

## Early Warning Systems for Hazardous Biological Agents in Potable Water

Jeffery A. Foran<sup>1</sup> and Thomas M. Brosnan<sup>2</sup>

<sup>1</sup>WATER Institute, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, USA; <sup>2</sup>Damage Assessment Center, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA

### Background

There is a growing concern with the potential for terrorist use of biological weapons (bioweapons) to cause civilian harm (1–5). This concern has been focused around two assumptions: that a terrorist is most likely to effectively disperse bioweapons through air (3), and that we must be prepared to address terrorist use of bioweapons through treatment of affected individuals, with emphasis on strengthening the response of the health-care community (3,5,6). For the most part, concern has not focused on the use of bioweapons in drinking water systems (4,7), and much less attention has been paid to preattack detection than to postattack treatment.

Threats to drinking water supplies have plagued humans since the dawn of history. These threats range from the spectacular and highly disruptive (e.g., floods, spills of oil or toxic chemicals) to the more mundane, but not necessarily less important, such as impacts from storm pipe discharges or runoff from agricultural lands. A recent conference, "Early Warning Monitoring to Detect Hazardous Events in Water Supplies," held 17–19 May 1999 in Reston, Virginia (8), concluded that terrorist use of bioweapons poses a significant threat to drinking water. Several pathogens (e.g., anthrax, *Clostridium perfringens*, plague) and biotoxins (e.g., botulinum, aflatoxin, ricin) have been weaponized, are potentially resistant to disinfection by chlorination, and are stable for relatively long periods in water (7). Further, although water provides some dilution potential, any size neutrally buoyant particle, as well as sophisticated technologies such as microcapsules, can be used to disperse human pathogens in drinking water systems. Effectiveness of an attack can be enhanced through introduction of the bioweapon near the tap, such as in the distribution system (postdisinfection). Water storage and distribution systems also facilitate delivery of an effective dose of toxicant to a potentially very large population, as well as a lower-level chronic dose (for chemicals) with longer-term effects and lower-detection thresholds.

Although the probability of a terrorist threat to drinking water is extremely low, the consequences could be very severe for exposed populations; thus, this conference concluded that national attention must be focused on detecting threats from biological terrorism, as well as other catastrophic events in drinking water supplies, and on preventing

human exposure wherever possible. To that end, the conference concluded that technology-based and other pre-event or pre-exposure management strategies can be effective deterrents to widespread human exposure to bioweapons, as well as other low-probability/high-impact contaminant events in drinking water supplies, such as the introduction of *Cryptosporidium* (9). Of particular note are new and developing technologies to rapidly detect pathogens in real time, both in source water and water distribution systems. Included among these technologies are DNA microchip arrays (10), immunologic techniques (11), microrobots (12), and a variety of optical technologies, flow cytometry, molecular probes, and other techniques (13,14). None of these technologies is presently available commercially nor have any of the technologies been tested in large drinking water systems. However, this conference concluded that these technologies may be among the most effective approaches for early detection and warning of the use of bioweapons, as well as other catastrophic contamination events in drinking water systems, and encouraged their rapid development.

Given that early detection technologies will likely be available in a few years, and that pre-exposure management, where it is successful, will prevent adverse health effects, it is prudent to address the myriad issues that are associated with the use of early detection and warning systems, as well as other pre-exposure management techniques. In this paper, we present characteristics of early warning systems (EWSs) and other pre-exposure management approaches that may increase the chances of preventing human exposure, if biological weapons are used in drinking water systems. We also address the interpretation of, response to, and communication of information derived from EWSs. This report reflects the deliberations of a breakout group from this conference that addressed system characteristics and interpretation, response, and communication issues.

### Early Warning Systems: Desirable Properties and Cost-Benefit Considerations

The goal of an early warning monitoring system is to reliably identify low-probability/high-impact contamination events (chemical and radiation as well as microbial) in source water or distribution systems in time to allow an effective local response to prevent

exposure. Although surveillance of infectious disease or other public health effects is an important component of impact assessment in contamination events, surveillance does not provide early warning, as it detects disease or other impacts after they have occurred, often with a long lag time. Rather, an EWS must detect a contamination event in a time frame that allows the implementation of an effective response to reduce or avoid entirely the adverse impacts that may result from the event.

The development and implementation of EWSs are likely to be costly and labor intensive; thus, several factors must converge to support their use. Generally, local support for EWSs will occur when the cost and frequency of false positives is less than the benefits of averting true positives. When, on the other hand, the cost of monitoring exceeds any benefit from the use of an EWS, it is unlikely that there will be support for the system.

The extent of the difference between benefits and costs that is required to support an EWS will be determined at the local level and will likely differ among localities. Local support will generally increase as the risk or perception of risk of serious illness increases. Risk or the perception of risk will also increase as the presence or effectiveness of existing barriers (e.g., chlorination for pathogens) decreases, as the seriousness (perceived or real) of the potential illness increases, and as the size of the affected population increases (among others).

Regardless of the cost-benefit ratio, the EWS must be reliable; that is, it must be sensitive, specific, reproducible, and verifiable [as well as supported by appropriate quality assurance/quality control (QA/QC) procedures]. It should minimize the potential for both high numbers of false negative and false

Address correspondence to J.A. Foran, WATER Institute, University of Wisconsin-Milwaukee, 600 E. Greenfield Ave., Milwaukee, WI 53204 USA. Telephone: (414) 382-1700. Fax: (414) 382-1705. E-mail: jforan@uwm.edu

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positive results. Additionally, receptivity for EWS and their attendant costs will increase as the ancillary benefits of the system increase. Systems that can detect and warn of many contaminants, or that provide broad coverage of many parameters, will be more desirable than systems that provide narrow coverage or detect relatively few parameters. However, it is likely that EWSs that provide broad coverage will be more expensive to operate and maintain than EWSs that provide narrow coverage; therefore, the cost-benefit ratio for each system and decisions regarding desirability must be assessed at the local level. Finally, systems that are easy to install and operate, that provide continuous monitoring, that use standardized analytical equipment, and that enhance source identification are likely to increase desirability. Continuous monitoring reduces the likelihood that contamination events will be missed (although it also increases the costs of equipment maintenance, data interpretation, etc.), whereas standardized equipment can be more easily shared among users and repaired and replaced than custom equipment.

### Interpreting the Output of EWS

The most effective use of an EWS will occur where there is a structured, well-defined approach to the interpretation of data generated by the EWS and to the types of responses that are triggered by data from the EWS. Interpretation of data from an EWS may be particularly problematic. Determining when a response is necessary, based on the performance of an EWS, requires a clearly established baseline for contaminants or events of interest, and a clearly established deviation from the baseline. Both the baseline and deviation from it that triggers a response must be determined in advance of any contamination event, rather than in response to a particular event. Ideally, both the baseline and deviation from it will be established at the time of EWS installation.

Baseline development will be contaminant or event specific and will likely be influenced by the toxicity of a compound or pathogen, the nature and extent of population or subpopulation exposure to the compound as well as to similarly acting compounds or pathogens, by the ability to detect the compound or pathogen (test sensitivity and specificity), and at least to some extent by the perceived risks associated with exposure to the compound or pathogen. In some cases, a maximum contaminant level (MCL) established by the U.S. Environmental Protection Agency may be used as the baseline. However, MCLs do not exist for most microbiological contaminants. In this case, a baseline level must be developed. This can be

done at the community level and should include a variety of stakeholders including but not limited to scientists, public health experts, emergency management officials, local politicians, and representatives from the community at large.

Establishment of a trigger (deviation from a baseline that results in a particular response such as a "boil water" advisory) will be influenced by the nature and magnitude of the adverse event (e.g., by the extent of public health impact that could occur as a result of the contamination event), by the nature of the action to be taken as a result of trigger exceedance, and at least to some extent by the perceived risk of exposure to the compound or pathogen. A stringent trigger (little difference between the baseline and deviation from the baseline that triggers an action or response) may be appropriate for events that have severe public health consequences. A less stringent trigger may be appropriate for actions that have significant costs (monetary or others) such as shutting down an entire water supply system to a large metropolitan area. However, a stringent trigger may be appropriate even where an action has significant costs, when a contamination event has a very severe public health impact, or where the perception of risk is very high. Finally, trigger development must be influenced by the sensitivity and specificity of the test; that is, triggers must be developed to minimize both false positives and false negatives associated with the analytical methodology.

A confirmation step, which does not necessarily preclude action, should also be included in the interpretation process for EWSs. Where a trigger is exceeded, steps should be taken to confirm the exceedance. Confirmation may include resampling or intensified sampling and analysis, duplicate analyses, and other QA/QC procedures. Depending on the nature of the contamination event and on the potential public health impacts, an action may or may not be taken until a confirmation process has been implemented and appropriate results provided. Clearly, where there are severe public health consequences, action should not await confirmation. However, subsequent actions, or delays in implementing them, may be influenced by the outcome of confirmatory steps. Where there is a high number of false positives (determined as a result of the confirmation step), subsequent actions based on trigger exceedance may be delayed. Additionally, a high number of false positives should trigger an assessment of the analytical equipment and methods, to determine the causes of the high false-positive rate and to identify improvements in the equipment and methods to reduce false positives.

### Response and Communication

Many responses are possible when an alarm is triggered by an early warning monitoring system. Responses may include modification to the drinking water system (shutdown, addition of disinfectants, etc.), notice (boil water advisory) either to the general public or to target communities or subpopulations, additional data gathering or monitoring, follow-on surveillance and epidemiologic studies, no action, and some combination of these, among others. The type of response will be dependent on the nature of the threat and the nature of the drinking water system, including the population served by it. For example, a response to a threat received by phone may differ from a response detected by an EWS. For a phone threat, a determination of credibility may be necessary prior to performing a response. Where an EWS is in place, credibility of the threat may be judged by the performance of the EWS itself, when it is capable of detecting the contaminants included in the threat. Where an EWS is not in place, additional steps may be necessary to judge credibility and to determine the appropriate response. Steps may include monitoring for the contaminant at appropriate locations in the source water or distribution system, and monitoring for surrogate parameters that may indicate contamination (e.g., increased chlorine demand, changes in pH). Additionally, law enforcement representatives and psychologists may provide insight into the credibility of the threat.

Regardless of their nature, a critical component to the success of any EWS is the preparation of a process or plan that provides guidelines for the type and extent of response to all potential threats. The plan must be developed in advance of the threat and preferably concurrent with the development of the EWS. In effect, the plan should be considered part of a comprehensive emergency planning process for a variety of threats to public health, both waterborne and non-waterborne.

The emergency response plan must be developed with the participation of all major stakeholders. Some stakeholders include

- Individuals with specific expertise (e.g., microbiologists, toxicologists)
- Politicians/community leaders
- Health department, hospital representatives, other health care professionals
- Representatives of the local water utility
- Representatives of water regulatory agencies (local, state, and federal)
- Representatives of high-risk groups
- Staff from the wastewater treatment plant
- Major water users and processors
- Law enforcement agencies
- Psychologists

- Other emergency preparedness groups (e.g., fire department)
- Representatives of sources that pose potential threats to the drinking water system

There is extensive experience with the development of emergency response plans that can be drawn upon by communities interested in implementing an early warning monitoring system. The U.S. Centers for Disease Control and Prevention, U.S. Federal Emergency Management Agency, the National Infrastructure Protection Center of the Federal Bureau of Investigation, and the Emergency Management and Emergency Preparedness Office of the U.S. Health and Human Services offer guidelines for emergency response plan development. Approaches to postevent response have also been developed (3,5,6).

The nature and extent of communication of the threat to the affected population should also be guided by the emergency response plan. A chain of communication should be established as part of the plan, from the point where information of the threat is received to the final implementation and communication of the response to the threat. Experts from the local utility and representatives from the health care community, hospitals, law enforcement agencies, and other emergency preparedness groups should be included in the chain of communication.

A particularly delicate matter is the communication of the existence of the EWS prior to any threat that it detects. It is conceivable that awareness of the EWS and its goal may stimulate a few individuals to perform acts that threaten the drinking water system or its users. Therefore, the existence of the EWS must be put into the context of preparations for a variety of events including floods, tornadoes, earthquakes, etc. It should not be advertised simply as a technology designed to address terrorism or other intentional or unintentional threats. The EWS must be framed in a positive manner by emphasizing the importance of real-time monitoring for a variety of chemicals and pathogens, designed to better understand all potential threats to the system and consumers. Additional steps to raise positive awareness of the EWS include general community education about where drinking water comes from, how it is handled at the treatment plant, and how it is dispersed in the community (without providing enough information to highlight a system's vulnerability). Tests of preparedness for and response to water emergencies (akin to testing the tornado sirens) should also be conducted and publicized in the community. Again, these tests should be cast in a positive light, with emphasis on

general preparedness rather than on preparations for specific events.

## Conclusions

An EWS must reliably identify low-probability/high-impact contamination events in source water or distribution systems in time to allow an effective local response. The type and nature of the response, and the method of communication of the response will be dependent upon the type and nature of the threat, on the characteristics of the EWS itself, and on the nature of the affected population. Critical to the successful development, implementation, and use of an EWS is strong community support for the system. This support must be derived from aggressive education activities regarding community drinking water supplies, and from active participation of community members and stakeholders in the development and implementation of the EWS. Especially critical is the development of an emergency preparedness plan that guides the type of responses associated with a signal from the EWS and the communication of actions based on the responses.

The resources necessary for the development, installation, operation, and maintenance of an EWS will be substantial; therefore, virtually all of the decisions regarding the EWS must be made at the local or community level. This includes the type of EWS to install (and its attendant costs), interpretation of information from the EWS, responses that should occur as a result of a signal from the EWS, and the nature of communications to the affected public. The emergency preparedness plan will play a crucial role in many of these decisions, and there should be significant local involvement in the development of the plan. However, funding assistance for EWS development, installation, and operation may be available from both the state and the federal government. Extensive guidance is also available from a variety of federal agencies on the development of emergency response plans.

An EWS should not preclude actions to ensure or strengthen the security of drinking water systems in every community. Points of vulnerability in both source water and distribution systems should be identified in each community, and steps taken to reduce the vulnerability at these points. Steps may be as simple as securing hydrants or other entry points to the distribution system, or installing improved security around treatment and storage facilities. These and many other simple steps may significantly reduce system vulnerability as EWSs are developed and as their costs decrease, so that they may be available to all communities, regardless of size and resources.

## Appendix. Conference breakout group members.

Jeffery Foran (Chair)  
University of Wisconsin - Milwaukee  
Milwaukee, Wisconsin

Kathleen Blair  
Milwaukee County Health Department  
Milwaukee, Wisconsin

Stephen Clark  
U.S. Environmental Protection Agency  
Washington, D.C.

Chuck Haas  
Drexel University  
Philadelphia, Pennsylvania

Rachael Herpel  
Groundwater Foundation  
Lincoln, Nebraska

Robbin Hough  
Oakland University  
Rochester, Minnesota

Tom Jacobus  
U.S. Army Corps of Engineers  
Washington, D.C.

Dennis Juranek  
Centers for Disease Control and Prevention  
Atlanta, Georgia

James Lambert  
University of Virginia  
Charlottesville, Virginia

Alan Vicory, Jr.  
Ohio River Valley Water Sanitation Commission  
Cincinnati, Ohio

Stephen Wust  
New Mexico Environment Department  
Sante Fe, New Mexico

There are also sociological issues that must be addressed as technological and non-technological approaches are implemented. This conference concluded that a threat (whether real or a hoax) to a drinking water system may pose as much problem as a terrorist act, and response plans should consider how to address potentially unrealized threats. Further, individuals involved in efforts to protect drinking water must be cognizant of the ramifications of the effort itself; even discussion of potential terrorism in drinking water systems, such as through this paper, must be done carefully so as not to provide a stimulus for the act.

To ensure the full protection of drinking water, or other media, a technology-based early warning monitoring system should be just one component of a comprehensive program to protect the public from biological terrorism and other low-probability/high-impact contamination events, whether they occur in air, water, or food. The program must also include physical, social, and economic steps to prevent the problem, as well as follow-up monitoring to ensure that early detection of disease will occur if a monitoring system or other steps fail.

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