BIOSECURITY AND BIOTERRORISM: BIODEFENSE STRATEGY, PRACTICE, AND SCIENCE
Volume 4, Number 2, 2006

The Biological Threat to U.S. Water Supplies: Toward a National Water Security Policy

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In addition to providing potable drinking water, U.S. water systems are critical to the maintenance of many vital public services, such as fire suppression and power generation. Disruption of these systems would produce severe public health and safety risks, as well as considerable economic losses. Thus, water systems have been designated as critical to national security by the U.S. government. Previous outbreaks of waterborne disease have demonstrated the vulnerability of both the water supply and the public's health to biological contamination of drinking water. Such experiences suggest that a biological attack, or even a credible threat of an attack, on water infrastructure could seriously jeopardize the public's health, its confidence, and the economic vitality of a community. Despite these recognized vulnerabilities, protecting water supplies from a deliberate biological attack has not been sufficiently addressed. Action in this area has suffered from a lack of scientific understanding of the true vulnerability of water supplies to intentional contamination with bioweapons, insufficient tools for detecting biological agents, and a lack of funds to implement security improvements. Much of what is needed to address the vulnerability of the national water supply falls outside the influence of individual utilities. This includes developing a national research agenda to appropriately identify and characterize waterborne threats and making funds available to implement security improvements.

In the United States, more than 160,000 public water systems provide drinking water to more than 300 million Americans. In addition to providing potable drinking water, U.S. water systems are critical to the maintenance of many vital public services, such as fire suppression and power generation. Disruption of these systems would produce severe public health and safety risks and could be associated with considerable economic losses. Previous outbreaks of waterborne disease have demonstrated the vulnerability of both the water supply and the public's health to contamination of drinking water. Such experiences suggest that a biological attack, or even a credible threat of an attack, on water infrastructure could seriously jeopardize the public's health, its confidence, and the economic vitality of a community. For these reasons, water systems have been designated as critical to national security by the U.S. government.

Concern over security at water utilities increased dramatically after September 11. Since 2001, there has been an increased investment in water security efforts. In fiscal year 2002, the U.S. Environmental Protection Agency (EPA) awarded approximately $51 million in grants to help the largest community water utilities complete vulnerability assessments. Since 2002, EPA has provided over $150 million in support for development of water security–related tools, training, and technical assistance to the water sector, states, and other supporting partners.[1]

Despite these investments, much work remains to pro-

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tect the U.S. water supply from attack. Most work to date has been at the local level and has been ad hoc; it has focused largely on physical security and has not benefited from a strategic analysis of risks and benefits. Current attempts to safeguard the nation's water supply are, therefore, hindered by a lack of science-based analysis of water threats, inadequate tools for detecting and responding to possible attacks, insufficient federal guidance to ensure that vulnerabilities are being thoroughly identified by individual utilities, and a lack of financial resources within the water sector to appropriately implement security programs.

Although there are several ways that U.S. water supplies could be disrupted, this article focuses on the specific threat of a biological attack on U.S. water supplies and outlines challenges to developing a national strategy to secure U.S. drinking water against this potential threat. Specifically, this article proposes priority actions that the federal government should take to achieve security in this area.

FEDERAL AGENCY RESPONSIBILITY FOR WATER SECURITY

In 1996, the nation's water supply was designated as one of eight national infrastructures vital to the security of the United States, through the issuance of Executive Order (EO) 13010. EO 13010 established the President's Commission on Critical Infrastructure Protection, which concluded in 1997 that there was inadequate protection against chemical or biological contamination of water supplies and insufficient technology for the detection, identification, and measurement of contaminants. In response to the Commission's findings, President Clinton issued Presidential Decision Directive 63 (PDD 63) in May 1998, which designated the U.S. Environmental Protection Agency as the lead federal agency responsible for protecting the U.S. water supply from intentional physical, chemical, and biological attacks. In response to PDD 63, EPA forged a partnership with the American Metropolitan Water Association (AMWA) to establish a secure system for sharing sensitive security information with water utilities. Security activities under PDD 63 focused primarily on the 353 community water systems that each serve more than 100,000 people.[2]

After September 11, 2001, EPA's role in water security was expanded under Title IV of the Public Health Security and Bioterrorism Preparedness and Response Act (PL 107-188). A central mandate of PL 107-188 is the requirement that all water utilities serving more than 3,300 people complete and submit to EPA vulnerability assessments (VAs) that address potential opportunities for biological, chemical, and physical attacks. To protect the information from widespread dissemination, access to the more than 8,000 vulnerability assessments that are to be submitted to EPA is limited to a few individuals designated by the administrator of EPA. Water utilities that serve fewer than 3,300 people have been encouraged, but are not required, to complete vulnerability assessments.[2]

Since 2002, President Bush has issued a series of Homeland Security Presidential Directives to supersede previous PDDs. Central to the management of national water security efforts is Homeland Security Presidential Directive 7 (HSPD7), which reinforces EPA's role as the sector-specific lead for water infrastructure. Under HSPD7, EPA is tasked with identifying, prioritizing, and coordinating water infrastructure protection activities, and it is directed to work with the Department of Homeland Security (DHS), which has the responsibility for coordinating the overall national effort to protect critical infrastructure.[3]

To that end, DHS released the Interim National Infrastructure Protection Plan (NIPP) in February 2005 as a draft framework for coordinating critical infrastructure protection across all critical infrastructure sectors. The plan states that, as the designated Sector Specific Agency for the Water Sector, EPA will "work with the private sector and State, local, and tribal entities to further refine stakeholder roles and responsibilities and implement the NIPP (Base Plan) and the Sector-Specific Plans (SSPs) that will become annexes to the NIPP."[4] A revised plan was issued in November 2005.[5] The plan is currently still in draft form.

Homeland Security Presidential Directive 9 (HSPD9) directs EPA to develop a surveillance and monitoring program to provide early warning detection of a terrorist attack using biological, chemical, or radiological contaminants. HSPD9 also requires EPA to develop a nationwide laboratory network to support the routine monitoring and response requirements of the surveillance and monitoring program.[6] In fulfillment of HSPD9, EPA announced in 2005 plans for its WaterSentinel, a pilot program to develop and evaluate systems for timely detection of drinking water contamination threats.[7] The potential success of the program is unclear, given that it was appropriated in its first year (FY06) at less than 25% of the President's $44 million budget request.[8]

In 2004, the National Drinking Water Advisory Council (NDWAC), an independent group that advises the administrator of EPA, formed a working group dedicated to water security issues. The Water Security Working Group (WSWG) was charged with identifying: (1) voluntary practices that would constitute an active and effective security program at water utilities, (2) incentives for utilities to implement those practices, and (3) measures of progress for security program implementation. The 16 members of the WSWG included representatives of water and wastewater utilities, public health practitioners, environmental regulators, and advocacy groups. The WSWG did not address specific vulnerabilities at utilities or recommend specific actions that utilities should take.[1]

PUBLIC RECORD OF PAST THREATS TO WATER SUPPLIES

The threat of intentional contamination of water supplies is not new. In 1941, Director of the Federal Bureau of Investigation J. Edgar Hoover acknowledged the vulnerability of the U.S. water supply to attack:

> It has long been recognized that among the public utilities, water supply facilities offer a particularly vulnerable point of attack to the foreign agent, due to the strategic position they occupy in keeping the wheels of industry turning and in preserving the health and morale of the American Populace.[2]

Recent threats to the U.S. water supply have been documented. In January 2001, the FBI warned U.S. water utilities of a threat from a "very credible, well funded, North Africa-based terrorist group" to "disrupt water operations in 28 U.S. cities."[9] In July 2002, following the acquisition of Al Qaeda documents that included detailed maps of several U.S. public water systems, the FBI warned of possible terrorist attacks against American targets and specifically advised the nation's water utilities to prepare for attacks on pumping stations and pipes that deliver water to consumers.[10] In 2003, when the national alert status was elevated to "high risk," the Centers for Disease Control and Prevention (CDC) and EPA issued a health advisory via the CDC's Health Alert Network (HAN) that recommended increased vigilance by the public health community and water utilities regarding the possibility of a terrorist attack on water supplies.[11] Later, in 2004, the FBI and DHS issued a four-page bulletin to law enforcement agencies and water utilities that detailed a plot by unnamed terrorists to inject poison into the water supply during chlorination. The bulletin suggested that terrorists were interested in recruiting water utility insiders to carry out the plot.[12]

There have been additional threats to the water supply that have not received widespread media attention. A 2003 report commissioned by the American Water Works Association Research Foundation queried water utilities, government agencies, and established terrorism incident databases and found more than 100 cases of actual, threatened, and disrupted plots to contaminate water supplies. Of those cases, 20 incidents involved actual contamination events, more than half of which occurred in modern water supplies with pressurized pipe distribution.[13]

OVERVIEW OF U.S. WATER SUPPLY

A major challenge to safeguarding the water supply is that water systems are highly variable. In the U.S., there are more than 54,000 community water systems* that provide water to approximately 300 million people; 7% of these systems provide water to 81% of the population. The sources of water for these systems are varied: approximately 53% of all drinking water in the U.S. comes from groundwater sources (wells), while the rest comes from surface water sources (reservoirs, lakes, and rivers).[14]

Drinking water quality depends on the initial quality of the rivers, lakes, reservoirs, and wells that serve as source waters and the effectiveness of treatment methods employed. Generally speaking, groundwater sources are more isolated from possible microbial contamination than surface water sources; however, there is less potential in groundwater for inactivation of microbes by natural environmental processes such as sunlight.[15]

Given the variable nature of water supplies, U.S. water utilities use a variety of treatment processes to remove contaminants from drinking water. The most commonly employed methods include: filtration (physical removal of particles), flocculation (coagulation of smaller particles into larger particles) and sedimentation (settling out from water of coagulated particles using gravity), and disinfection (ultraviolet or chemical inactivation of microbial contaminants).[16] The specific treatment scheme used by a water utility may vary, depending on utility size, cost, and quality of the source water. Most bacteria can be effectively inactivated by disinfection; however, conventional treatment methods (disinfection and filtration) may not inactivate some toxins and pathogens.[15]

In a typical community water supply system, treated water is transported under pressure through a distribution network of buried pipes, where it may be diverted into storage containers or delivered directly to consumers. For the most part, major investments in the infrastructure that supplies, treats, and distributes water in the U.S. have not been made for decades, and, as a result, many components of the systems are aging and in need of replacement.[17]

In light of the heterogeneity of water systems in the U.S., the national approach to safeguarding water supplies has placed the responsibility for assessing vulnerabilities and making security improvements on individual utilities. In conducting vulnerability assessments, it is up

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*The U.S. EPA defines community water systems as those systems that are connected to 15 year-round residences or serve 25 persons in a residential setting on a year-round basis. In this way, community water systems are a subset of public water systems, which include any water supply systems that deliver water for human consumption through a pipe or pipes.[14]

to each utility to determine its most likely threat scenario—for example, whether it is more likely to experience a terrorist attack or tampering by vandals—and to identify components of its system that are most vulnerable. The decentralized nature of this process has made it difficult to measure on a national level what progress has been made in securing the U.S. water supply.

VULNERABILITY OF WATER SYSTEMS TO INFECTIOUS DISEASES AND BIOTOXINS

Drinking water could be intentionally contaminated at the original water source (e.g., a lake or reservoir), during treatment, in pipes that distribute water to points of use, or in storage containers. Water systems could be intentionally compromised through biological (or chemical or radiological) contamination or through physical damage to the treatment or supply infrastructure. In addition to biological attacks, water supplies could be disrupted through cyber attacks on computerized operations that control delivery and treatment, or through interruption of interdependent activities, such as transportation of chemical disinfectants or electricity for pumping. Although utilities will have to consider all of these threats, this article focuses on the possibility of a biological attack on water supplies.

There is evidence to suggest that drinking water could be a vehicle for intentional contamination with a biological agent (microbe and biotoxin). Many Category A and B biological agents are believed or known to be transmissible by water. According to one list developed by the U.S. Army, of 18 organisms and 9 biotoxins that may be used as biological weapons, 44% and 89%, respectively, have been identified as water threats.[18] Another 28% of biological organisms and 11% of biotoxins are considered probable water threats. Several waterborne pathogens and toxins are known to be stable in water for long periods and are resistant to commonly employed disinfection methods.

Moreover, the ability of waterborne pathogens to cause massive outbreaks has been demonstrated. In 1993, a huge outbreak of cryptosporidiosis occurred in Milwaukee, Wisconsin. *Cryptosporidium* organisms passed undetected through two water treatment plants and are estimated to have caused more than 403,000 illnesses and 4,400 hospitalizations among the 800,000 customers served by the water system.[19] Although this incident was not the result of bioterrorism, it demonstrated to public health professionals the vulnerabilities of populations to microbial contamination of treated water supplies. *Cryptosporidium* was first identified in 1907, but it was not recognized as a source of waterborne disease until 1987 when it was associated with a 15,000-person outbreak in a filtered system in Georgia.[20] This suggests that there is much work to be done in improving our understanding of drinking water as a source of community illness.

PROTECTION AFFORDED BY WATER TREATMENT

Water treatment (filtration and disinfection) can reduce the risk posed by pathogens if microbial contaminants are introduced into the source waters of a water supply. The use of chlorine to disinfect drinking water is commonly cited as one of the major public health successes in reducing community illness of the 20th century. Despite the use of filtration and disinfection in U.S. water systems, outbreaks of disease associated with drinking water in those systems continue to occur. The effectiveness of water treatment in removing or inactivating pathogens depends largely on the type of treatment method employed and the resistance of a particular pathogen.

While the threat posed by conventional microbial contaminants may be reduced by common methods of treatment, there is limited information regarding what levels of reduction are possible for many potential bioweapons agents. It has been shown that some waterborne pathogens, such as *Cryptosporidium* and *Bacillus anthracis,* are resistant to disinfection by chlorination. The tolerance of a number of other potential water threats—such as *Brucella* species, plague, and smallpox—to disinfection by chlorination is unknown or unpublished.[18] Increasing the amount of disinfectant used in a water supply may improve the efficiency of pathogen inactivation; however, water utilities generally maintain chlorine residuals at the lowest levels that will keep the system in compliance with conventional microbial requirements, in an effort to minimize the formation of potentially harmful disinfection by-products.[15] Physical removal of pathogens through filtration is widely used in U.S. water system treatment, but it is generally not an efficient means of removing smaller pathogens, such as viral particles.[21]

Many experts agree that the best approach to ensuring water quality is through application of multiple barriers to contamination in supply, treatment, and distribution, but some community water systems have not adopted this approach. In particular, some surface water systems, including those that serve some of the largest U.S. cities, do not use filtration to remove pathogens that may resist the disinfection process.[17]

THE ROLE OF DILUTION

It is a widely held view that it would be difficult to effectively poison the water supply because contaminants would be diluted by large volumes of water in most systems. It is certainly true that dilution of a contaminant reduces the amount of a biological agent to which an individual would be exposed, but the actual reduction in risk posed by the diluted contaminant is difficult to calculate. The threat of illness resulting from intentional contamination of the water supply depends in part on the infective dose of the introduced pathogen. For some waterborne pathogens, it can take as few as 1 to 10 organisms to make an individual ill. The infective dose for other waterborne pathogens, however, is not known.[21] If water supplies are contaminated, it will not be possible to dilute the level of biological agents below a concentration of one.

Intentionally contaminating most surface water source waters with sufficient quantities of pathogens or toxins to sicken hundreds, thousands, or more people could be logistically difficult. Nationally, most reservoirs contain from 3–30 million gallons of water. Larger cities may be served by reservoirs that contain several hundred billion gallons of water. For example, water resides in the 412-billion gallon Quabbin reservoir that serves metropolitan Boston for years before it reaches the distribution system.[22] Given the immense size of the nation's larger reservoirs and long residence times of water in reservoirs, it is not likely that reservoirs can be intentionally contaminated with most pathogens in sufficient quantities to cause widespread illness.

A more concerning source of vulnerability is the potential introduction of a microbial agent into the distribution system of a water supply, because such systems are highly accessible, are downstream from water treatment processes, and are closer to the point of consumption than reservoirs. A biological attack on the distribution system would use utility pipes for the opposite of their intended purpose: Instead of carrying water out of a tap, the pipes would spread pathogens or biotoxins to nearby homes or businesses. With an understanding of hydraulics, an attacker could use utility pipes to inject and deliver pathogens to consumers.

The introduction of contaminants to the water supply via access points in the distribution system was demonstrated in a widely reported incident in Charlotte, North Carolina, where a fire truck accidentally pumped more than 60 gallons of firefighting foam into the distribution system through a fire hydrant.[23] In addition to fire hydrants, taps in residences and businesses may be potential points of access to the distribution system.

In a recent Government Accountability Office (GAO) report, which sought water security experts' views on key security-related vulnerabilities of drinking water systems, an attack on the distribution system was named as a key concern. Seventy-five percent of these experts cited the ease with which distribution systems can be accessed as a main concern regarding the vulnerability of the distribution system. In particular, they mentioned the difficulty of preventing the introduction of a contaminant into the distribution system from inside a public building.[24]

CONSEQUENCES OF AN ATTACK

There is ample evidence to suggest that contamination of U.S. water supplies could produce significant public health and economic consequences. Experience with nondeliberate contamination events has demonstrated that, even when the number of deaths associated with an outbreak is low, the healthcare costs to the community may be considerable. A study that examined the financial impact of the 1993 Milwaukee outbreak estimated illness-related costs (medical costs and productivity losses) of more than $96 million.[25] Only 1% of cases were hospitalized, but their medical costs accounted for 89% of total outbreak-related medical costs. Moreover, costs to government agencies that were involved in the outbreak investigation (CDC, EPA, Wisconsin Division of Public Health, City of Milwaukee Health Department, Milwaukee Water Works, and 17 local health departments) were estimated at more than $2 million immediately following the outbreak.

An important consideration regarding the strategic importance of the U.S. water supply is that the national water infrastructure affects every single U.S. citizen. Without an effective government response and proper management, an attack on a U.S. water supply could have an economic impact and cause a loss of public confidence not only in the affected system, but also in water supply systems throughout the country. Maintaining consumer confidence is an ongoing challenge for the water industry, even without having experienced an attack. The 1999 nationwide survey by the National Environmental Education & Training Foundation found that 65% of Americans either take additional steps to treat their drinking water or drink bottled water in their homes. Moreover, some 24% of Americans reported that they do not drink tap water at all.[26] The study authors concluded that, despite the fact that U.S. water companies and utilities maintain some of the highest quality public drinking water in the world, many consumers are wary of tap water. Given the challenges already facing the industry, an attack on one portion of the water supply could further erode public confidence in the safety of drinking water as a whole.

Contamination events can result in political repercussions at all levels of government. In 2000, an outbreak of E. coli 0157 and Campylobacter occurred in Walkerton, Ontario, when improperly treated water was pumped to taps throughout town and sickened more than 2,000 people. Although the individual water operators were convicted of criminal charges (for falsifying water treatment reports), a public inquiry also placed blame on the provincial government. In particular, the report criticized Ontario's privatization of water quality testing as failing to provide adequate oversight to ensure water safety: "If the Ministry of Environment had adequately fulfilled its regulatory and oversight role, the tragedy in Walkerton would have been prevented . . . or . . . reduced in scope."[27] Following the inquiry, an outraged public held its political leaders accountable: In the next provincial election, the opposition party won majority control in Ontario, partially campaigning on safe drinking water.[28]

Water supplies do not actually have to be contaminated for disruption to occur. Given the lack of diagnostic tools to rapidly and reliably rule out a threat of contamination, hoaxes or threatened incidents of contamination can pose considerable management and response challenges for water utilities and political leaders. One example was in the Village of Orwell, Ohio, which received a generic threat against its water supply just before the 2004 Thanksgiving weekend.[29] In the interest of safety, the local leaders made the decision to advise citizens not to use their tap water for consumption while the incident was being investigated; it was ultimately determined to be a hoax. The do-not-use order lasted through the holiday weekend. To ensure that the Village's thousand or so residents received the notice, Village employees directly contacted every home in the affected area via phone or by paper notice if they were not able to reach a household by phone (Village of Orwell, Ohio, Water/Sewer Department; personal communication). This single incident demonstrates the considerable amount of resources that hoaxes can demand even in small communities.

CURRENT LIMITATIONS TO ACHIEVING SECURITY

Difficulty Detecting and Recognizing Contamination Events

A fundamental challenge to protecting water supplies from deliberate or threatened contamination is our inability to rapidly assess whether an attack has occurred. Strategies that are currently used for routine monitoring of water supplies are not adequate for detecting threats real-time or for determining the presence of exotic contaminants. Water supplies are monitored routinely for only a small number of contaminants, and results may take from hours to days.

For more than a century, public health professionals have relied on an indicator organism approach to assessing microbial contamination of water supplies. That is, drinking waters are routinely monitored for enteric bacterial organisms that might suggest the presence of microbial contamination from human waste. This conventional analysis is slow and will not detect the presence of bioweapons agents that are not likely to be associated with sewage.

Additionally, the sampling strategies commonly associated with conventional water quality monitoring may not detect the presence of bioweapons before the contaminated water reaches the population. This is because monitoring of water quality in the distribution system may be conducted less frequently than sampling of reservoirs, other source waters, and treated water as it leaves the water treatment plant.

The emphasis on source water monitoring may have implications for the ability to prevent outbreaks, as there is evidence to suggest that distribution systems may be an increasingly important source of outbreaks of waterborne disease. The National Research Council (NRC) reports that the percentage of outbreaks attributable to distribution systems is on the rise. From 1999 to 2002, 50% of outbreaks reported in community water systems were related to problems in the water distribution system (as compared with 30% of outbreaks from 1971–1998).[30] The reasons for this upward trend are not clear, but the NRC report suggests a possible reason may be the fact that regulations for distribution systems have not been as extensive as they have been for surface waters. Both the reliance on indicator organisms for monitoring water quality and the focus on monitoring water at the source suggest that traditional water sampling schemes may not detect a biological attack on water supply, especially one targeting the distribution system.

Enhanced techniques for real-time or near–real-time detection of contaminants (including bioweapons agents) in water supplies are currently being investigated, but considerable work is needed before they will be available for widespread use.[31] The availability of specialized water testing (i.e., reference laboratories) is limited in most parts of the country, which further limits our ability to respond to a biological attack.[32] The importance of improving detection capabilities and developing real-time monitoring capabilities was highlighted in a GAO survey of drinking water experts.[24] Approximately 93% of the experts in the GAO report rated the expansion of research and development of near–real-time monitoring technologies as a high-priority activity for federal support. Moreover, nearly 70% of the experts rated this activity as warranting the highest priority for federal funding, which far surpassed the rating of any other activity.

Until more sophisticated monitoring capabilities are developed, it is highly probable that there will be a limited ability to detect an attack before a population is exposed, and the first signs that that attack has occurred may be the recognition of increased morbidity (sickness) within a community. However, experience with naturally occurring waterborne outbreaks suggests that it may be difficult to recognize through epidemiologic investigation that a water supply has been contaminated.

Identifying drinking water as a source of an outbreak is difficult, given the epidemiologic characteristics of waterborne illness. First, many of the signs and symptoms of waterborne disease are nonspecific and often mimic more common medical conditions and disorders. While waterborne pathogens may cause significant illness, including chronic and life-threatening disease in immunocompromised populations, the health effects may be more limited in healthy patients. Even if a pathogen causes significant and recognizable morbidity in a population, it may be difficult to assess the extent of illness (i.e., case numbers) within the community. Infected individuals may not be detected by the public health system, as was observed in the Milwaukee outbreak in which it was determined that 88% of infected patients did not seek medical attention for their symptoms. Consequently, health authorities in Milwaukee did not recognize the waterborne outbreak until nearly a month after contamination began.[19]

Second, when a waterborne disease outbreak is recognized, the causative agent may never be identified. According to a report by the National Academies of Science, the etiology of 50–60% of identified waterborne disease outbreaks is never determined.[31]

Finally, it may be difficult to identify drinking water as the source of the outbreak. Even if infected individuals do seek clinical care and are reported as cases to public health authorities, these patients may not be aware of previous waterborne exposure and may not be able to provide an accurate exposure history. This decreases the likelihood that drinking water will be identified as the source of infection within the community. Furthermore, water samples taken after illness has shown up in a community may not reveal contamination, as the pathogen that caused infection is likely to have left the water system by the time illness is detected.

Therefore, it is critically important for clinicians to be familiar with the signs and symptoms of waterborne exposure to biological agents; detecting a biological attack on the water supply will be difficult if clinicians limit exposure histories to inhalational and cutaneous routes of exposure. But most practicing physicians have received limited training to help them diagnose and evaluate waterborne disease either from intentional or natural contamination of water supplies.[11]

Some communities have implemented syndromic surveillance systems in hopes that they will provide early recognition of disease outbreaks or a biological attack. The concept of using syndromic surveillance for detecting waterborne outbreaks is based on experience from the 1993 Milwaukee outbreak of cryptosporidiosis (which, at that time, was not a reportable disease). The outbreak was detected through reports to the city health department of widespread absenteeism and substantial increases in sales of over-the-counter antidiarrheal medications.[33] There is no evidence that syndromic surveillance systems offer a comparative advantage over the likelihood that an astute clinician would notify the health department of an unusual public health event. The utility of syndromic surveillance systems in detecting any biological attack, including one on the water supply, simply has not been demonstrated. However, an evaluation of syndromic surveillance in recognizing a hypothetical aerosol attack suggests that these systems may not significantly improve the ability to recognize or respond to a biological attack.[34]

Some utilities also monitor calls to customer complaint centers to provide early warning of an unusual change in drinking water quality. However, given that biological agents are odorless and tasteless, it is unlikely that a biological attack will be recognized by customer complaints prior to an increase in morbidity within the community.

Lack of Data to Inform Response Planning

Most research on microbial bioweapons has focused on aerosols, rather than waterborne exposure.[35] As a result, there is a paucity of data surrounding the vulnerability of the water supply to contamination with a bioweapon. How biological organisms, including most bioweapons, will perform in distribution systems is largely unknown as are infectious dose and tolerance to disinfectants. It is also not understood if known bioweapons will display similar clinical pictures when ingested as they do when acquired via airborne or dermal exposure. Such information is critical for recognizing a waterborne outbreak and for assessing its likely morbidity and mortality.

These data are critically important for utility operators and public health officials to accurately assess the degree to which public health may be threatened by an attack on the water supply. Consequently, experts have highlighted the need for additional research in the water sector. In reviewing the state of science surrounding water security, a National Academies panel found that while "conventional wisdom holds that water's dilution effects would necessitate large quantities of contaminants to pose health problems" it is a "conjecture . . . poorly supported by research."[32] As a result of the paucity of scientific data, the National Academies have called for more careful analysis to determine precisely what agents, and in what quantities, pose a serious threat if present in a potable water supply.

There are also limited data available on how best to respond to a biological attack on the water supply. Since public safety concerns (such as firefighting capabilities) may prevent shutting off contaminated supplies, a routine response is to issue a boil-water advisory. This usually means that consumers are told to bring water to a boil for 1 minute before using it for drinking, brushing teeth, or washing dishes.[36] While this method may be effective for inactivating pathogens commonly associated with contamination by human or animal waste, some research suggests that it may not be effective for some bioweapons agents. A study by the EPA found that holding water at a rolling boil for 1–3 minutes in an open container would not be sufficient to inactivate *Bacillus anthracis* spores.[37] Therefore, issuing standard boil-water advice may not be adequately protective.

There is also some evidence to suggest that boiling water contaminated with certain pathogens may increase the risk of exposure.[38] In 1999, researchers examined the safety of boil-water advisories if water was contaminated with an anthrax-like bacterium. The investigation found that boiling water contaminated with the spore-forming bacterium *Bacillus subtilis* (a surrogate of anthrax) can result in dispersal of the bacteria to local air environments. Thousands of viable spores were found in aerosols generated during the vapor phase of boiling, which led the authors to conclude that boiling contaminated water may constitute a considerable risk of exposure via aerosol inhalation and deposition on surfaces.

It is also not clear under what conditions utilities could urge customers not to use contaminated water even for showering, as the risk of possible inhalational exposure is not understood. Although respiratory infections associated with inhalational water exposure are well documented for the bacterium *Legionella pneumophila*, it is unclear if other waterborne pathogens could be transmitted through inhalational exposure.

A very limited set of data suggests there is at least some risk of acquiring a respiratory infection from *Cryptosporidium* species, though it is unknown to what extent drinking water plays a role in such cases.[39–43] Although infections of this kind are rarely reported, it is unclear how infection would occur within a community if more people in the community were exposed to high doses of infectious agents. Without compelling scientific evidence to support the safety of the water, public perception may necessitate the provision of alternate water supplies following an attack. Experiences with natural disasters have demonstrated that it takes considerable planning and resources to be able to provide external sources of water to communities for more than a few days.

RECOMMENDATIONS FOR FUTURE ACTIONS

Develop a Comprehensive Research Agenda to Improve Knowledge of Water Threats

There is currently not enough of an evidence base to assess the true vulnerability of water supplies to biological attack. A national water security policy should include a research agenda to address critical knowledge gaps. The EPA's National Homeland Security Research in this area must be publicly available so that water utilities and the public health and healthcare communities that are responsible for preventing or responding to biological attacks on the water supply have the appropriate information to develop preparedness and response plans and to communicate with the public should an event occur. Until the state of knowledge regarding water biothreats is improved, utilities and public health authorities may have very little evidence to guide their preparations to thwart an attack on the water systems or their response to actual attacks on these systems. This research would also help federal authorities assess national progress in preparing for biological attacks on water supplies.

Although there has been some federal activity in creating a national research agenda, recent analyses of these activities have revealed gaps. The EPA's Water Security Research and Technical Support Action Plan identified critical research needs and created a plan for addressing those needs. However, a National Research Council (NRC) panel evaluation of EPA's Plan identified critical gaps in the scope of the research plan and suggested alternative priorities for EPA to pursue. Furthermore, the NRC panel criticized the plan's failure to address the financial resources required to complete the research and to implement needed countermeasures to improve water security.[2,44] The EPA's Office of Inspector General (OIG) also has been critical of the agency's research activity, citing failure to use information from completed vulnerability assessments to identify water security research needs. The OIG report included the following quote from a member of the National Research Council panel that reviewed EPA's research plan:

> The vulnerability assessments provide information that could provide guidance. It will provide EPA an opportunity to address vulnerabilities instead of guessing what they are. It will provide assurance that all that needs to be

> considered have been considered or we risk leaving our self at risk. Access to the vulnerability assessments would strengthen whatever plan is developed.[45]

Information contained in vulnerability assessments should be used to identify and prioritize research needs.

Improve Federal Guidance to Ensure Vulnerabilities Are Adequately Addressed by Individual Utilities

Although the water supply has been designated as a critical asset to the security of the nation, the responsibility for securing the sector rests with individual utilities, and there is limited opportunity for oversight by the federal government. This decentralized approach has made it difficult to assess whether increased activity has resulted in greater security across the nation, in part because there are no mechanisms for measuring progress across the water sector.

The EPA has limited authority to: (1) ensure that individual utilities have accurately characterized and prioritized their vulnerabilities commensurate with the threat, (2) identify specific areas where security improvements are needed, and (3) prioritize future program needs. This is because while EPA is the repository of more than 8,000 utility VAs, it is precluded by the Bioterrorism Act from disclosing any information derived from the VAs. Only individuals specifically designated by the EPA Administrator may have access to the assessments and related information. These individuals are precluded from using information gleaned from VAs to allocate funds to specific utilities for implementing security improvements and for issuing guidance documents for the water sector.

The EPA's OIG has expressed concern over the lack of federal oversight over the completion of vulnerability assessments. In a 2003 report, the OIG reported that it was "important that EPA promptly analyze vulnerability assessments submitted by large utilities . . . to determine whether the assessments adequately and comprehensively address terrorist threats."[46] Of particular worry to the OIG was evidence from interviews with utilities and water security experts that suggests that "vulnerability assessments submitted may emphasize traditional, less consequential and less costly threats, such as vandalism and disgruntled employees . . . and may not necessarily address terrorist scenarios of the events of 9/11 that motivated passage of the Bioterrorism Act."[46] The OIG also expressed concern that neither the EPA nor the methodologies used by utilities to complete the vulnerability assessments provided threat guidance that identified the most vulnerable components unique to water systems. Specifically, the OIG report maintained that distribution system threats have not been adequately emphasized.

Critical decisions regarding how to prioritize and address the bioterrorist threat to water supplies should not be left solely up to water utilities. While water utilities may have the best understanding of the specific vulnerabilities and physical limitations of their systems, they do not have the analytical and institutional resources required to assess the relative likelihood and potential impacts of national security threats, particularly those without well-defined solutions. This is especially true with respect to the potential for a biological attack on the water supply, as it is a threat that is not well understood and something with which utilities have very little expertise.

Even in situations where clear guidance exists, some utilities find it difficult to address fairly straightforward public health threats, such as lead contamination of drinking water. A 2004 investigation by *The Washington Post*, which examined 65 large water systems across the country that had reported lead levels near or exceeding federal standards, found that dozens of utilities obscured the extent of lead contamination in their systems, ignored requirements to correct problems, and failed to report data to regulators.[47] According to *The Washington Post*, some of the nation's largest and arguably better-funded water systems did not report lead-level tests that showed high readings to regulators or their consumers. Furthermore, in their sampling, utilities may have avoided retesting homes that had previously demonstrated high lead levels.[47] These utilities have maintained that these inconsistencies represent differences in interpretation of water regulations and were not attempts to deceive the government. At the least, this investigation illustrates that active and directive federal guidance in interpreting water security threats and implementing programs to appropriately address these threats is warranted.

Vulnerability assessments, which also are used to inform emergency response plans and to help identify (and, hopefully, implement) corrective actions to system vulnerabilities, are a fundamental basis of our current national approach to ensuring security of the water supply. Since the strength of water security programs rests on the quality of each utility's VA, it is in the best interest of the nation to be sure that utilities have completed these assessments appropriately. Moreover, it will not be feasible to prioritize future program activities without a national assessment of how thoroughly individual utilities are addressing the threat and where additional improvements are needed. The U.S. government should develop a mechanism whereby the EPA can confidentially evaluate (i.e., protect from Freedom of Information Act requests) all vulnerability assessments and can report extracted information in aggregate to identify areas where additional commitment of federal financial resources and technical assistance can improve progress.

Increase Federal Funding for Security Improvements

To secure the nation's water supply, the federal government must create a grant program specific to water sector security improvements. The financial state of the water sector is such that utilities will be unable to maintain comprehensive security programs for the long term. As reported in a 2004 GAO report, drinking water and wastewater utilities will need to invest hundreds of billions over the next 20 years just to maintain their infrastructure for routine operations. The projected needs range from $485 billion to nearly $1.2 trillion.[48] EPA estimates 20-year needs for drinking water transmission and distribution to be $83.2 billion, plus an additional $18.4 billion for storage facility infrastructure needs.[39]

In 2002, a survey of several thousand water utilities reported that 29% of drinking water and 41% of wastewater utilities were not generating enough revenue from user rates and other local sources to cover their full cost of service. As a result, roughly one-third of the utilities deferred maintenance because of insufficient funding, had 20% or more of their pipelines nearing the end of their useful life, and lacked basic plans for managing their capital assets.[49]

Although some federal funds have been made available for security activities at utilities, current funding levels are insignificant with respect to the sector-wide needs. In fiscal year 2002, EPA awarded approximately $51 million in grants to help the community water systems serving more than 100,000 customers complete vulnerability assessments. Since 2002, EPA has provided over $150 million in support for development of water security–related tools and for training and technical assistance. These funds, however, have not focused on making security improvements within systems.

Following September 11, the American Water Works Association (AWWA), a trade organization representing the water industry, estimated that it will cost $1.6 billion for initial security upgrades at all drinking water utilities.[50] The extent of true costs of protecting the water supply from biological attack is not well defined, in part due to lack of understanding of the nature of the biological threat. However, as stated above, the water sector faces critical financial shortfalls just to maintain normal operations, without the added responsibility of making security improvements.

It has been suggested that EPA's Drinking Water State Revolving Fund (DWSRF) program can be used to help states assist utilities in making security improvements. This program provides funding to states to allow them to help water systems to make infrastructure improvements to meet public health standards and reliably deliver safe drinking water. However, there are limitations to the use of these funds.

First, since the purpose of these funds is to help drinking water systems meet public health standards and reliably deliver safe drinking water, security improvement projects will have to demonstrate a direct relationship to these aims to be eligible for funding.

Second, the amount of monies available through these funds is limited and does not match the sector needs for meeting current public health standards, much less for addressing additional security-related needs. According to a 2003 report by the Association of State Drinking Water Administrators (ASDWA), a professional association serving state drinking water programs, the gap between the financial and personnel resources that state programs have to ensure protection of drinking water is growing. ASDWA's 50-state survey found that funds available in 2002 covered only 78% of program needs, and it projected that, by 2006, available funding will meet only 62% of program needs.[51] This assessment did not consider the additional resource demand associated with water security programs.

Finally, there are additional requirements for using these funds that may make them difficult to use for maintaining security programs or making security-related system improvements, not the least of which involves public disclosure requirements for funded projects.

In addition to implementing security improvements, federal funds also are critically important for the development of molecular technologies for detecting and monitoring bioweapons agents in water supplies. An NRC report, which examined the barriers to the development and standardization of advanced monitoring technologies, found that the principal impediments to progress in this are the lengthy requirements for technical development, the cost of more sophisticated monitoring, and institutional resistance to change. The NRC panel concluded that government investment will be required to overcome these hurdles. In particular, government funding will be necessary to provide the impetus required for technical development and to ensure that the consumer cost of these technologies is low enough to facilitate the implementation.[31] In funding research and development programs, the federal government must consider the needs and operational limitations of water utilities, to ensure that developed technologies will actually improve the sector's capacity to respond to real or threatened contamination events. Many of the water utilities' concerns about implementing monitoring technologies are documented in AWWA's 2005 report, *Contamination Warning Systems: An Approach to Providing Actionable Information to Decision-Makers*.[52]

CONCLUSION

Although federal activity has designated the water supply as a critical infrastructure vital to the security of the United States, there has not yet been a strategic analysis on the national level of what it would actually take to achieve security in this area. Water security activities to date have largely centered on implementing physical security measures (such as security guards and fences).

Protecting water supplies from a deliberate biological attack on the distribution system has not been sufficiently addressed, partially due to a lack of scientific understanding of the true vulnerability of water supplies to intentional contamination with bioweapons. Although the current strategy to secure national water supplies places the bulk of the responsibility on individual utilities, much of what is needed to address the vulnerability of the national water supply falls out of the influence of individual utilities. This includes developing a national research agenda to appropriately identify and characterize waterborne threats and to improve methods for real-time detection of waterborne pathogens, developing biologically sound plans for responding to real and threatened contamination events, and making funds available to implement security improvements.

Given the limited funding available within the water sector, it is likely that significant progress toward securing national water supplies will not be made without greater federal involvement. The water sector needs both additional funding to maintain security programs and technical assistance to ensure that security improvement projects are appropriately identified and prioritized. Progress in this area will require substantial commitment of the federal government with substantive input from the utilities.

ACKNOWLEDGMENTS

The author would like to thank Thomas V. Inglesby, Michael Mair, Beth Maldin, Ari Schuler, Molly D'Esopo, and Jaclyn Fox for their assistance in reviewing the article.

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