Setting the Alarm for an Early Warning

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This article was published in the American Water Works Association publication

Opflow Vol.29, No.6 June 2003

The unprecedented attacks of September11, 2001 brought into focus the possibility that drinking water systems would be prime targets for further terrorist activity aimed at the United States. Destructive or contaminant-based sabotage of raw water sources, transmission pipelines, treatment plants, or distribution networks could have disastrous consequences for millions of people. It quickly became evident after 9/11 that existing security procedures had to be enhanced and new monitoring systems developed and implemented.

Water utilities always have been vulnerable to various conditions that can degrade the quality and quantity of their finished product. Thankfully, serious deficiencies in treatment and water quality have been relatively few over the years as the industry has steadily improved operational, maintenance, and monitoring practices. However, during the past five years, distribution systems have been responsible for 45% of the outbreaks of waterborne disease (AWWA Journal, Sept 2001). Now the threat of chemical and biological attack by terrorist factions has raised the bar to an even higher level and pressed the water industry to investigate the possibility of using on-line, real time monitoring along with rapid screening of the water for toxic substances. These systems may prove to be a valuable tool to the industry, to water quality and to the safety of the American public.

Recognizing the need for increased security, Congress approved, and President Bush signed into law on June 12, 2002, the Bioterrorism Preparedness and Response Act. Title IV of this Act calls for drinking water treatment systems to conduct vulnerability assessments and submit emergency response plans to the federal government on a specific schedule. Utilities serving more than 100,000 people had to submit proof of their assessments by March 31, 2003, and the emergency plans six months later. Smaller systems have later deadlines. Federal funds are available to assist in this effort, and a number of water utilities have received grants up to $115,000.

Mohawk Valley Water takes steps to develop early-warning system

Shortly after the 9/11 events, and before any legislative requirements were approved, the staff of the Mohawk Valley Water Authority in Upstate (Utica) New York began to look into ways to improve protection of the utility's physical assets and finished water product. Basic measures, such as better plant site security, increased patrols along distribution system routes, positive-identity entry procedures, and camera surveillance, were put in place.

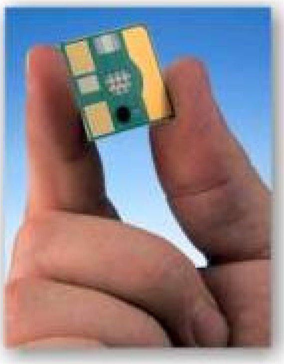
The next level would be to find technologies that would enable us to implement a utility-wide early-warning water quality monitoring system coupled with rapid screening methods to detect or confirm a contamination event. Such a system would have to be accurate and reliable, possess on-line, real-time monitoring capabilities, and have a means to detect the presence of bacteriological or chemical contaminants rapidly.

With a customer base of over 125,000 people, the MVWA's distribution network contains more than 600 miles of mains serving areas of dense population as well as thinly populated rural regions. The 20-mgd system also includes two open finished-water storage reservoirs, all of which led the water utility to be classified in a high-risk security category.

Remote on-line sensing probe measures six parameters

In December of 2001, MVWA staff decided to pilot test a multi-parameter sensing instrument that has the capabilities and performance we sought for an online monitoring system component. The device can measure chlorine or monochloramine, dissolved oxygen (DO), conductivity, pH, oxidation/reduction potential (ORP), and temperature.

The "brain" of the device is an array of five electrochemical sensors mounted on a one-inch square chip layered with gold on to a ceramic base. These sensors function using well-known electrochemical principles. One of them eliminates the need for the reagents commonly required to determine chlorine concentration, while another does away with the use of membranes for measurement of dissolved oxygen. Also included on the chip is an ink membrane over a noble metal that measures pH, and a sensor embedded in the device to measure temperature and conductivity. A standard reference electrode also is included in the probe head.



Dascore Six-CENSE Chip

"Chip" inserted into a water main

During development and testing the chip's ceramic substrate was found to be robust and resistant to corrosion, biofouling and abrasion. All materials in the chip are inert, have been extensively tested, and were approved by the NSF in mid-February of this year for contact with potable water. Conceived to provide data from within a pressurized water distribution system, the device is a probe that can be inserted using a standard 2-in. corporation stop into mains ranging in diameter from 2 to 72 in.

About 30 such probes have been operated in Yorkshire Water's network in the UK over the last several years. Yorkshire Water produces more than 475 mgd of potable water, runs 116 treatment plants, and serves a population of more than 4.6 million. While most probes were monitoring chlorine concentration, 11 were multi-parameter units. The data collected from them demonstrated the validity and user-friendly characteristics of the technology, the probe's robust design, and the ease with which it can be calibrated and maintained.

Test unit installed downstream of treatment plant

To evaluate the probe in the MVWA system, a point in a pressurized main representing approximately 30 min of downstream flow from the Hinckley Reservoir Treatment Plant was chosen for its installation. The instrument was connected to the existing SCADA system, and we reasoned that the half-hour elapsed time would allow the unit to demonstrate its capabilities if we arranged a specific change in the treatment process.

Initially several problems were encountered. Scaling developed on the chip sooner than expected. We surmised this was caused by the low conductivity of the source raw water and low water flow conditions across the chip. The problem was corrected by simply inserting the probe deeper into the water stream in the main with modifications provided by the manufacturer. The instrument then began to produce reliable readings. Some early signal transmission and communication discrepancies between the test probe and the SCADA system were resolved by installing new software also provided by the manufacturer.

Figure 1 tracks a test conducted on Aug. 15, 2002, and indicates values generated by the probe in response to chemical feed changes at the treatment plant. The addition of lime and soda ash, which are used for pipeline corrosion control protection, was discontinued at the treatment plant. An immediate drop in pH and conductivity was detected (t_0) by the treatment plant instrumentation and thirty-nine minutes later, the probe detected the change in process conditions and indicated the anticipated drop in both pH and conductivity. Three conventional instruments were used to also measure the parameters being monitored by the test unit.

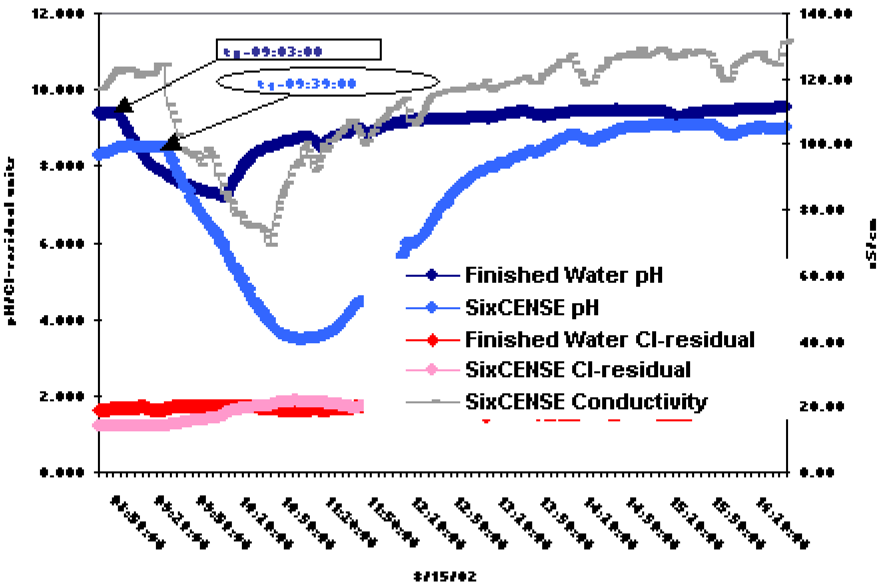


Figure 1

A chlorine analyzer, pH meter, and water quality probe were also used to evaluate the unit and all produced readings very close in value to those of the new device. Mohawk Valley Water Authority's experience with the probe indicates that it has pilot tested well, and we have ordered two more units. The utility is moving forward to complete an early-warning monitoring system by installing the probes in the distribution system at areas of concern determined by the System's vulnerability assessment. The instrument's small size, ease of insertion in pipelines, lack of any need for chemical reagents, compatibility with our SCADA electronics, and demonstrated performance have made it a key component of our utility's security plan.

Rapid screening methods and a sampling station network

Along with the installation of the water quality monitoring probes several rapid screening processes have been evaluated by the MVWA and incorporated into the water quality-monitoring program. These include a toxicity testing system, a rapid method for quantification of total viable bacteria, flow cytometric methods for rapid detection of pathogenic microorganisms and biological (fish) monitors.

Gaining access to reliable sample taps for monitoring purposes is often a challenge in a large distribution system. During 2002, ten water-sampling stations were installed in remote areas at the far reaches of the distribution system. Capital plans include the installation of ten stations each year until a complete sampling network is established.

Toxicity testing and bioluminescence-based assays

A bioassay system utilizing a highly sensitive variant of the luminescent

acterium *Photobacterium leiognathi* allows for the detection of a diverse group of toxicants, at levels elow milligrams per liter, in water (Ulitzur *et al,* 2002).

The use of luminous bacteria for toxicity assessment has advantages that have been scientifically alidated by Bulich and Isenberg, 1981 and Kaiser, 1998. The bacteria are self-maintained uminescent units that emit high and steady levels of luminescence that can be detected at 490 nm by luminometer. Biological toxicants and chemical agents (pesticides, herbicides, heavy metals and hlorinated hydrocarbons) that effect cellular respiration, protein or lipid synthesis, or the integrity of he cell membrane alter the level of luminescence produced by the bacteria. The toxicity test kit ontains the bacteria in a freeze-dried state and once hydrated the bacteria become luminescent. An liquot of the bacterial culture is added to tubes containing the water in question. By comparing the evels of luminescence produced by bacteria added to a water sample suspected of being toxic with hat of a clean control water sample plus the bacterial culture, low concentrations of a broad range of oxicants can be detected.

Toxicity testing has been phased into the daily routine monitoring performed by the MVWA Water Quality Laboratory. The Authority has open finished water storage reservoirs within the distribution system and toxicity testing is performed daily on the effluent from these reservoirs as well as representative points throughout the distribution system.

ATP Analysis

Toxicity Testing

Rapid Quantification of Viable Bacteria Using an ATP Assay

The heterotrophic plate count (HPC) is used to estimate the number of heterotrophic bacteria that form colonies on agar plates. The present Standard Method currently used takes 48 hours to seven days to obtain a result.

The determination of adenosine triphosphate (ATP) using a bioluminescence assay is based on a eaction between the enzyme luciferase, the substrate luciferin and ATP (Trudil, D. et al. 2000, Lee nd Deininger 2001). Light is emitted during this reaction and can be measured quantitatively by a uminometer to estimate the amount of bacteria present in a water sample in as little as five minutes.

The ATP assay of viable bacteria has also been phased into the routine monitoring program of the MVWA distribution system. The procedure has been compared to the Standard Method Heterotrophic late (HPC) count method (48-hour incubation at 35^{o}C) and the Heterotropic plate count on R2A gar (7-day incubation period at room temperature) and the ATP assay showed better correlation with acterial counts obtained from the 7-day plate count method.

iological Monitors

Organisms such as fish, clams, mussels, daphnia, algae and bacteria have been used as biomonitors. rior to September 11th there were very few biomonitors in the United States. However, since that ime water systems have been investigating their usefulness. While biological monitoring systems that ely on a single species have limitations, they may prove useful when used in conjunction with other nonitoring methods.

A simple fish monitor that utilizes the "avoidance principal" (Grayman, Deininger, Males, 2001) was onstructed in the laboratory at MVWA's treatment plant. The monitor is based on the fact that fish vill swim away from water that is contaminated with toxic agents. Five tanks connected in series are tocked with native fish. When fish sense a toxic substance they tend to move downstream. If the fish n tanks 3, 4, or 5 exceed the number of fish in tanks 1 and 2, treatment plant operators will be alerted o a possible contamination event.

Immunomagnetic Separation Methods and Flow Cytometry

Flow cytometry has traditionally been used in hospital laboratories for the identification of bacteria n clinical samples of body fluids. The food and beverage industry have pioneered the development of his technology to detect pathogens that may enter their processes and find their way into the finished roduct. Flow cytometric methods are rapid, and quantative and can be versatile since many methods an be combined such as nucleic acid probes and immunofluorescence. They are also rapid and may e used to monitor viability. (Grayman, Deininger, Males, 2001). The flow cytometer, mmunomagnetic separation techniques and fluorescent antibody tagging have been evaluated in the vater industry for the identification of organisms such as *Escherichia coli* O157:H7 (Smith and Rice 000) and *Cryptosporidium parvum* (Laskey and Chen 2001, Schreppel, Tangorra, Harkins, Harrigan nd Fredericksen 2002).

Conclusions

Water system distribution networks are a major area of vulnerability. Water systems need the ability to predict the movement of contaminates and to monitor these levels at points throughout the distribution system. This is an extremely complex process that will require distribution water quality modeling and real-time monitoring. The combination of these two processes will begin to provide an effective tool for enhancing the security of the water system. While it isn't reasonable or feasible to use real-time monitoring for every agent that could be introduced deliberately into a water system it is practical to monitor using indicator parameters where a change can signal the possibility of hazards in the water. Monitors must be able to be remotely operated, maintainable, not overly sensitive, quality assured, and last but not least affordable. Mechanisms must also be in place to interpret the data that the monitoring produces and communications and response actions must be planned. While September 11th taught us that there is no such thing as an "unthinkable act" it has prompted utilities to better monitor distribution systems for water quality, which in turn will benefit our everyday lives. Peace of mind? Better water quality monitoring may bring us one step closer but will we ever really have peace of mind again?

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