TIP No. 019-1223

Public Health Concerns from Flooding, with Emphasis on Potable Water System Recovery

1. General. This paper focuses largely on the threats and hazards posed by flooding events, and the recovery operations necessary to mitigate impacts. Ever-changing weather patterns and the prevalence of weather-related natural disasters have required greater time and resources to be expended for emergency planning and preparedness. Significant natural disasters such as hurricanes and flooding can cause extreme damage to community infrastructure. Thoughts of hurricanes conjure up visions of significant damage caused by strong winds, unrelenting rain, and uncontrolled flooding causing population displacement and the required restructuring of entire communities. Such events pose innumerable threats to public health which must be considered and addressed.

The frequency of major flooding events is increasing worldwide as a consequence of climate change, urbanization, and other factors. Flooding is defined as a temporary situation where land that is normally dry is covered with water. According to the World Health Organization, the primary reasons this type of natural disaster occurs include—

- The gradual rising of inland water sources, such as rivers, lakes and groundwater, due to heavy rainfall or snowmelt;
- Coastal flooding caused by a tropical cyclone, storm surge, or tsunami;
- The accumulation of water on the surface due to prolonged rainfall, resulting in soil saturation and the rise of the groundwater table above the ground surface;
- The breaching of a dam or levee; or
- Sudden flooding with short duration as a result of heavy rainfall in a storm, or a release from a dam. This is known as a flash flood and is particularly destructive on sloping terrain where the water flows very rapidly.

Public Health authorities must be cognizant of the general public health threats/concerns associated with flooding events and prepare to educate installation personnel of the dangers posed and the resultant actions to be taken. One critical public health threat involves the physical status and water quality character of the drinking water supply system during and after an event. This paper also addresses the detailed assessment of potable water systems, the water quality issues of concern, and the impacts of flooding upon Department of Defense (DoD) facilities and operations.

2. Public Health Concerns Regarding Areas of Flooding.

Flooding events can occur for many reasons. Personnel and installations located along the ocean's coastlines can experience a rise in water caused by storm surge associated with hurricanes/typhoons. Many coastal regions feature low-lying ground which is susceptible to flooding with *any* increase in water level. Recent hurricanes have displayed an elevation of surge water at 6–12 feet above normal water levels. Similarly, inland waterways (e.g., rivers, lakes, ponds, etc.) can overflow their banks or levees during periods of prolonged or intensive precipitation (rain, snowmelt, etc.). This overflow commonly results in the flooding of adjacent communities. Further, some regions of the country have experienced periods of intense precipitation which exceeds the area's capability to absorb and/or discharge the water through normal streams, ditches, or storm drains. "Flash flooding" has become more prevalent across large portions of the country. Urbanization and widespread construction play a major role in such events, as areas that historically served as buffer zones where precipitation could flow or absorb into the soils are now covered by asphalt or structures.

The public health hazards concomitant with such flooding events cover a large variety of issues. One of the largest threats associated with flooding is the threat of drowning. Four to six inches of flowing water can sweep people off their feet; a foot of moving water can move a car or sports/utility vehicle off a road. Personnel can readily be trapped in their vehicles or be struck by logs, branches, rocks, debris, and construction materials entrained by the water's flow. Floodwaters often contain sewage and agricultural wastes from the overflow of treatment plants, pumping stations, and animal lots. Exposure to contaminated floodwater can cause wound infections, skin rashes, gastrointestinal illness, and tetanus. Any injury can readily become infected from these materials. Potentially hazardous chemicals can also be present from gas stations, automobile maintenance businesses, chemical warehouses, and other commercial and industrial operations. The best way to protect yourself is to stay out of the water. If you must enter floodwater, wear rubber boots and waders, rubber gloves, and goggles. Wash all skin with soap and clean water as soon as possible. If soap or water is not available, use alcohol-based wipes or sanitizer. Take care of wounds and seek medical attention if necessary. Wash clothes contaminated with flood or sewage water in hot water and detergent before reusing them. Do not allow children to play in floodwater or to play with toys that may have been contaminated by floodwater and have not been disinfected. Do not bathe or swim in rivers, streams, or lakes that may have been contaminated by floodwater.

Flooding events can significantly impact public health, acutely and chronically, in many other ways. Subsequent to such events, rodents are prevalent as they become more active in their search for food. These animals can spread disease throughout large areas. Other dangerous animals may lurk in floodwaters. Alligators, insects, and poisonous snakes have been observed posing a distinct threat to populations, depending on the location of the event. The debris transported by flowing floodwaters poses a serious threat to the public and first responders, as well. Trash and construction debris, possibly containing nails, screws, or sharp edges, can cause scrapes and cuts that could readily become infected in such waters. Further, the presence of charged or damaged electrical wires from poles that have been downed or damaged during flooding can cause electrocution of exposed personnel traversing such waters.

Power outages, both local and widespread, are often associated with flooding events. In flooded households, food-containing refrigerators and freezers, as well as foodstuffs not contained in cans, may become compromised. All such food, including that held in refrigerators and freezers, should be considered contaminated and thus be discarded to avoid the spread of gastrointestinal diseases. Further, a common long-term issue is the formation of mold in flooded zones. Where water levels have risen above floor levels in inundated buildings, fast action is required to avoid exposure to mold. If such flooded areas are not completely dried out within approximately 24–48 hours, debilitating mold spores will grow. Saturated wood and wallboard surfaces must be replaced quickly to avoid negative health outcomes such as exacerbating symptoms in people with asthma or causing more serious issues for individuals who are immunocompromised.

Another threat noted regarding recovery from flooding conditions and associated power outages is the possibility of carbon monoxide poisoning. When electrical or gas service remains interrupted for an extended period, many families rely on portable generators to power heaters, fans, microwave ovens, or portable stoves for comfort and meals. Using gasoline, propane, natural gas, or charcoal-burning devices in enclosed spaces can cause a buildup of noxious carbon monoxide gas, an odorless, colorless, and tasteless gas that overtakes individuals silently and without warning. It can cause headache, weakness, dizziness, chest pain, nausea, and death.

Vector management must also be considered after flooding, which causes hatching of mosquito eggs previously laid in soil. The prevalence of standing water also enhances the proliferation of mosquito populations. The “biting pressure” created by these populations can overwhelm residents and recovery workers during clean-up activities. Mosquitos have also been known to transmit arboviruses such as West Nile virus, Eastern Equine encephalitis virus, and Zika virus during the weeks following such disasters. Following major hurricanes, such as Katrina and Harvey, considerable resources were expended on hiring pest control contractors to spray major areas of standing water to limit the growth of mosquito populations which impeded recovery operations.

The inundation of an area with water can cause chemical release in other ways. In rural areas, runoff from flooded areas can carry eroded soil containing fertilizers, herbicides, and insecticides. Runoff from motorways, roads, and bridges may contain heavy metals, petroleum hydrocarbons, and polycyclic aromatic hydrocarbons. The erosion of soil during flooding can also cause the undermining of trees and structural foundations. Recent flooding events have exhibited the collapse of houses into adjacent flowing water, and the downing of trees that can destroy homes, automobiles, and pose a direct threat to affected personnel.

3. Assessment of Water Supply Systems after a Flooding Event.

Flooding events can significantly impact water supply systems, as well. The structural stability of all aspects of the system must be evaluated throughout such an event to ensure the system’s continued integrity. Each stage of the water system must be monitored to discern any system upsets or adverse impacts upon water quality. The water source(s), treatment processes, distribution system, and storage must be assessed on a recurring basis. Damage incurred to any primary component of the water supply system can cause an upset of the entire system. This includes not only treatment processes but also main lines, pumps, and valves.

Flooding can adversely impact surface water sources in several ways. The floodwaters can entrain wastes from overflowing sewage and animal feedlots; chemical wastes from commercial and industrial facilities; pesticides, herbicides, and fertilizers from agricultural lands; and fuel and oil products emanating from automobiles and pavement/parking areas within the drainage area. Routine water treatment plant processes would likely not successfully remove many of these materials. Further, debris and trees picked up by flowing waters can clog intake structures and filters. Such problems can limit water intake and place significant demands upon the time and attention of system operators.

There have been instances of floodwater overflow into the treatment basins of water treatment facilities, although physical contamination may be limited because the walls surrounding treatment processes are often somewhat elevated. Of greater concern, from an operations perspective, is the need for chemical addition. The changing water quality entering the treatment plants will require constant monitoring and adjustment as surface water quality changes during a storm/flooding event. Ideally, “jar testing” or computer modeling can be performed to determine the proper amount of chemicals to add to ensure proper coagulation, sedimentation, and filtration within the treatment plant. The appropriate volume of chlorine or chloramine to add for system disinfection should be adjusted based on residual readings obtained from the distribution system. A measurable residual must be maintained throughout the entire distribution system. Conversely, the addition of too much disinfectant may lead to the formation of disinfection by-products which may pose long-term harm to consumers. Operational experience will play an important role in chemical use/addition. Operators may already have a good idea of how much and what type of chemicals to add based on the changing quality of influent water from the surface source(s). The amounts used, and under what conditions, should be documented to facilitate operations during future flooding events.

Groundwater obtained from subsurface aquifers is usually not directly impacted by surficial flooding events. The wells must be protected and suitably sealed with appropriate caps/covers at the surface to preclude infiltration or entrainment of surface waters. Properly constructed wells will, therefore, provide a measure of protection against immediate contamination. Caps/covers must provide a watertight seal to prohibit contaminants from washing directly into the wells and impacting these subsurface resources. Properly sealed wells may be overwhelmed by the flooding of well vents, depending on the elevation of the vents relative to the height of the floodwater. Another possible concern for potential contamination created by such conditions would be from direct access to surface water or perhaps from groundwater under the direct influence of surface water. This latter condition, which generally affects water table resources only, should be assessed and handled in a manner similar to that applied to surface water sources. Treatment of groundwater resources is often accomplished locally, at the well points. Since the raw water quality should not be significantly altered during storm events/heavy precipitation, and the use of coagulation/sedimentation/filtration is rare, the chemicals used for water treatment should remain relatively consistent. As stated before, disinfection levels will be based on conditions observed throughout the distribution systems. Any well impacted by flood waters should undergo a process of comprehensive disinfection and flushing prior to the well’s further use as a potable water source.

Operation of water treatment plants must be amended for surface water facilities during such flooding events. The potential for these facilities to become hydraulically overloaded not only affects the debris entering the treatment processes but also increases the rate at which water may flow through the flocculation and sedimentation basins. The carry-over of floc particles into the filtration basins will cause the filter media to clog much more rapidly, requiring frequent backwashing, as well as shortening the usable life of the filter media. Water treatment operators must remain cognizant of these physical and chemical anomalies and adjust their attention and manpower schedules accordingly.

Distribution system piping laid in solid ground generally poses no significant threats during flooding events. However, flooded soils can frequently shift, causing leaks and breakage of aging pipes and joints. Breaks in the piping network allow a possible influx of soil and bacteria into the water supply. Soil and soil bacteria are often very difficult to remove from the system. Flushing velocities utilized to clean the distribution system are the primary means of removing accumulated soil from the piping network. If allowed to accumulate, soil settles in the piping network and provides a substrate for bacterial growth that may ultimately reach consumers. As identified previously, all free-standing water and soils should be considered contaminated. Further, a loss of pressurization and water volume makes the piping network susceptible to backflow/backsiphonage situations and may impact the delivery of water to areas of the installation for consumptive use, hygiene, and fighting fires. Also impacting water system pressurization is the operation of pumps and the effective use of storage tanks within the water supply system. The interruption of electrical infrastructure is common during storms that cause flooding. Pumps must be well-maintained and in good working condition to keep system pressures within their normal operating ranges. Emergency power supplies are often required to ensure proper flow and pressurization. Similarly, water storage tanks—whose manual and electronic controls are frequently found below ground at the base of elevated tanks—must remain operational during flooding events to ensure an adequate water supply during such emergencies.

As carriers of fluids inside buildings, plumbing systems are usually watertight, so infiltration is less likely inside a building even if a loss of pressure occurs. However, some connections, such as water heaters, booster pumps, lift pumps, valve components, and fittings, can be damaged by fast-moving flood water and debris impacts. Such facilities must be inspected and repaired as necessary.

Overall, any potential for a compromise to the water system integrity or a loss of pressurization can impact the status of the entire system. Notices must be publicized immediately to institute a “boil water” order or the use of an alternative water supply (i.e., bottled water) for temporary consumption and hygiene purposes. The installation public health authority should be able to assist the facility engineering/public works department and public affairs office to develop and disseminate such instructions to all affected personnel as quickly as possible. Messages should be updated and repeated routinely (every hour) throughout the duration of the emergency event.

Such actions have proven useful in addressing major hurricanes and their subsequent large-scale flooding. In 2005, for example, Hurricane Katrina made landfall in southern Louisiana and Mississippi as a Category 3 hurricane. In Louisiana, more than 600 public water systems in 15 parishes were affected; in Mississippi, nearly 1000 systems were impacted. Water treatment plants and distribution systems throughout these states incurred significant damage. During the early phases of the storm, local radio and television stations, public and government websites, and written notices provided instructions to residents for treating water (via boiling or adding bleach or iodine) to remove possible pathogens. This information was published in English, Spanish, and Vietnamese, and the status of water supplies was updated daily. The boil water advisories continued until water operators notified state regulators that the systems had regained power and pressure, had been flushed thoroughly to remove potentially unsafe or contaminated water, had been disinfected properly, and had passed the necessary bacteriological sampling (all samples testing negative for total coliform). Subsequent disease monitoring indicated that no drinking water supplies were considered a source of bacteriological infections.

At one location in Louisiana, over one million gallons of crude oil were released from a tank damaged by soil erosion caused by the fast-moving water. Although oil contamination was evident throughout all surrounding floodwaters, no evidence of oil in drinking water was observed. Statewide, the estimates for repairs to the water system infrastructure was approximately $380 million in Louisiana and over $235 million in Mississippi. In 2017, Hurricane Irma, followed closely by Hurricane Maria, made landfall in the U.S. Virgin Islands (USVI) as a Category 5 storm and in Puerto Rico as a Category 4 storm. In both locations, all utilities were interrupted significantly. Both regions relied heavily on small water systems to provide potable resources to consumers. In some instances, water systems were out of service for over 9 months while repairs to water infrastructure were completed. The cost of repairing the damage at these locations was estimated at $132 billion in Puerto Rico and $10.7 billion in the USVI, including the re-development of several hundred small water systems and the replacement of several larger Public Water Systems.

Surviving a major emergency event such as widespread flooding requires significant facility engineering/public works and public health authority expertise and dedication. The levels of monitoring and system observation must be maximized throughout these events, as the potential for system damage and degradation is considerably increased. During such emergencies, it is often necessary to call in additional operators and public health personnel or for these personnel to work extra shifts or overtime, as the water quality and structural integrity of treatment processes, storage tanks, and the distribution piping network must be continually appraised and guarded. At a minimum, the performance of disinfection residuals, pH, and bacteriological analyses must be enhanced far beyond the scheduled, routine monitoring. The tests for disinfection residual and pH can be accomplished quickly and inexpensively using a colorimetric test kit and a simple meter, respectively; these items are normally maintained within the public works and Public Health authorities. These tests allow a quick assessment to note differences in basic water quality to discern the possibility of a disruption in service or if chemical or biological material has entered the supply system. All remedial actions undertaken during such emergencies, the chemicals used for treatment, the data recorded throughout the water system, or any signs of system breakage or compromise must be documented.

Following any disruptive emergency event, an after-action report should be developed. This information will be advantageous both to understanding how resources were expended and to assist in planning for similar events in the future. Further, if any drinking water system compromise was noted or recorded, the system should be thoroughly assessed to discern whether additional cleaning, flushing, or disinfection is necessary. Areas that displayed potential chemical anomaly should be resampled to ensure that the system has returned to its normal operation, and that segments of the system exhibiting zero disinfectant residual or bacterial growth during the emergency have been flushed and disinfected adequately to protect consumers.

4. Flood Events Occurring at DoD Facilities.

Installations representing all Services have incurred significant damage and disruption caused by flooding events in recent years. Many of the same issues related to general public health and the needed assessment of and mitigation for drinking water supply systems, discussed above, have besieged DoD facilities around the world. An additional factor that must be considered for

DoD facilities during such events is the potential impacts to the mission(s) served at the affected installations. These installations are where many of the DoD Service personnel and their families live, and where they and the rest of the facility employees work, train, and maintain equipment. These missions are critical for the protection of our nation and the preservation of our beliefs and way of life.

Changing weather patterns, causing increased precipitation in some regions, along with rising seawater levels, have enhanced the potential for surficial flooding. In 2019, the DoD reported that 25 Air Force bases, 17 Army installations, and 16 Navy bases were subject to, and/or had recently experienced, significant flooding. A three-foot rise in sea level, a conservative estimate of what could be anticipated by the year 2100, would reportedly threaten 128 military bases. For example, Naval Station Norfolk, Virginia (VA); Fort Eustis, VA; U.S. Naval Academy, Maryland (MD); Aberdeen Proving Ground, MD; and 15 other military installations along the East coast of the U.S. would be mostly submerged should water levels continue to rise at the current rate. Similar circumstances would prevail on the West coast (e.g., San Diego, Camp Pendleton, and Port Hueneme, all in California) should these ocean levels rise. Overall, the training and readiness of U.S. Forces would experience significant upheaval if coastal installations were to incur such flooding.

During the 2019 flooding of the Platte and Missouri Rivers, in the mid-section of the U.S., over one-third of Offutt Air Force Base (AFB), Nebraska, was inundated with floodwater when the levees overflowed. The flooding closed most of the runways and affected many buildings. This installation is home to the U.S. Strategic Command, which oversees the Pentagon’s nuclear strategic deterrence and global strike capabilities. Flight operations ceased for months while runways and support facilities were repaired and inspected. Previous flooding events had indicated that such conditions might occur; however, work ordered by the Federal Emergency Management Agency in 2011 to raise the levees had progressed slowly.

Similarly, Tyndall AFB, Florida, experienced flooding associated with Hurricane Michael in 2018, causing damage to such an extent that the long-term recovery of all operations has yet to occur. (Many operations at both bases were forced to relocate to other installations.)

In all cases, public health authorities have worked in conjunction with public works/facilities engineering and emergency management personnel to prevent public health hazards from occurring at these installations. The increased monitoring of source and system water quality, the timely implementation of repairs and mitigation measures, and the dissemination of “do not drink” notifications with instructions for consumers have precluded the outbreak of any widespread disease due to water supplies that have been contaminated during flooding events.

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