated sewage into nearby receiving waters (e.g., bays, rivers, ocean). This will cause contamination and regulating agencies to issue warnings to the population.
- It is not possible to shut off all wastewater collection. As long as the population has water, toilets can flush and sinks can drain, and the sewer system will discharge waste to the collection system. As the amount of drinking water begins to decrease, it is expected that wastewater will begin to decrease.

LONGER-TERM EFFECTS (UP TO 1 WEEK)

- It is uncommon for water systems or customers to have more than 1 week of potable water storage. Water in the distribution system empties and is not replenished, meaning that no water is left in the system for human consumption, fire suppression, sanitation, or other needs.
- Water quality in storage facilities degrade after about 3 to 5 days.[27] By the end of 1 week, water remaining in reservoirs and storage facilities will revert back to untreated water. Once the distribution system is operational, water may need to be retreated. Depending on the cause of the outage, chemicals to treat water may be either degraded or in short supply.[28]
- It is expected that residents would purchase all available bottled water and other beverages.
- Hospitals will have to turn away both emergency and non-emergency patients.
- In the event that the distribution system is not pressurized, there will be little to no ability to provide water for fire protection or sanitation.[29,30] Therefore, it is likely that high-rise residential buildings and other commercial, industrial, and government buildings will be evacuated for safety concerns. Depending on the initiating event, the decision could be made to keep the system pressurized with non-potable source water. In this case, fire protection requirements could be met with do-not-use notices issued to customers.
- Seasonal effects of water loss can be significant. For example, loss of water during hot summer months could result in significant health concerns (e.g., heat stroke). Loss of water during cold winter months

[25] As an example, the Clark County (NV) Fire Department regulations specify, "Situations that are suitable for partial building evacuation include, but are not limited to, loss of fire protection water supply for a portion of a high-rise building. When evacuating only a portion of a building, review must be taken to ensure that the remainder of the building that continues to be occupied is provided with all fire protection intended for full building operation, and that a fire in the unprotected portion will not negatively affect the occupied portion of the building." Clark County Fire Department, "Violations and Stop Work Orders," November 15, 2011 at http://fire.co.clark.nv.us/files/pdfs/111%20stop%20work%20order.pdf, accessed October 3, 2014.
[26] U.S. Centers for Disease Control and Prevention, "Healthcare Water System Repair Following Disruption of Water Supply," http://www.bt.cdc.gov/disasters/pdf/watersystemrepair.pdf, accessed August 8, 2014.
[27] American Water Works Association, "Advancing the Science of Water: AwwaRF and Distribution System Quality," http://www.waterrf.org/resources/StateOfTheScienceReports/DistributionSystemWaterQualityResearch.pdf, accessed August 11, 2014.
[28] Not all water systems use chemicals to treat water.
[29] United States Department of Labor, Occupational Safety & Health Administration. "Standard Number 1926.150: Fire Protection." https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10671, accessed October 6, 2014.
[30] United States Department of Labor, Occupational Safety & Health Administration. "Standard Number 1910.141: Sanitation." https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9790, accessed October 6, 2014.

could result in frozen distribution pipes due to the lack of water movement in pipes (which normally keeps pipes from freezing), and in places that use steam boilers for heating, a loss of ability to generate heat could result. This has the potential to cause major damage to the infrastructure and significant health concerns.

- First responders should anticipate an increased risk in waterborne illnesses, as residents may consume or come into contact with untreated water. For example, diarrheal illness was noted after Hurricanes Allison and Katrina, and norovirus, Salmonella, and toxigenic and nontoxigenic V. Cholerae were confirmed among Katrina evacuees.[31]
- The minimum amount of water required for survival varies based on current weather conditions. The World Health Organization estimates that the basic requirement for survival is 2 to 4 gallons per day per person, which accounts for drinking and food, basic hygiene, and basic cooking needs.[32] In extreme situations, people require approximately 1 gallon per person per day.[33]
- Wastewater will decrease significantly since the supply of drinking water has stopped.
- The inability to properly discharge wastewater will result in significant health hazards, and generally contribute to unpleasant living conditions.

WATER SYSTEM RESTORATION

Water utilities tend to prioritize the restoration process, with high-priority customers receiving attention, when possible. These high-priority customers include hospitals, schools, and emergency services. However, in many cases, utilities only know the identity of the customers being billed and not the identity of the entity occupying the space (e.g., a landlord may be billed even though a critical government agency occupies the space). Utilities generally prioritize repairs in order to restore the largest number of customers in the shortest time. Complete restoration of a system is highly dependent on the nature of the initiating event. For instance, an earthquake that completely destroys a water treatment facility may require 4 months to restore 50 percent of the operations and about 7 months for complete restoration.[34] Wells and pumping stations require less time, while pipes depend on the amount of damage and the number of available crews.[35]

ISSUES TO CONSIDER DURING RECOVERY

- The average daily water use is about 100 gallons per person per day for both indoor and outdoor use.[36] This number varies widely from less than 75 gallons per person per day in many midwestern and eastern States to over 150 gallons per person per day in the mountain States.[37] Water use curtailment may cut daily per person water use by 50 percent, though this may vary by season.
- Boil water notices will continue until utilities can verify that the water is safe to drink. This will be done by testing samples throughout the system.
- As water lines are recharged, there is an increased potential for additional leakages and failures in older pipes, potentially resulting in additional contamination and damage to surrounding infrastructure (e.g., roads).
- Utilities will likely see an abnormal increase in demand as residents and businesses use water for clean-up and recovery. The water requirement for clean-up is dependent on the event causing the outage. For

[31] Watson, J., Gayer, M., Connolly, M. (2007). "Epidemics after Natural Disasters." Emergin Infectious Disease Journal, 13(1), Available at: http://wwwnc.cdc.gov/eid/article/13/1/06-0779_article.
[32] World Health Organization. "How much water is needed in emergencies," Technical notes on Drinking water, sanitation, and hygiene in emergencies.
[33] FEMA, "Managing Water," http://www.ready.gov/managing-water, accessed August 8, 2014.
[34] Hazus – MH 2.1 Technical Manual, www.fema.gov/media-library/assets/documents/24609?id=5120.
[35] Hazus indicates that crews can repair 0.33 to 0.50 failures per day per crew member. Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. It was developed by the Federal Emergency Management Agency. See www.fema.gov/hazus.
[36] U.S. Geological Survey Circular 1344 dated 2009, "Domestic Water Withdrawals and Deliveries, 2005," http://water.usgs.gov/edu/wateruse/pdf/wudomestic-2005.pdf, accessed August 8, 2014.
[37] U.S. Environmental Protection Agency, "Tomorrow & Beyond," http://www.epa.gov/watersense/our_water/tomorrow_beyond.html, accessed August 8, 2014.

example, a flood often results in accumulation of sediment and other material within and near buildings. Common practice is to use water to wash the debris away from structures.

- Wastewater collection systems are expected to come back online with limited difficulty. Depending on capacity and relative uniqueness, lift station pumps could take more time to replace. Pumps and screens are custom made with 4-6-week lead times.[38] The ability to treat incoming wastewater will depend on the initiating event and the ability to maintain bacteria-consuming organisms within a treatment plant. It can take more than 1 week to stabilize a treatment plant with sufficient bacteria.
- Water treatment and distribution systems will face significant challenges in purging air and re-pressurizing the water system. The process may result in equipment and pipe failures, due to pressure surges and aging infrastructure. Staffing for restoration in less urban areas may be challenging, particularly if the service area spans thousands of square miles. Boil water notices will remain in effect for an extended period until residual chlorine levels can meet regulatory standards.

WATER SYSTEM REDUNDANCY

Many water systems, but not all, have redundancy in the water supply and distribution. These include redundant sources (e.g., multiple lakes, groundwater, and interconnections), redundant treatment capacity (e.g., multiple treatment plants), and redundant distribution components (e.g., pumps and pipes).

In the case of system redundancy, some or all of the lost water supply can be replaced. Factors affecting the ability to mitigate water loss include topography and capacity of redundant infrastructure.

- For example, the Atlanta metropolitan area has two treatment plants: Chattahoochee Water Treatment Plant (CHWTP), which treats Chattahoochee River water from Lake Lanier, and the Atlanta-Fulton County Water Treatment Plant (AFCWTP), which treats water from the Chattahoochee River. Treated water from CHWTP accounts for 75 percent of Atlanta's water. Therefore, if the CHWTP plant fails, it is expected that there will be some water loss to customers, but this loss can be mitigated by the AFCWTP. However, if the source of water is disrupted (e.g., Chattahoochee River), it is likely that water outages will be widespread.

For more information, contact OCIA@hq.dhs.gov or visit our Website: www.dhs.gov/office-cyber-infrastructure-analysis.

[38] Conversation with DC Water, October 2, 2014.