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# Interim Voluntary Guidelines for Designing an Online Contaminant Monitoring System

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# Preface

The water infrastructure of the United States[1] is vulnerable to accidental impacts as well as purposeful attack. Contamination that causes the long-term shut down of a major segment of water supply can result not only in economic losses in the community, but health problems for the public. Utilities, depending upon the assessment of risk reduction, may find it appropriate to establish monitoring systems capable of detecting contaminants in the water to mount an appropriate response that would protect the public health and safety and help manage the complex risks that are related to contamination.

The guidance needed for the design and implementation of an online contaminant monitoring system (OCMS) is in the form of best practice standards. There are many definitions of "best practices" but they all hinge on the availability of knowledge acquired through experience and/or research that, when applied to the situation at hand, can reliably lead to an effective and beneficial (hopefully, although not necessarily, optimal) solution to a problem.

Very few utilities have online contaminant monitoring systems, although many have established limited real time monitoring of a small number of parameters. Thus there is only very meager knowledge derived from experience in online contaminant monitoring. At the same time, as will be clear from the body of this document, there are many key questions that must be addressed even though the necessary research-based knowledge needed to answer them is not yet available. This presents a dilemma: why pursue the development of guidance on a topic where there is limited experience and research. The answer lies in the public policy arena; because the risks of contamination of any particular water system merit attention, utilities and the public may see online contaminant monitoring as an important element in risk management. Finally, water utility managers are dedicated to serving the public's needs, and in that context may see potential value in establishing contaminant monitoring systems.

The result of these various forces create a demand for guidance in spite of the lack of a solid knowledge base upon which to build it.

This document aims at providing the water infrastructure community guidance based upon the current state of knowledge in applying standard engineering and analysis approaches to the design and implementation of an online contaminant monitoring system. As more experience is gained and more research relevant to these problems done, this guidance will need to be revisited to reflect the then current state of knowledge.

Several additional important caveats must be mentioned at the outset. First, this problem is a very complex engineering challenge because much of the basic scientific and engineering knowledge needed is not yet available. Second, the instrumentation needed to accomplish the job directly,

[1] There are about 170,000 water systems in the United States and 15 percent of community water systems (i.e., about 8,100) are very large and serve 90 percent of the people who get water from a community water system. http://www.epa.gov/safewater/pws/factoids.html

particularly for water supply systems, is not available in the marketplace. There is research and development activity within the scientific and engineering communities toward producing such instrumentation. Third, the diversity among real world water utilities implies a need for extensive adaptation of any general guidance provided to the specific circumstances of the utility in question. Much is dependent upon the specific configuration and operational aspects of the water system that one should not expect to be able to provide detailed quantitative specifications for most of the elements of an OCMS that would be generally relevant to the water community. Finally, in some systems there is a lack of the understanding that pertains of the mechanics and hydrodynamics of the water systems.

## Guidance and the Standards Process

Standards are particularly important to trade and commerce because they promote predictability in expectations when purchasing from a manufacturer, interchangeability and compatibility in systems from different vendors, and best practices and policies for an enterprise. In addition, they set targets and expectations for performance and therefore may affect questions of liability, accountability, and responsibility.

Standards are developed by industry, professional communities and, governments. In the United States, the federal government sets standards related to its own procurement needs as well as those standards needed to meet certain legislated requirements and mandates. However, most standards are voluntary standards developed by industry and professional groups and are aimed at facilitating and improving the performance of products and the rendering of services.

ASCE has a long-standing role in facilitating the development of standards relating to those industries involving civil engineering. Among the industries that fall into this category are the water supply and wastewater/stormwater infrastructures. In light of the growing concern over the vulnerabilities of the nation's water infrastructures to purposeful assault, ASCE has established a Water Infrastructure Security Enhancements Standards Committee (WISE-SC). This committee has three sub-committees:

- Water: concerns itself with security issues in water supply.
- Wastewater/stormwater: deals with security issues in the wastewater and stormwater infrastructure.
- Methodology and characteristics (M&C): addresses standards issues, primarily in the form of best practices, in the development and use of various methodologies for design, assessment, planning, and operations related to security.

These three subcommittees have developed work-plans that address security enhancement issues in their respective areas of responsibility.

The first step in developing appropriate standards is to develop pre-standard guidance documents that identify the key issues, and the factors that affect them and that point the way toward the development of voluntary standards.

With WISE-SC oversight, ASCE, in cooperation with the AWWA and the WEF, has entered into a cooperative agreement with the U.S Environmental Protection Agency (EPA) for development of physical security standards for water utilities. AWWA is the executive agent for the water supply portion of the project, WEF for the wastewater/stormwater portion and ASCE for the methodology and characteristics portion.

In each case, the effort is designed to be pursued in three phases. Phase I is the development of pre-standards guidance documents, Phase II is the preparation of training materials that can carry the effort to the water infrastructure community, and the Phase III is the actual development, vetting, and acceptance of appropriate standards though an accepted consensus process.

This pre-standards document can also suggest goals and objectives in "best practices" to OCMS manufacturers that can be used to guide their research and development efforts in developing new systems. As more useful OCMS technology becomes available, the water community may, in turn, adopt performance standards based at least in part upon particular manufacturer's technology. The lack of a definitive base of experience and knowledge argues at this stage for a concurrent and more collaborative effort by both manufacturers of instruments and the water utility communities.

## Methodology and Characteristics Project

The M&C portion of the project is ultimately (and that clearly is not until a more substantial knowledge base is available) to develop standards and/or guidance documents for the design and implementation of an online, near real time, OCMS that would facilitate the mitigation of public health and other important risks arising from purposeful or accidental contamination of water supply and wastewater systems by chemical, biological, or radiological materials. These standards are "best practice" standards rather than standards that specify dimensions and numerical performance measures.

This problem exemplifies the kind of standards development work that the M&C Subcommittee is expected to undertake. It is one of the most important, urgent, and sensitive matters in enhancing the security of both water supply and wastewater/stormwater utilities.

The first phase of the M&C project is reported in this document. It pertains to both water supply and wastewater/stormwater systems, although the amount of information acquired regarding wastewater and stormwater contamination is much less than for water supply and the discussion and guidance provided at this stage for wastewater contamination monitoring is very limited. It addresses utilities from small to very large. The report:

- Identifies the key elements of design methodology applicable to an OCMS.
- Discusses the important issues that need to be resolved in designing such a system.
- Identifies key decisions that need to be made in the design process.
- Explores the direction in which such standards might be developed by postulating interim guidance.

Figure P-1 depicts the process used to develop the Phase I pre-standards guidance document for this report.

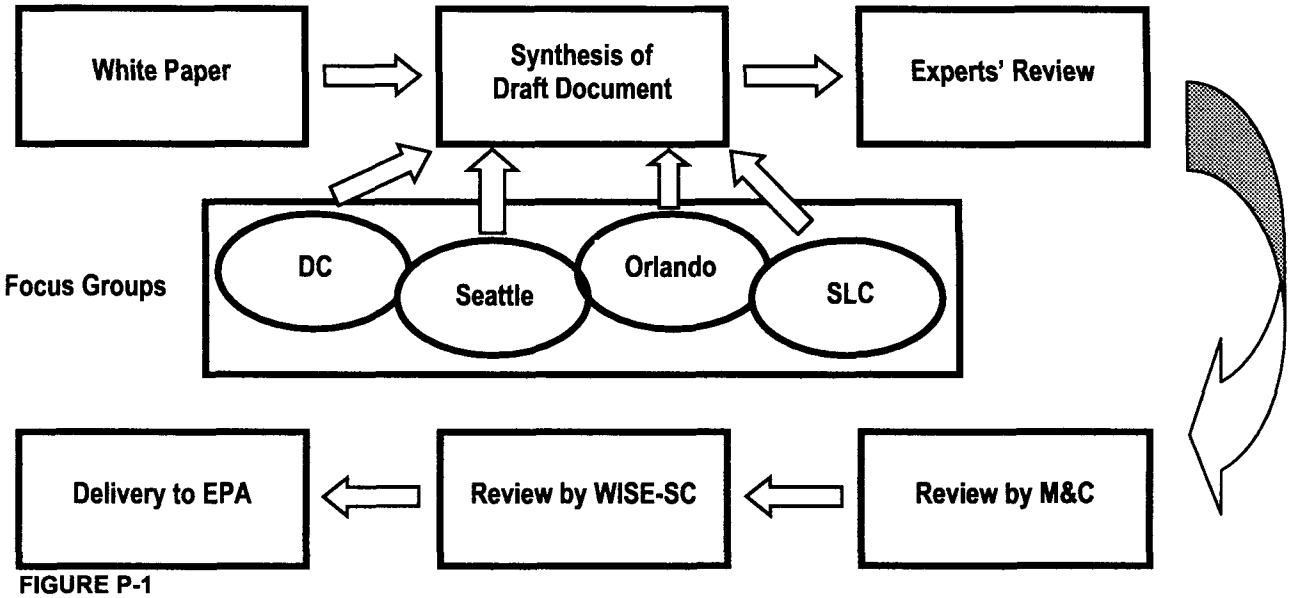


**FIGURE P-1**
Process of Developing the Document

The review process is designed to elicit information and critique from a broad audience of water utility owners and operators, engineering and consulting firms, academics, and government officials. The focus groups have been an important mechanism in this process and they supplement the more focused reviews of the selected experts, the M&C subcommittee and the WISE-SC.

The effort was initiated with a request for proposals from a wide field of experts to address a number of specific issues that had been identified for us as important to both utilities and the designers of OCMS. The requests for proposal asked bidders to address both water supply and wastewater/stormwater systems. The responses, however, focused almost completely upon water supply and therefore the treatment of wastewater and stormwater contamination monitoring in the white papers is minimal. That does not mean that the wastewater contamination problem is insignificant. It simply points out that a) the degree of awareness and interest in the contamination problem is much less among the wastewater/stormwater community than in the water supply community and b) there seems to be much less information available about the wastewater/stormwater contamination problem.

The issues addressed in the white papers are reflected largely in the section titles of this document. These "white papers" are presented in whole as Appendix A to this report.

# This Document

The presentation of material is organized in sections each of which addresses one or more of the key issues raised. As is true in any real life systems engineering problem, these issues are interdependent. The white paper authors were tasked to address these interdependencies in their work and the text reflects these relationships.

The material in the sections was derived from, or based on, the white papers to the extent that was possible. The text can be read as a stand-alone document, as can each white paper. Both the text and the white papers provide references and discussion of literature relevant to the subject.

The contamination problem is very different in water supply systems and wastewater/stormwater systems. Where appropriate, the report treats the situation for water supply separately from wastewater/stormwater. As noted above, the information found and made available pertinent to the wastewater/stormwater contamination monitoring problem was severely limited and that is reflected in the brevity of discussion and guidance on that aspect of the problem presented in this draft.

In each appropriate section, a statement of interim guidance is provided and presented in a separate section, usually at the end of the section or the end of a major discussion topic. These statements of guidance are meant to focus further discussion on some of the key issues. They are not expected to be near final form in this document.

## Next Steps

Following the development of this Phase I interim voluntary guidance document, ASCE will undertake in Phase II the development of appropriate training materials for use in the water sector. The objective of Phase II is to provide a vehicle for very broad-based exposure throughout the water supply and wastewater industries to build the basis for Phase III, which will be the development of voluntary water community standards on this subject. Because of the need for much more information on which to base standards and because there is now a very active research effort related to this problem, Phase III of the effort may be expected to be a very dynamic phase. The final articulation of best practice guidelines for the design of an OCMS may be some time off. However, the strong interest and concern over this problem is powerful motivation for providing the best available guidance to the community as soon as possible, even though better understanding and more experience may require substantial revision.

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| | |
|---|---|
| David Byer | Colorado State University |
| Kenneth Carlson | Colorado State University |
| John Cook | Advanced Data Mining |
| Terry Engelhardt | Hach Company |
| John Frazey | Colorado State University |
| Yakir Hasit | CH2M HILL |
| Anita K. Highsmith | Highsmith Environmental Consultants |
| Gary Jacobson | CH2M HILL |
| Karl King | Hach Company |
| Alan R. Kolnik | ARK Associates |
| Stephen Margolis | Highsmith Environmental Consultants |
| William J. McShane | Highsmith Environmental Consultants |
| Perrin Niemann | CH2M HILL |
| Kenneth Ogan | Hach Company |
| Edwin Rochl, Jr. | Advanced Data Mining |
| Donna L. Smith | Highsmith Environmental Consultants |
| David E. Stangel | CH2M HILL |

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| | |
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| | |
|---|---|
| Wayne Einfeld | Sandia National Laboratory |
| Yakir Hasit | CH2M HILL |
| Petr Ingeduld | DHI Water & Environment |
| Conrad G. Keyes, Jr. | Chair, Water Infrastructure Security Enhancements (WISE) Standards Committee |
| Tom Mattiacci | Lakeland, Florida |
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Despite all the advice, suggestions, guidance, and reviews, the author takes full responsibility for any omissions or errors as well as for the points of view expressed in this report.

# Executive Summary

The American Society of Civil Engineers (ASCE)—acting as executive agent for a consortium comprising ASCE, the American Water Works Association (AWWA), and the Water Environment Federation (WEF)—has entered into a cooperative agreement with the U.S. Environmental Protection Agency (EPA) for a three pronged effort to develop standards documents and guidance aimed at enhancing the physical security of the nation's water, and wastewater/stormwater systems. AWWA is leading the effort concerning guidance for enhancing the physical security of water supply systems; WEF is leading a similar effort focused on wastewater and stormwater systems; and ASCE is leading the effort on developing guidance for applying methodologies to a specific, highly important area within the universe of physical security challenges to water systems, namely the subject of this paper. Each prong of the effort is being pursued in three phases: first is the development of a pre-standards document that can serve as the basis on which further development of standards and guidance can proceed; second is the development of appropriate training and outreach materials; and third is the consensus process under which voluntary standards can be articulated and accepted by the water community.

The present report is the Phase I pre-standards document for the ASCE effort, which is focused on the design of online contamination monitoring systems (OCMSs) for both water supply and wastewater/stormwater systems.

The main difficulty in developing standards or guidance for the design of an OCMS at this time is the dearth of available knowledge, gained either from experience or research, needed to provide a reliable basis for resolving the many issues that must be addressed. From that viewpoint, the pursuit of standards in this case may be seen as premature. However, the vulnerability of many water systems to contamination and the consequences for public health and safety that would be generated by a serious contamination event create a strong widespread demand for such guidance, even though the requisite knowledge base is not there. Despite the lack of a definitive base of knowledge, some utilities are proceeding in establishing and operating OCMSs. Moreover, most of the problems highlighted in this document are now the subjects of a growing research effort sponsored and conducted in large measure by the federal government. Therefore, this effort to develop guidance should be viewed as the initial stage in what will almost certainly need to be an intensive, longer-term effort to incorporate new knowledge and technological capability into the guidance as it becomes available.

## The Contamination Problem (Section 1)

This section provides a brief introduction to the problem that spawned this effort; accidental or purposeful introduction of contaminants into the water supply or the wastewater/stormwater system. Contaminants can be chemical (including biotoxins), biological, or radiological.

Contamination of water supply systems has been a problem for as long as such systems have existed. In ancient times, intentional contamination of wells and other water supplies was an accepted tactic

in warfare. Today, the intense concern over terrorism has led to serious examination of water system vulnerabilities and steps toward their mitigation.[2] However, the contamination problem goes beyond terrorist actions. Other intentional contamination events have been threatened or perpetrated by vandals and by extortionists. There have also been a number of hoaxes claiming water contamination. Also, accidental or negligent contamination, particularly through backflow of contaminated water from user facilities or through infiltration of sewage through breaks in pipes, has occurred with disturbing frequency.

The problems caused by contamination in water supply and in wastewater/stormwater are qualitatively different. In water supply contamination the most serious problems include public health problems (death and illness among the consuming public) that arise from the use of contaminated water, economic problems that arise from either the use of contaminated water or the unavailability of potable water, and the loss of public confidence in the ability of the utility to provide potable water. The wastewater system typically includes sewers, which collect and convey domestic and industrial wastewater to municipal wastewater treatment plants or facilities. Wastewater contains a variety of materials (both organic and inorganic in nature), including human waste, industrial wastewater, infiltration and inflow, and a wide range of chemicals and materials that are discarded into the system. Wastewater is conveyed to a treatment facility where the solids are removed and the wastewater is treated to produce an effluent that meets or exceeds limits on the concentrations of contaminants, which is summarized on the plant's discharge permit. Typically, a wastewater treatment plant consists of preliminary and primary treatment, which typically consists of screening and sedimentation for removal of large debris or objects. The water is then treated through a secondary biological treatment process to remove soluble organics. The final steps are removal of the biological solids and disinfection of the clarified effluent. The residual solids that are generated in both the primary and secondary treatment processes are further stabilized via digestion, and then the remaining solids are removed from the treatment plant as called for in its permit. Typical applications of the digested solids may include land application or land fills. The wastewater collection system is situated in the ground and consists of a network of gravity sewers, pump or lift stations, and force mains. Some communities combine their stormwater collection and disposal systems with their wastewater systems while others maintain them as separate systems.

Because wastewater is inherently contaminated, it may seem an unlikely target for a contaminant attack. Nevertheless, there are contaminants that can wreak havoc in the wastewater and stormwater systems. For example, in 1981 Louisville, Kentucky suffered an explosion in the sewer system that ripped up more than two miles of street.[3] Apparently, it was caused by the accidental igniting of hexane fumes in the sewer. Thousands of gallons of hexane were illegally introduced into the wastewater collection system by a local industry and, it is thought, the fumes were ignited by a spark from a passing car. The explosion occurred early in the morning when the streets were nearly deserted and that may explain why there were no fatalities reported. A sewer explosion in

[2] See: Critical Foundations: The Report of the President's Commission on Critical infrastructure protection, October 1997; PP A-44 et seq.

[3] http://www.courier-journal.com/cjextra/2003projects/toxicair/0713/2wir-5-blast0622-7937.html

Guadalajara, Mexico, in April 1992 killed 215 people, injured about 1,500 and damaged a number of buildings.[4] Some major cities in the United States have experienced sewer explosions that launch manhole covers many feet into the air. Such events happen a dozen times a year or more. Some of these cases involved the igniting of methane that is produced naturally in the decay of organic matter. Combined wastewater and stormwater systems allow easy entry of materials into the sewer system and may also allow direct venting of fumes or airborne pathogens to street level, exposing pedestrians and motorists to significant risk.

The types of contamination events that could affect wastewater systems include:

- Contaminated drinking water that also contaminates the wastewater system.
- Disposal of byproducts from a decontamination event in the community (including decontamination of the drinking water itself as well as decontamination of persons and property following a chemical, biological, or radiological incident).
- Direct intentional contamination attack on the sewers or the wastewater treatment plant.
- Accidental discharge of a contaminant into the sewers.
- A contamination event in the system's service area that could result in runoff of the contaminant into the storm sewers.

When a wastewater treatment process fails due to a high concentration of a contaminant, the effects on the treatment process will vary depending on the type of contaminant. For example, if a chemical that is toxic to the biological treatment process was introduced into the sewers it may cause the activated sludge process to be adversely affected in that it kills the "bugs" used to stabilize or remove the organics from the wastewater. This in turn may result in a higher concentration of biochemical oxygen demand or suspended solids in the effluent, which in turn may prevent a wastewater treatment plant from meeting its discharge permit limits.

In wastewater and stormwater systems, the main problems are that igniting volatile explosive materials dumped into the sewers can injure or kill people and destroy property. Volatile toxics, as well as pathogens, might become airborne and be vented to populated areas, threatening public health. In addition, contaminants can disrupt the wastewater treatment processes, resulting in detrimental effects on the environment and community from contaminated sludge or effluent or the need to take a portion of the plant offline or it may result due to the contaminants being contained in the residuals or discharged into the effluent.

## Rationale for Online Monitoring and System Design Basics (Section 2)

This section addresses the initial question that most utilities raise—"Do I really need an OCMS?" Online contaminant monitoring systems can become very expensive. Furthermore, there is not yet sufficient experience with or knowledge about OCMSs to allow confident design and reliance on such systems. Before undertaking the development and establishment of an OCMS, utilities should assure

[4] http://www.corrosion-doctors.org/Localized/sewer.htm

themselves that the effort is expected to be worthwhile. This hinges on the ability of an OCMS to substantially reduce the risks engendered by contamination. If, compared with the costs, the OCMS can significantly reduce the risk, it may be justified.

Underlying this judgment is the need to assess the risks due to contamination. Existing risk (or vulnerability) assessment methodologies may not be appropriate for this problem. Indeed, many utility representatives have informed us that they believe their own vulnerability assessments have not dealt adequately with the contamination problem. EPA has undertaken a research effort (the TEVA research program) to develop an assessment methodology more appropriate for contamination scenarios.

An OCMS should be designed to detect contamination events and provide information on the location of the contaminants within the system. In the future, when the technological capability is available, such systems should aim to characterize the contamination event by identifying the contaminant or its class, indicating the concentration of the contaminant, calculating its spread within the system, and determining the duration of the event.

All water utilities, whether water supply or wastewater, should ensure that they have a current assessment of their risks due to contamination. However, it is recognized that packaged assessment tools accepted by the water community at large and tailored to the contamination problem, are not yet available. Nevertheless, until such tools are available, utilities should estimate their needs for an OCMS by the following rough process that applies a standard risk assessment or vulnerability assessment methodology:

- Identify all practical potential points of insertion.[5]
- Identify the insertion points of highest criticality based on the population affected.
- Among the critical insertion points, choose those that are most readily accessible to an attacker or to accidental contamination.
- Postulate a set of contamination threats.
- Estimate the consequences.

If the risk assessment indicates that contamination poses a significant risk, the utility should consider a range of measures to reduce that risk. Among the measures that should be considered are enhancements to physical security, personnel security, and cyber security that would make the introduction of a contaminant more difficult or more easily detected.

If the risk remaining after reasonable security enhancements are considered is still significant, the utility should consider establishing an OCMS. If the reduction in risk due to the OCMS is commensurate with its costs (development, establishment, and operations), an OCMS is justified.

[5] The judgment of which potential points of insertion are practical from the viewpoint of an attacker is difficult but can benefit from the participation of persons intimately familiar with the operation of the system.

The objectives of an OCMS are:

- To provide an early reliable warning of a contamination event so that steps can be taken to reduce its effects by limiting exposure of the at-risk population.
- To indicate the location and travel of the contaminant in order to facilitate implementation of the appropriate responses.
- Insofar as possible, to identify the contaminant and determine its concentration so that the most appropriate response can be mounted, and to alert and inform the medical community about the potential need for treatment.
- To provide information on the "normal" operating characteristics of the water supply or wastewater system.
- To support or supplement the existing regulatory surveillance activities.

The first three purposes are the most important from the point of view of contamination events as described in the first section. The last two are desirable but probably would not provide the justification for a substantial OCMS by themselves. That is, the last two purposes can be served with a much more limited monitoring system than the first three.

## Using Contaminant Lists and Determining Concentrations to be Detected (Section 3)

A comprehensive list of potential contaminants would be extraordinarily large and unwieldy. However, more easily handled listings would not be comprehensive. EPA has developed lists of contaminants of concern. Due to the sensitive nature of these lists, the Agency is determining how best to share this information with the water community.

There are many lists of potential water contaminants. Some have been prepared by professional or trade organizations, some by academic researchers, some by government researchers, and some by industry.

- EPA has an extensive list of contaminants whose maximum allowable concentrations in water are regulated. http://www.epa.gov/safewater/mcl.html#mcls
- CDC (Centers for Disease Control and Prevention) maintains a list of biological contaminants, many of which pose a water contamination threat. http://www.bt.cdc.gov/agent/agentlist.asp
- U.S. Food and Drug Administration (FDA) publishes the Bad Bug Book on pathogens and biotoxins. http://www.cfsan.fda.gov/~mow/intro.html
- Several companies have produced proprietary lists used primarily in their own instrument and sensor design efforts.
- ATSDR maintains a large database on toxic chemicals. http://www.atsdr.cdc.gov
- Research organizations have published lists. http://www.mitretek.org/home.nsf/HomelandSecurity/Toxins

Several engineering and consulting firms have prepared lists for their own use or for application on behalf of customers.

These lists have many common entries but are not completely congruent. Moreover, except for those that have been published in the open literature, or in regulatory documents, these lists are sensitive or proprietary and not made publicly available.

Regardless of which list one has available, certain modifications may be in order before it can be applied in the design of an OCMS. As noted in some detail above, the chemical and physical properties of contaminants are important on their own but also in connection with the peculiarities of the water utility. For example, the particular disinfectant used, where the chemical is introduced, reaction rates and products of the chemical with specific contaminants, system flow properties and residence times all play a role in differentiating the importance of specific contaminants.

There may be contaminants on the list that are not particularly worrisome because they will not survive well in the specific system. Some contaminants that are unimportant when introduced a few days' flow away from the tap may become very important when introduced a few hours away from the tap. Because of amounts needed or properties of the contaminant, some points of vulnerability may be more important than other points so that where one looks for a particular contaminant is a function of system properties. For example, there may be potential contaminants that should be of concern to the utility because they are readily obtainable in the area, or are shipped on navigable waters that serve as the water source, but are not on the available list of contaminants.

In the end, the utility or local government will probably bear responsibility in the eyes of the public (as well perhaps as in the courts) for ensuring that the OCMS can detect any significant contamination event. Therefore, the utility must examine the initial list to make sure that it contains all the contaminants of importance in its particular circumstances. No list prepared for general purposes can be expected to be applicable as-is to any particular utility. Furthermore, the lists of contaminants prepared and noted above are more pertinent to water supply than to wastewater systems.

Therefore the utility, with appropriate assistance, ultimately has the responsibility for identifying the contaminants for which the OCMS must function.

No listings have been found in the literature for contaminants of concern in wastewater and stormwater systems.

# Selection and Siting of Instruments and Platforms (Section 4)

While it might be cost effective if the objectives of the OCMS could be accomplished with a single tier of instruments, at the present stage of instrument development it is likely that specifically identifying a contaminant and determining its concentration will require a different approach. That is, for the foreseeable future, until state-of-the-art instrument design and manufacture advances appropriately, the approaches most likely to succeed will involve one tier of instruments to detect contamination

events and provide location information (the OCMS), while a second tier—which will likely require laboratory analysis of samples—will be needed to identify and measure the specific contaminant(s).

For water supply utilities, the ideal instrument would a) detect any of the contaminants of concern, b) reliably and accurately (to at least an NOAEL value in the case of chemicals or a single organism in a sample for pathogens) identify and measure contaminant concentration, c) be fully functional in field operations, d) require minimal down time, maintenance and housekeeping, e) produce a digital data stream, and f) have the capability of some onboard processing to minimize data transmission and analysis requirements. The instrument described above does not currently exist and may not exist for a long period of time.

For wastewater systems, instruments to measure volatile hydrocarbons exist in a fieldable form, whereas online instruments to measure the range of potential airborne toxins and pathogens under field conditions do not. An OCMS system for immersion in wastewater has distinct differences from one intended for water environments. Problems that may occur in a wastewater system include accumulations of grease and debris that may foul the probes. The background environment is both more diverse and more concentrated. Normal levels fluctuate more both at individual locations and between locations, and larger ports, tubes, and channels are required to prevent plugging.

The next best instruments would be tuned to detect specific kinds or classes of contaminants in water (and in air for the wastewater problem) and at least roughly indicate their NOAEL concentrations. Several research and development organizations are currently developing such instruments. The National Laboratories, several government labs (for example, National Institute of Standards and Technology (NIST), Naval Research lab (NRL)) a number of academic research organizations, and several companies are pursuing such efforts. However, there are very few such instruments now available on the market, and they have not been tested in realistic field circumstances.

Contaminants in water may affect measurable properties of the water and thus signal their presence through changes in those "surrogate" parameters. Such instruments are commercially available now, although there are indications that higher sensitivity may be needed to address the contamination problem more effectively. The kinds of changes that may be caused by contaminants include:

- Changes in chemical makeup of the water through chemical reactions or changes in the amount of carbon or other elements.
- Changes in pH, oxidation-reduction potential, and electrical properties through reaction of the contaminant with the water constituents or ionization of either the contaminant or water constituents.
- Changes in optical properties such as absorption, emission, or scattering of light at various wavelengths.
- Changes in biological makeup of the water.
- Changes in mechanical and acoustic properties of the water.

Within the classes of instrument to be used, four categories of factors should be considered in selecting a suite of instruments for an OCMS:

- The capabilities of the individual instruments including: parameter measured, sensitivity, accuracy, reliability, fieldability, and cost.
- The capabilities of the set of instruments whose data are analyzed together. including: whether the measures are complementary and the ability to cross-correlate data.
- Characteristics and constraints of the site such as: size constraints, power and telecom requirements and availability (for example, SCADA availability), environmental conditions such as humidity and temperature, and access to water flow and waste disposition.
- Operational considerations, particularly: maintenance, down time, calibration, testing, housekeeping (for example,— reagents, etc.), and onboard data analysis.

**TABLE ES-1**
Potential Locations for Instruments—Water Supply

| Location | Advantages | Disadvantages |
|---|---|---|
| Source waters | Covers large segment or all of system<br>Long lead time for response<br>Long time for corroboration<br>For navigable source waters threat of contamination can be relatively high<br>To be of concern to public health, large quantities of contaminant needed—therefore easier to detect | Threat of intentional contamination of source waters is relatively low for source waters on which no commercial traffic flows |
| End of water transport or aqueducts | Threat of intentional contamination is slightly higher than for sources<br>Covers large segment or all of system | Low threat for intentional contamination |
| Treatment plant | Threat of intentional contamination is slightly higher than for source or transport<br>Insider threat higher | Relatively low threat for intentional contamination because access is limited and there is potential for discovery |
| Finished water reservoirs | Threat of intentional contamination considerably higher | There may be many of them requiring coverage |
| Early distribution system | Moderate threat, particularly at sites to which access can be gained (including valves, pumps and check points) Relatively long time available for warning and response | Need several platforms to cover entire system |
| Mid distribution system | Higher threat, covers many of the likely contamination entry points including valves, pumps and inspection ports | Need multiple platforms to get full coverage, moderate to little warning time |
| Entry pipes for likely targeted customers | Higher risk area; expect better cooperation from such customers | Locating so close to user leaves very little time for effective response |

Among all the elements affecting platform location, the one that should have the biggest effect is the importance of the information to be gained by measurements there. For example, contamination in the part of the system that serves residential communities in general would be expected to have a

greater impact on public health than a part of the system that serves mainly business or industrial customers. Locations that allow earlier detection in these more sensitive portions of the system ordinarily would be expected to have a higher priority than those locations that are better suited to less sensitive portions. In many cases, the convenience and cost issues associated with communications links, power, and other environmental factors will be highly important in determining location.

When selecting the sites, the following recommendations are offered:

1. The utility should identify as many candidate sites at the outset as practical. The beginning step is to identify, the highest priority vulnerabilities to contamination, using the contaminant risk analysis methodology. This assessment would include evaluations of accessibility of the insertion point as well as the criticality of the affected population segment.
2. If the utility has a functional and well-calibrated network model, it should determine the dominant contaminant pathways. If the utility does not have such a model, then, using its knowledge of the system, it should make educated guesses on where the dominant pathways might be.
3. For corroboration purposes during normal operations, the utility should choose existing compliance sampling locations close to the dominant pathways, and start collecting samples there. Alternatively, with state regulatory agency approval, it might be able to move its compliance sampling points to locations that are better suited for contaminant detection monitoring. If the utility is not restricted in its resources, then it could select the best locations based on its hydraulic analysis.

The methods for selecting sampling locations to detect contaminants within a distribution system network have been either intuitive or analytically over-simplified. Intuitive methods cannot account for the variability and uncertainty inherent in the intentional or unintentional contamination of water distribution systems. However, more detailed analytic approaches such as mathematical programming are currently too complicated for the water utilities to implement on their own. Furthermore, little guidance has been available to utilities that do not have the resources to develop such sophisticated approaches. Currently, for water distribution systems, hydraulic/water quality network models are the most practical tools for identifying the candidate locations for monitoring instruments and sensors.

It is apparent that the identification of sampling locations is an iterative process involving many diverse sources of information and will be different for every utility. A utility will also be able to shape the analysis by identifying policy direction prior to the evaluation. Ultimately, a series of steps would be undertaken, based on the analysis described above, that would allow the utility to identify a number of targeted sampling locations.

The number of sampling points recommended by the analysis will probably be higher than what a utility with a limited budget can implement. In this case, additional prioritization will be required to identify the relative importance of each of the parameters represented by the steps. Several iterations may be required before an acceptable number of locations can be identified. Another option would

start with a desired or target number of sampling locations. However, it may prove valuable for the utility to go into the process without any expectation of the target number of locations, therefore allowing the process to identify an appropriate number.

A knowledge-based risk assessment evaluation of the local site conditions and system-wide factors discussed earlier is advised for each utility before conducting any detailed hydraulic analysis. Such an assessment will help narrow the number of iterations and analyses and, ultimately, the number of monitoring locations recommended.

It is also important to note that the quality of the predictive information from the utility's network model will be only as good as the investment made in developing that model and the skill and experience of those operating it. Of particular importance is a spatially accurate demand allocation and true model representation of operational settings. The quality of the network model is validated by performing comprehensive steady state and extended period calibration prior to any use of the model as a predictive tool. An OCMS for water supply should include a number of platforms containing instrument suites that can measure surrogate parameters with sufficient accuracy, sensitivity, and reliability so that the correlation of contemporaneous measurements from the suite will indicate the presence of contaminant at levels at or above the NOAEL values and provide information on the location and extent of the contaminant in the system. An indication of the class of contaminant, if not its specific identity and concentration, is desired that is not possible with currently available technology with the possible exception of few select contaminants.

No analytic basis exists yet for understanding the specific relationships between contaminants and surrogate measures, although some partial empirical work indicates such relationships for a limited class of situations. From the limited empirical studies performed and reported to date, it is recommended that, for water supply, the candidate instrument suite should include instruments to measure:

- Flow/pressure
- Temperature
- pH
- Conductivity
- Residual chlorine
- Turbidity
- TOC
- Oxidation reduction potential (ORP)
- Ammonia, chloride, and nitrate
- Toxic materials (for example, a toximeter)
- Radiation (alpha, beta, and gamma)

From this suite of options, based on further laboratory and field study, a smaller set of options should be chosen. As a general rule, in comparing options for particular instruments, the primary factor should be their performance characteristics. An instrument with higher sensitivity, accuracy, and reliability is clearly preferred, unless other characteristics of the instrument or site preclude its use. Because sample acquisition is likely to be a crucial aspect of verifying the contamination event, as

well as necessary for identifying and quantifying the contaminant, the capability of taking a sample when a threshold is reached is an important characteristic.

Two specific resources should be monitored for current information on instruments:

- EPA's Environmental Technology Verification site, which verifies the performance of technology submitted by manufacturers. www.epa.gov/etv/verifications/verification-index.html
- EPA's Security Product Guide, which describes a number of sensors for water monitoring and gives vendor contact information. www.epa.gov/safewater/watersecurity/guide/tableofcontents.html#water

Early warning devices have been in use for sewer systems primarily to avoid damage to receiving facilities or waters. These systems have included alerting for overflows and avoiding spills, avoiding treatment system upsets (especially biological treatment systems that are susceptible to toxic contaminant overloads), and ensuring the safety of sewer workers.

As noted earlier, the primary public health and safety concerns in wastewater/stormwater systems are: the potential for injury to persons or property by fire or explosion of volatile materials in the collection portion of the system, and the public health risk from toxic materials and pathogens in public places as a result of escaping from wastewater or stormwater in the collection portion of the system.

Monitoring against toxic materials or pathogens in the wastewater/stormwater system would be best accomplished by instruments that detect such materials either in the wastewater or in the air spaces within the collection system.

For wastewater collection systems, the monitoring system should include instruments to measure volatile organic compounds (VOCs), residual chlorine, and biological oxygen demand (BOD)[6] in the wastewater and hydrocarbons above the wastewater surface. When appropriate instrumentation for online detection of pathogens in the wastewater and in the air spaces within the collection system becomes commercially available, it should be incorporated into the monitoring system.

Potential sites for wastewater system monitoring include major source locations as well as portions of the system near vents to public places.

**TABLE ES-2**
Potential Sites for Instrument Platforms - Wastewater/Stormwater

| Location | Advantages | Disadvantages |
|---|---|---|
| Wastewater collection | Would cover likely entry points for wastewater contamination | Would require fast response and many platforms |
| Wastewater treatment | Would require fewer platforms and would pick up contamination that would degrade bio process or effluent | Would miss the collection system problem |

[6] Current technology requires days for the measure of BOD in wastewater.

**TABLE ES-2**
Potential Sites for Instrument Platforms - Wastewater/Stormwater

| Location | Advantages | Disadvantages |
|---|---|---|
| Effluent and sludge | Would require few platforms | Would miss many contamination problems, but pick up problems affecting effluent, sludge, and treatment process too late for effective response |

Major source locations should include wastewater streams from major industries from which VOCs might be more likely to accidentally or purposely flow. Significant amounts of VOCs can also be introduced to any wastewater or stormwater sewer, however, the cost of monitoring at all such locations would be prohibitive.

# Data Analysis and the Use of Models (Section 5)

The objectives in analyzing the data obtained from monitoring instruments are to:

- Identify the presence and location of significant contamination in the system. *(essential)*
- Identify the contaminant or its class with sufficient specificity to allow appropriate responses. *(desirable)*
- Characterize the contaminant concentration profile (pulse morphology). *(desirable)*
- Determine time to tap (water supply systems) or time to treatment/disposal (wastewater systems). *(essential)*
- Eliminate false negatives and minimize false positives. *(essential)*
- Assess public health risk. *(highly desirable)*
- Provide timely information to decisionmakers. *(essential)*

The data to be analyzed consists of a time series of data points from each instrument on a particular platform and from all of the platforms in the system. The data from an instrument vary over time for several reasons. First, there may be noise in the instrument. This generally (though not always) can be characterized as stochastic and treated as a random variable following a particular intensity and frequency distribution. Second, there may be non-stochastic variations in the instrument response (for example, drift) that need to be taken into account as well. Third, there always are variations in the actual properties of the water. For example, water age affects residual disinfectant levels as well as reaction product concentrations. Depending upon the sensitivity of the instrument, these variations may be at various scale sizes. Finally, there are variations in the measured parameters that arise from changes in operating conditions (for example, opening or closing of valves, flushing of major systems, adding disinfectant, etc.). These changes would be registered as unusual but explainable and, from the point of view of contamination monitoring, benign.

To interpret a set of measurements as an indication of a contamination event, one must distinguish between such an event and all the other possible causes of the measured changes. The primary

challenge here is to distinguish between the benign anomalies that arise in the operation of the system and potential contamination events. This requires a thorough understanding of these benign changes and what characteristics can be used to differentiate them from contaminant events.

Water utilities should model their systems not only as a prerequisite to establishing an OCMS, but to understand and better manage normal operations. A model that has the capability to include insertion of contaminants at the appropriate locations, and to model flow and chemistry should be selected. The utility will need some experience in applying, validating, and tuning the model to the particular circumstances of the system to ensure its validity under all anticipated operating conditions.

Once a model has been tuned for use in the system, it can be accommodated in the data analysis scheme.

- Data analysis must be automated. The analysis program should be written to address contamination scenarios ranging from very short insertion pulses (on the order of a few minutes) to long-term bleeds (on the order of a few days) and cover most likely potential insertion points. It should allow for weighting (prioritizing) the scenarios and insertion points according to threat information received (most likely from external sources) and the results of the utility's vulnerability assessment. It should be able to characterize the measurement noise spectrum and apply appropriate data analysis filtering or other techniques to facilitate signal extraction.
- A catalog of potential pulse characteristics should be developed and the data analysis program should apply the library of pulse shapes to the task of signal processing.
- The OCMS responses to benign variations in operational characteristics must be registered and a library of such variations constructed. It is desirable to have an analysis program that can learn from experience which variations are recognizable as likely to be benign.

The analysis program should have a built-in decision tree that directs corroboration and verification activities under circumstances that differentiate between:

- Event signatures that have been seen previously and determined to be benign.
- Event signatures that have been seen before but for which the cause has not been determined to be benign.
- Event signatures that have not been seen before.

Event signatures that have not been seen before should be treated as potential contamination events and the analysis program should trigger the appropriate confirmatory responses.

The analysis program should provide for the comparison and correlation of measurements from different instruments on the platform (including signature computation) as well as the measurements from instruments on different platforms.

Distribution system models have evolved over the years to meet water system requirements. The first models were based upon steady-state hydraulic principles. In the 1980s, increasingly sophisticated codes were developed that included stand-alone water quality models. In the late 1980s, the first

models able to simulate time-varying conditions were developed. Most of these were able to use extended-period simulation (EPS). These types of models do not simulate the inertial effects due to rapid changes in velocity; however, they do simulate flow reversal and the reactivity of constituents and track conditions in tanks. Fully dynamic models and models that account for dispersion have been developed. For the last decade, attention was focused on algorithms for use in modeling water quality in pipe systems. EPS models are currently the most advanced technique that is widely deployed for practical applications. Based on this, modeling water quality in water distribution systems is becoming a more widely accepted tool in support of water supply planning, operations, and research.

There are numerous models available, each with unique abilities in regard to hydraulic capacities and *applications in water security. Security applications of distribution system hydraulic models include:*

**Instrument placement.** Models can be used to help determine the optimum placement of monitors.

**Pre-event response scenarios.** Extensive modeling could be conducted before an event occurs to facilitate response planning. Various scenarios can be input into a model and then run to determine the extent of the contamination and to develop and test response plans to minimize impacts.

**Design/upgrade of water systems.** Once the model is run, and the possible contamination areas are highlighted, the next step will be to identify the weak points in the water system.

**Identifying location of contamination.** During an actual contamination event, a model could be used to determine and predict the location of the contaminant bolus.

**Confirmation of positive event.** One positive alarm from a monitor may not necessarily indicate contamination. There could be numerous causes that would result in a false positive, and therefore, a reasonable approach for confirming a positive alarm must be developed. Verification of a contamination event would be done through predicting where the contamination, if truly in the system, would travel to next and the appropriate reading that would be expected at that point. Once the water reaches that point, and the monitor responds in the model-predicted manner, the second response has been found.

There are several models applicable to wastewater and stormwater systems. A few of these models are described here.

- **HYDRA V6.** HYDRA is a comprehensive hydraulic model designed specifically for the unique challenges of storm and sanitary sewer modeling. It can be used to model almost any collection system. HYDRA combines powerful hydraulic analysis and Geographic Information System (GIS) features with a user-friendly interface for the municipal engineer. HYDRA can exchange data with ESRI's ArcInfo and ArcView Shapefiles.
- **Sewer CAD.** SewerCAD is an advanced design, analysis, and planning tool, handling both pressurized force mains and gravity hydraulics. It has features such as steady-state analysis using various standard peaking factors, extended period simulations of complete collection systems, and advanced automatic system design. SewerCAD allows users to construct a graphical representation of a pipe network that contains pipe data, pump data, loading, and infiltration

information. It has the flexibility to mix gravity and pressure components, enabling the user to model the systems exactly as they are in the field.

- **TOXCHEM+.** A model that can be used to estimate emissions of organic and metallic contaminants from wastewater treatment and collection systems. It also has a "backsolve" feature that enables the user to work backwards to an allowable headworks concentration by specifying a contaminant concentration of a liquid, air, or solids stream in downstream processes. TOXCHEM+ allows for the modeling of activated sludge, fixed film, lagoon, closed tanks, industrial pretreatment systems, collection system effects, and spill flows. The new Version 3 of TOXCHEM allows users to execute multi-contaminant model runs and view the results on screen. It also gives the user the ability to create a grouping of contaminants for modeling runs. With these new features, TOXCHEM Version 3 is at the forefront of predictive fate modeling.
- **Water 9.** Water9 is a wastewater treatment model that estimates air emissions of waste constituents in wastewater collection, storage, treatment, and disposal facilities. It can provide a model for a full facility and has the ability to produce reports about constituent fates, including air emissions and treatment effectiveness. It can be used to obtain emission estimates for individual compounds. The total air emission then can be obtained by summing the individual compound estimates. It can be used to estimate air emissions from site-specific water treatment plants for common wastewater treatment units. It utilizes theoretical models and correlations of data from Enviromega and the University of Texas at Austin for its collection system components and is updated as new data become available.

# Communication System Requirements (Section 6)

An online contamination monitoring system would be expected to consist of a number of instrument platforms located throughout the water system—whether supply or wastewater—operating continuously and producing large quantities of data. The data would be sent to a central data analysis facility at which they would be processed. Under normal conditions, the results of the data analysis would not trigger any of the contamination alarms or responses, but certain results might be available to illuminate the operational aspects of the utility. Under conditions recognized as a possible contamination event, certain information and alarms would be provided to a decisionmaker and possibly certain other actions would be triggered as well, for example, taking samples or initiating a corroborative investigation. The decisionmaker would then evaluate the situation and take further appropriate actions such as issuing advisories, contacting local, state or federal officials, directing actions of utility personnel, and dealing with the media. To transport the data and conduct these actions effectively, there must be a communications system in place that is reliable, effective, and secure.

The data can be transmitted to the data analysis center over existing SCADA linkages (hard wire, public switched network, or radio frequency) or over separately configured and managed linkages. Most utilities would most likely prefer to use an existing SCADA system for OCMS communications. However, to make sure that the OCMS system is secure, the better practice would be to encrypt its data, which may make it more difficult to ensure compatibility with an existing SCADA system. In

addition, since SCADA systems are themselves potential targets, it is a better practice to maintain firewalls between the OCMS and the SCADA. While that may still allow for a combined communication system, greater care must be taken in designing and implementing the SCADA system to preserve the necessary degree of security for the OCMS.

The engineering design of the communications system is straightforward and must take into account the multiple objectives to be served, the available resources (including existing communications links, other assets, and budget), and the constraints (including data handling requirements, time constraints, security, and reliability).

The full OCMS might require communications links beyond the utility's SCADA, in which case the utility should decide whether to invest in an entire new communications link or expand the SCADA to cover new instrument locations.

In any event, since some possible responses will require communications with utility personnel or assets, the OCMS communications system will have to connect with the SCADA and management networks.

Also, the communications system should include the protocols and equipment necessary to communicate with the media and other outside organizations such as local emergency response teams and state and federal organizations, as appropriate.

## Responses to Contamination Events (Section 7)

The main objective of response actions is to minimize the exposure of the public to contaminants or the effects of contaminants while providing additional time to evaluate the nature and severity of the event. In general, containment of the contaminated water would be a desirable option for an operational response. However, containment is not always a realistic possibility. Other options can also be pursued. For example, elevating the disinfectant levels or adding materials to counteract the contaminant in a targeted area may be considered. Public notices or advisories to boil, not drink, or not use the water may be issued.

To assist the water community in responses to contamination events (as well as other emergencies) EPA has developed its Response Protocol Toolbox (RPTB). The RPTB is composed of an overview and six interrelated modules, which focus on different aspects of planning a response to contamination threats, and incidents long before they occur. The RPTB is primarily concerned with drinking water contamination threats. Module 1 is an overarching document that serves both as a primer on contamination threats to drinking water systems and an overall guide to utility planning for such incidents. Module 2 is the hub of the toolbox; it addresses the overall management of a contamination threat. The remaining modules support Module 2 by presenting information and protocols for investigating the contamination threat or implementing actions in response to a contamination threat or incident.

Most emergency responses are handled within the guidelines of the National Response Plan (NRP) by the utility with assistance from local and state responders. The NRP is the overarching document that helps provide coordination between local, state, and federal agencies responding to a disaster.

The plan determines the roles of each participating agency and provides common language, communication, and actions among the first responders. The development of coordination between local, state, and federal agencies resulted in the Incident Command System (ICS) which provides disaster management including use of common terminology, modular organization, integrated communications, unified command structure, action planning, manageable span of control, and comprehensive resource management.

Response options fall into three main categories:

- Notices to the public
- Utility actions
- Outside emergency response

For water supply, three primary types of notices can be provided to the public. The most common is a "boil water" notice. This advises the public to boil tap water for a minimum length of time before using. It is usually invoked when pathogens are suspected in the water. Boiling water for ten minutes or more has a very strong likelihood of killing or disabling most pathogenic organisms. However, boiling water containing some pathogens may not be advisable because it may result in carrying them into the air through steam without destroying them. Boiling may also decompose many toxic chemical species but has no effect on radioactive materials.

A boil water notice can be provided to the broadcast and print community media in relatively short time once the utility management has agreed upon issuing it, and can be made known to the public within a matter of hours or less. The impact of a boil water notice is relatively low. People can still use the water for nearly any purpose, and because the issuance of such notices is not very rare, the psychological impact and loss of confidence by the public is manageable.

Notices to not drink or not use water also can be issued quickly. These notices are much less often used and they may cause some loss of confidence in the system. Their impact on the user community would be moderate. Alternate sources of water particularly for drinking and sanitary purposes would have to be found if the notice were expected to be in effect for more than a day. Typical contamination event scenarios are likely to be two or three days in duration, so if boiling the water or other measures are not effective in countering the contaminant, alternate sources of water supply should be sought. A do-not-use notice would also affect the use of the contaminated water for fire fighting, unless specifically exempted.

If an explosive potential or toxic/infectious emanations from a wastewater collection system are identified, the area at risk should be closed off to vehicular and pedestrian traffic and the public notified to avoid the area. Such actions can be taken in a matter of hours or less and, in general, would be expected to have low impact on the community but a high impact on businesses in the closed area.

In principle, some contaminants can be countered by adding specific material to the water. Some pathogens can be killed by temporarily increasing the disinfectant residual. In any case, the additive must meet the following requirements:

- Significantly reduce the infectious or toxic potential
- Must not have, or create byproducts that have, a significant public health risk
- Be acquirable and storable for long times
- Able to be added to the contaminated portion of the water

Utilities for the most part, do not have the capability to identify such materials and leadership at the federal level is needed to make this an effective response option. The time needed to institute this option is moderate and the cost may be high.

For wastewater systems, contamination by volatiles in the collection system can be treated by forced venting, which would substantially reduce the explosive potential. Toxic or infectious materials can be mitigated through the addition of a higher concentration of disinfectant or by materials that counteract the toxin or pathogen. Again, this would require a moderate length of time to be implemented and its cost could be high.

In light of the range of possible responses, in general it will not prove worthwhile to install monitoring platforms using currently available instruments closer to the customer taps than the distance it takes flow to travel two hours.

## Interfacing with Existing Surveillance Systems (Section 8)

The Clean Water Act (CWA) gives EPA (and delegated states, territories, and tribes) responsibility for implementing programs to protect and restore water quality of natural waters (both surface and groundwater) in the United States, including monitoring and assessing the nation's waters and reporting on their quality. The Safe Drinking Water Act (SDWA) provides for protection of drinking water quality, including the establishment of primary and secondary water quality standards for treated water. In addition to the federal standards established by EPA, delegated states have the option of implementing more stringent standards.

To meet these regulations, water supply systems conduct surveillance programs based on taking water samples at specific locations and testing them in a laboratory to determine the level of specific contaminants. The number of regulated contaminants in drinking water is very large—over 90—and likely to grow. Regulated contaminants include pathogens, toxic chemicals, and radioactive nuclides. The list includes many contaminants that are unlikely to be involved in short-term, intense contamination events, but may have long-term consequences through chronic exposure.

In these programs, samples are taken from a relatively small number of locations, which can vary from time to time, on a schedule of relatively infrequent sampling. For contamination events that may last only a few days, the grab sample process is likely to miss the events. That is, this type of program has a very low potential for detecting such contamination events. The samples are handled to preserve their in situ properties and to protect the sample grabbing personnel from exposure to potentially harmful contaminants. The samples are then sent to a laboratory that may be within the utility or may be run by an outside organization. The laboratory studies are performed on high quality, often state-of-the-art instruments and the results are generally highly accurate and reliable. The process

generally incurs a time delay on the order of days or weeks from the time of the sample to the return of results from the laboratory. In emergency situations, some labs can provide analyses within 24 hours. The process is labor intensive and moderately costly when the initial investment in laboratory equipment and the personnel costs are taken into account.

The OCMS will operate nearly continuously so it should be active during any significant contamination event. The monitoring instruments will be installed at relatively permanent locations; but there may be many of them. Most utilities do operate limited OCMS-style systems today. Continuous monitoring for flow, pH, turbidity, chlorine, fluoride, and many more parameters is routine within the plant operation. Therefore there is a nucleus to develop for use in OCMSs. Unfortunately, because at this stage in the development of instrumentation the presence and properties of contamination must be inferred from changes in surrogate measures, the sensitivity and accuracy with which the contamination event can be described is questionable. The initial cost of a full scale OCMS is high, but because it is technology intensive, the operational costs may be less than for the grab sample system.

Both the OCMS and the grab sample system are focused on water quality. The OCMS is used to detect significant contamination events and provide an appropriate alarm; the grab sample system ensures that the water system meets regulatory requirements that are focused mainly on long-term chronic exposure to specific contaminants.

In establishing an OCMS, one question is its relation to the existing surveillance and monitoring system. From a management perspective, it would be best to have the two systems functioning in cooperation rather than in competition. This suggests that they should both be in the same organization. Because the skill sets required for each system are somewhat different, there may be limited opportunities to share staff. If the utility operates its own in-house laboratory facilities, there may be some commonalities in personnel who maintain the instruments. Likewise, field trained sample takers could be used for some housekeeping functions for the OCMS.

## Operations, Maintenance, Upgrades and Exercise of the System (Section 9)

This section provides a set of practical operating guidelines for OCMS. It addresses questions of maintenance, spare parts, housekeeping, upgrading the system, and exercising the system.

Key recommendations in this section include these:

- The monitoring system should be designed for minimal downtime for repair and routine maintenance—replacement of limited life components, replenishment of reagents, and calibration. A target for average up-time should be at least 99.9 percent.
- If a monitoring system is off-line for more than 10 minutes, substantial amounts of toxic materials could flow past a site without detection. Consider the consequences if the monitored site is one of the primary transmission mains in the distribution system. That implies a Mean Time Offline of not more than 10 minutes.

- Security monitors must not be allowed to run until they break; preventative maintenance procedures should be considered mandatory. Scheduled maintenance will be essential for such systems, and the operations staff must plan for maintenance regardless of the size of the installation.
- Scheduled downtime should be not more than 30 minutes. In order to minimize downtime, substitute components should be hot swapped for the one under maintenance. The implications of being off-line for more than 30 minutes should indicate that maintenance procedures should be reconfigured so that time off-line is minimized. Consideration should be given to having redundant systems so that little or no down-time is needed.
- Consideration should be given to scheduling maintenance at random times rather than in a predictable pattern that might facilitate planning by attackers.
- One alternative to using in-house scheduled maintenance is to contract with an external service company. Only service companies with technicians trained by the manufacturer should be considered for contract services. This may be advantageous depending on the size and resources of the system, but introduces complications with security.
- It would be useful if a monitor had Built In Test Equipment (BITE) to enable online testing. BITE or diagnostic information is beneficial because it can decrease the time spent in troubleshooting a failed piece of equipment.
- Instruments should have built-in self-diagnostics to assist maintenance personnel in identifying the probable cause of instrument malfunction.
- Instruments should have predictive diagnostics that can estimate time for service or remaining sensor life so that system down time can be minimized, or scheduled at times of low use.
- Whatever hardware and software are selected, it should be designed to use commonly available hardware and software interfaces so that it is compatible with typical HMI (SCADA) systems. System manufacturers must be able to accommodate data transmission over one of the commonly used "BUS" methods (MODBUS, PROFIBUS, etc.).
- An assessment of supply needs must be done to ensure that supplies and expendables are available on a timely basis. Stocking some supplies at the measuring site may be necessary.
- It is prudent for the utility to stock a two-month inventory of spare parts and limited life components (such as, lamps, replacement electrode elements, analytical reagents) to effect repair of the instruments for normal maintenance and calibration procedures.
- Depending on the system design, it may be prudent to stock spares for items that have long procurement lead times. For certain critical monitoring sites it may be prudent to install instruments in replicate or have complete replacement elements of the monitoring system available.
- At minimum, crews of at least two persons should be trained for system operation and maintenance. Having two crews will allow at least one crew to be on call at all times. The total

number of crews trained should be the number necessary to respond to all system maintenance needs in any part of the OCMS within 2 hours.

- Utility personnel assigned to operation and maintenance of the monitoring systems will be senior employees of the utility with a proven track record of reliability (including trustworthiness, attendance record, interpersonal problems, etc.).
- It may also be prudent to require security clearances for manufacturers' service personnel.
- Any monitoring system should report, or be polled, on a frequent basis to assure that it is still there and functioning.
- Monitoring system hardware and software should be designed under the assumption that the system will be attacked and should be able to recognize and report the condition. If data transmission is interrupted for any reason, the monitoring system should include local data logging to permit onsite access, download, and analysis of data if necessary.
- Operators will need to be trained on the monitoring equipment and its emergency replacement (such as portable analytical instruments or grab sample programs).
- It is prudent and cost-effective to standardize as much as possible using a single manufacturer's equipment to minimize training needs and to make supply and parts inventory as simple as possible.
- Instrumentation placed into the water system must be rugged, require little operator intervention, and be reliable. It must also be easy to install, service, and use.
- In the interests of security, personnel should follow procedures that will not compromise system operation or reporting.
- During maintenance or repair procedures, the maintenance personnel will notify a central control manager of the off-line status of the system, and the system should be capable of providing automatic notification at the time it is taken offline for maintenance.
- If a system will be off-line for any significant length of time, the maintenance staff should notify critical personnel of the system status and implement grab sampling at a frequency established by the utility (based on the current knowledge or suspected threats to the system and/or the area being monitored by the analytical instrumentation).
- To the extent possible, when new designs become available, they must be backward compatible with existing instrumentation including communications protocols and software interfaces.
- Just as with hardware, it is assumed that software will advance and the system will benefit from software upgrades. If the software has information in the form of agent libraries, decontamination procedures, or treatment, such libraries could be upgraded much like computer anti-virus software.
- To maintain an effective level of readiness, it will be important to exercise the system and, in the process, maintain the training level of utility personnel. There are several ways to exercise an OCMS:

- The use of tabletop simulations.
- The use of benign contaminants. This could be used for testing most parts of the system as well as the organization's response. That is, the utility would inject a substance (compliant with NSF-61) into the water supply or the wastewater system that causes one or more of the instruments (or perhaps a separate instrument not part of the system) to register a change that would be interpreted as a contaminant event.
- Exercising a single or multiple parts of the system. For example, one set of sensors could be focused on a test chamber in which a known contaminant has been placed. The signals coming from those instruments would then be fed to the data analysis center and should cause an alarm to be generated, or the data analysis system could be isolated and tested using simulated data from a set of instruments. Also, the communications system could be tested by an attempted hacking or by observing the fidelity and reliability of its transmissions under a given set of circumstances.

# Glossary

**Activated Sludge Process:** A biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation and wasted or returned to the process as needed.

**Agent:** Any physical, chemical, or biological entity that can be harmful to an organism.

**Aliquot:** A measured portion of a sample taken for analysis.

**AMSA:** Association of Metropolitan Sewer Agencies

**AMWA:** Association of Metropolitan Water Agencies

**ASCE:** American Society of Civil Engineers

**ATSDR:** Agency for Toxic Substances and Disease Registry

**AWWA:** American Water Works Association

**AWWARF:** American Water Works Association Research Foundation.

**Backflow/Back Siphonage:** A reverse flow condition created by a difference in water pressures that causes water to flow back into the distribution pipes of a drinking water supply from any source other than the intended one.

**Bacteria:** Singular: bacterium. Microscopic living organisms usually consisting of a single cell. Bacteria can aid in pollution control by consuming or breaking down organic matter in sewage, or by similarly acting on oil spills or other water pollutants. Some bacteria in soil, water, or air may also cause disease in humans, animals, or plants.

**BASIS:** Biological Aerosol Sentry and Information System

**Biological Contaminants:** Living organisms or derivatives (for example, viruses, bacteria, fungi, and mammal and bird antigens) that can cause harmful health effects when inhaled, swallowed, or otherwise taken into the body.

**Biochemical Oxygen Demand (BOD):** An indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic waste.

**Biomonitoring:** The use of living organisms to test for water quality including the quality of water supplies, and the suitability of effluents for discharge into receiving waters downstream.

**BITE:** Built-in Test Equipment

**Bolus**: A single, relatively large quantity of a substance, in this case a contaminant.

**Chemical Abstracts Service (CAS) Registration Number:** A number assigned by the Chemical Abstracts Service to identify a chemical.

**CDC**: Centers for Disease Control and Prevention

**Check Valve:** A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flow.

**Chemical Oxygen Demand (COD):** An indirect measure of the amount of oxygen used by inorganic and organic matter in water. The measure is a laboratory test based on a chemical oxidant and therefore does not necessarily correlate with biochemical oxygen demand. A measure of the oxygen required to oxidize all compounds, both organic and inorganic, in water.

**Chlorine Demand:** The difference between the amount of chlorine added to water and the amount of remaining residual chlorine in the water after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water. Chlorine Demand in milligrams per Liter (mg/L) = Chlorine Applied in mg/L – Residual in mg/L

**Chronic Exposure:** Multiple exposures occurring over an extended period of time or over a significant fraction of an animal or human lifetime. A lifetime is usually defined as 7 years.

**Chronic Toxicity:** The capacity of a substance to cause long-term poisonous health effects in humans, animals, fish, and other organisms.

**Clarification:** Clearing action that occurs during wastewater treatment when solids settle out. This is often aided by centrifugal action and chemically induced coagulation in wastewater.

**Clarifier:** A tank in which solids settle to the bottom and are subsequently removed as sludge. A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom. Clarifiers are also called settling basins and sedimentation basins.

**Combined Sewers:** A sewer system that carries both sewage and stormwater runoff. Normally, its entire flow goes to a wastewater treatment plant, but during a heavy storm the volume of water may be so great as to cause overflows of untreated mixtures of stormwater and sewage into receiving waters. Stormwater runoff may also carry toxic chemicals from industrial areas or roads into the sewer system.

**Community Water System:** A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. Contrast with non-community water system, transient water system and non-transient non-community water system.

**Compliance Monitoring:** Collection and evaluation of data, including self-monitoring reports, and verification to show whether pollutant concentrations and loads in water supply and contained in permitted discharges are in compliance with the limits and conditions specified in regulations and permits.

**Conductivity:** A measure of the ability of a solution to carry an electrical current.

**Contaminant:** Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

**Contamination:** Introduction of microorganisms, chemicals, toxic substances, wastes, or wastewater into water, air, and soil in a concentration that makes the medium unfit for its next intended use.

**Cooperative Agreement:** An assistance agreement whereby EPA transfers money, property, services, or anything of value to a state, university, non-profit, or not-for-profit organization for the accomplishment of authorized activities or tasks.

**CWA:** Clean Water Act

**Dechlorination:** Removal of chlorine from a substance.

**Decomposition:** The breakdown of matter by bacteria and fungi, changing the chemical makeup and physical appearance of materials.

**Decontamination:** Removal of harmful substances such as noxious chemicals, harmful bacteria or other organisms, or radioactive material from the water environment.

**Diffusion:** A microscopic process that results in the movement of suspended or dissolved particles (or molecules) from a more concentrated to a less concentrated region. The process tends to distribute the particles or molecules more uniformly.

**Disinfectant:** Any oxidant, including but not limited to, chlorine, chlorine dioxide, chloramines, and ozone, that is added to water in any part of the treatment or distribution process and is intended to kill or inactivate pathogenic microorganisms.

**Dissolved Organic Carbon (DOC):** All the organic carbon present in water that passes through a 0.2 millimeter (mm) filter. It is a mixture of simple substances such as sugars, fatty acids and alkanes, and of complex polymeric molecules. These have a wide range of molecular weights and are often referred to as "humic-acids." They can be present as truly dissolved molecules, as colloids or as viruses.

**Dissolved Oxygen (DO):** The oxygen freely available in water that is vital to fish, other aquatic life, and the prevention of odors. DO levels are considered an important indicator of a water body's ability to support desirable aquatic life. Secondary and advanced waste treatment are generally designed to ensure adequate DO in waste-receiving waters.

**Dosage/Dose:** The actual quantity of a chemical or pathogen administered to an organism or the quantity to which it is exposed.

**Dose Response:** Shifts in toxicological responses of an individual (such as alterations in severity) or populations (such as alterations in incidence) that are related to changes in the dose of any given substance.

**Dose Response Curve:** Graphical representation of the relationship between the dose of a stressor and the biological response thereto.

**Effluent:** a) A liquid which flows out of a containing space. b) Wastewater or other liquid, partially or completely treated, or in its natural state flowing out of a reservoir, basin, treatment plant, or industrial treatment plant, or part thereof. c) An outflowing branch of a main stream or lake.

**Environmental Technology Verification (ETV)**: EPA's Environmental Technology Verification Program

**EPA:** United States Environmental Protection Agency

**EPS:** extended-period simulation

**ERP:** emergency response plan

**Exercising**: This refers to running the monitoring system under defined conditions to provide a training platform for system operators and decisionmakers, testing of the integrity, functionality, and readiness of the system, and c development of new or revised operational policies and plans to meet new contingencies.

**FCC**: Federal Communications Commission

**FDA:** United States Food and Drug Administration

**Filtration:** A treatment process, under the control of qualified operators, for removing solid (particulate) matter from water by means of porous media such as sand or a man-made filter; often used to remove particles that contain pathogens.

**Finished Water:** Water is "finished" when it has passed through all the processes in a water treatment plant and is ready to be delivered to consumers.

**Flocculation:** Process by which clumps of solids in water or sewage aggregate through biological or chemical action so they can be separated from water or sewage.

**Free Available Residual Chlorine:** That portion of the total available residual chlorine composed of dissolved chlorine gas cl2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

**Fungi:** A group of organisms lacking in chlorophyll (that are not photosynthetic) such as molds, mildews, yeasts, mushrooms, and puffballs that are usually non-mobile, filamentous, and multicellular. Some grow in soil, others attach themselves to decaying trees and other plants from which they obtain nutrients. Some are pathogens.

**GIS:** Geographic Information System

**Grab sample:** A single sample, collected at a particular time and place, which represents the composition of the water at that specific time and place.

**Groundwater:** The supply of fresh water found beneath the Earth's surface, usually in aquifers, that supplies wells and springs. Because groundwater is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants or leaking underground storage tanks.

**Half-Life:** a) The time required for a pollutant to lose one-half of its original concentration(or example, the biochemical half-life of dichlorodiphenyltrichloroethane [DDT] in the environment is 15 years). b) The time required for half of the atoms of a radioactive element to undergo self-

transmutation or decay (for example, half-life of radium is 1620 years). c) The time required for the elimination of half a total dose of a pollutant from the body.

**Hazard:** a) Potential for radiation, a chemical or other pollutant to cause human illness or injury. b) In the pesticide program, the inherent toxicity of a compound. Hazard identification of a given substances is an informed judgment based on verifiable toxicity data from animal models or human studies.

**Hazard Assessment:** Evaluating the effects of a stressor or determining a margin of safety for an organism by comparing the concentration that causes toxic effects with an estimate of exposure to the organism.

**HSPD:** Homeland Security Presidential Directives

**Hydrolysis:** A chemical reaction in which one compound is converted into another compound by taking up water.

**Hypochlorite:** Chemical compounds containing available chlorine; used for disinfection. They are available as liquids (bleach) or solids (powder, granules and pellets). Salts of hypochlorous acid.

**IC:** inorganic carbon

**In Situ Flushing:** Introduction of large volumes of water, at times supplemented with cleaning compounds, into soil, waste, or groundwater to flush hazardous contaminants from a site.

**ICS:** Incident Command System

**ISAC:** Information Sharing and Analysis Center

**kg:** kilogram

**L:** Liter

**Large Water System:** A water system that serves more than 50,000 customers.

**LD50/Lethal Dose:** The dose of a toxicant or microbe that will kill 50 percent of test organisms within a designated period. The lower the LD50, the more toxic the compound.

**LEL:** lower explosive limit

**Leachate:** Water that collects contaminants as it trickles through wastes, pesticides or fertilizers. Leaching may occur in farming areas, feedlots, or landfills, and may result in hazardous substances entering surface water, groundwater, or soil.

**LFL:** lower flammable limit

**Lift:** In a sanitary landfill, a compacted layer of solid waste and the top layer of cover material.

**Lowest Observed Adverse Effect Level (LOAEL):** The lowest level of a stressor that causes statistically and biologically significant differences in test samples as compared to other samples not subjected to stressors.

**M&C Sub Committee**: The Methodology and Characteristics Sub Committee of the Water Infrastructure Security Enhancements Standards Committee.

**MALS:** Multi-angle light scattering

**Maximum Contaminant Level (MCL):** The maximum permissible level of a contaminant in water that is delivered to the free flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system. Contaminants added to the water under circumstances controlled by the user are excluded from this definition, except those contaminants resulting from the corrosion of piping and plumbing caused by water quality. MCLs are enforceable standards.

**Maximum Contaminant Level Goal (MCLG):** Under the Safe Drinking Water Act, a non-enforceable concentration of a drinking water contaminant, set at the level at which no known or anticipated adverse effects on human health occur and which allows an adequate safety margin. The MCLG is usually the starting point for determining the regulated MCL.

**mg:** milligram

**NaI:** Sodium iodine

**NIST:** National Institute of Standards and Technology, an organization within the US Department of Commerce

**No Observable Adverse Effect Level (NOAEL):** An exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered as adverse, or precursors to adverse effects. In an experiment with several NOAELs, the regulatory focus is primarily on the highest one, leading to the common usage of the term NOAEL as the highest exposure without adverse effects. NOAEL considers the structure and function of the entire exposed organism and does not focus on any one subsystem unless so specified.

**NPDES:** National Pollutant Discharge Elimination System

**NRL:** Naval Research Laboratory

**NRP:** National Response Plan

**NTU:** Nephelometric Turbidity Units

**Nuclide:** An atom, characterized by the number of protons, neutrons, and energy in the nucleus.

**OCMS:** Online contaminant monitoring system.

**Oxidation-Reduction Potential (ORP):** The electric potential required to transfer electrons from one compound or element (the oxidant) to another compound (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

**Pathogens:** Microorganisms (for example, bacteria, viruses, or parasites) that can cause disease in humans, animals, and plants.

**pH:** An expression of the intensity of the basic or acid condition of a liquid; may range from 0 to 14, where 0 is the most acidic and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5.

**Population At Risk**: A population subgroup that is more likely to be exposed to a chemical, or more sensitive to a contaminant, than the general population.

**ppb:** parts per billion

**ppm:** parts per million

**Pressure Sewers:** A system of pipes in which wastewater or other liquid is pumped to a higher elevation.

**Protozoa:** One-celled animals that are larger and more complex than bacteria. May cause disease.

**Public Network**: The publicly available communications system based on the hard wired telephone system, but also including the Internet.

**Radioactive Decay:** Spontaneous change in an atom by emission of charged particles and/or gamma rays; also known as radioactive disintegration and radioactivity.

**Radionuclide:** Radioactive particle, man-made (anthropogenic) or natural, with a distinct atomic weight number. Can have a long life as a soil or water pollutant.

**RAM-W™:** Risk Assessment Methodology-Water

**Receiving Water:** A river, lake, ocean, stream, or other watercourse into which treated wastewater effluent, stormwater, or combined sewer flow may be discharged.

**Residual Chlorine:** The amount of free and/or available chlorine remaining after a given contact time under specified conditions.

**RPTB:** Response Protocol Tool Box

**Risk Assessment:** Qualitative and quantitative evaluation of the risk posed to human health and/or the environment and/or the achievement of an entity's goals and objectives by the actual or potential presence and/or use of a threatening agent.

**Risk Characterization:** The last phase of the risk assessment process that evaluates any uncertainty and estimates the potential for adverse health, ecological, or other effects to occur from exposure to a stressor.

**Risk Management:** The process of evaluating and selecting alternative regulatory and non-regulatory responses to mitigate or transfer risk. The selection process necessarily requires the consideration of legal, economic, and behavioral factors as well as engineering, environmental, physical, and cyber factors.

**Run-Off:** That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

**SDWA:** Safe Drinking Water Act

**Satellite Communications System:** A communications system for transporting data from monitoring platforms to data analysis center by transmitting to an earth-orbiting satellite which relays the data to a ground station and then to the system receiver. Communications through satellites can be jammed, interfered with, and intercepted. Therefore, special precautions should be taken to safeguard sensitive data and to ensure critical communications links.

**Supervisory Control and Data Acquisition (SCADA):** The system that provides automatic or semi-automatic sensing of key parameters and control of key elements of the water system. It generally provides for communications, notifications, and alarms, as well as for manual over-ride of controls.

**Sedimentation:** Letting solids settle out of wastewater by gravity during treatment.

**Sewer**: An underground system of conduits (pipes and/or tunnels) that collect and convey wastewater and/or runoff; gravity sewers carry free-flowing water and wastes; pressurized (force main) sewers carry pumped wastewaters under pressure.

**Slurry:** A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

**Spore:** The reproductive body of an organism which is capable of giving rise to a new organism either directly or indirectly. A viable (able to live and grow) body regarded as the resting stage of an organism. A spore is usually more resistant to disinfectants and heat than most organisms.

**Surrogate Parameters**: Properties of water that can be measured with existing instrumentation from which the presence and perhaps properties of contaminants can be inferred.

**Surveillance System**: The system of monitoring water quality to meet regulatory requirements. Normally, surveillance comprises the taking of samples from defined locations at specific times and intervals and a thorough characterization of the samples as to the presence and amount of named contaminants.

**TEVA:** Threat Ensemble Vulnerability Assessment. This is the name of a current EPA research effort aimed at developing a new vulnerability assessment methodology better suited to the problem of contamination of water supply systems.

**TOC:** total organic carbon

**Toxicity:** The degree to which a substance or mixture of substances can harm humans or animals. *Acute toxicity* involves harmful effects in an organism through a single or short-term exposure. *Chronic toxicity* is the ability of a substance or mixture of substances to cause harmful effects over an extended period, usually upon repeated or continuous exposure sometimes lasting for the entire life of the exposed organism. *Subchronic toxicity* is the ability of the substance to cause effects for more than one year but less than the lifetime of the exposed organism.

**UV:** ultraviolet

**Uncertainty Factor:** One of several factors used in calculating the reference dose from experimental data. Uncertainty factors are intended to account for a) the variation in sensitivity among humans; b) the uncertainty in extrapolating animal data to humans; c) the uncertainty in extrapolating data

obtained in a study that covers less than the full life of the exposed animal or human; and d)the uncertainty in using LOAEL data rather than NOAEL data.

**VOC:** volatile organic compounds

**Wastewater**: The used water and solids from a community (including used water from industrial processes and domestic uses) that flow to a wastewater treatment plant. Stormwater, surface water, and groundwater may also may be included in the wastewater that enters wastewater treatment plant.

**WEF:** Water Environment Federation

**Water Solubility:** The maximum concentration of a chemical compound, which can result when it is dissolved in water. If a substance is water soluble, it can very readily disperse through the environment.

**Wastewater Treatment Plant (WWTP):** A facility that receives wastewater (and sometimes runoff) from domestic and/or industrial sources, and by a combination of physical, chemical, and biological processes, reduces (treats) the wastewater to less harmful byproducts; known also by the acronyms STP (sewage treatment plant) and POTW (publicly owned treatment works).

**Water Infrastructure Community:** The collection of utilities (and their owners and operators), trade associations, professional societies, manufacturers, engineers, consultants, educators, and researchers who are professionally concerned with the delivery of potable water and disposal of wastewater.

**Wide Area Network**: A network that spans a relatively large geographical area. Typically, a WAN consists of two or more local-area networks (LANs). Elements connected to a wide-area network are often connected through public networks, such as the telephone system. They can also be connected through private networks or satellites. The largest WAN in existence is the Internet.

**WISE-SC:** Water Infrastructure Security Enhancements Standards Committee

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SECTION 1

# The Contamination Problem

This section provides a brief summary of the elements of the contamination problem. It is not an in-depth discussion and is meant only to provide an appropriate context for the discussion of online monitoring.

## 1.1 Water Supply

Contamination of water supply systems has been a problem for as long as such systems have existed. In ancient times, intentional contamination of wells and other water supplies was an accepted tactic in warfare. Today, the intense concern over terrorism has led to serious examination of water system vulnerabilities and steps toward their mitigation.[7] However, the contamination problem goes beyond terrorist actions. Other intentional contamination events have been threatened or perpetrated by vandals and extortionists. There have also been a number of hoaxes claiming water contamination. Also, accidental or negligent contamination, particularly through back flow of water contamination from user facilities or through infiltration of sewage through breaks in pipes, has occurred with disturbing frequency.

Water supply systems include source waters that may be either or both groundwater (for example, aquifers) and surface water (for example, reservoirs, lakes, rivers). Groundwater systems differ from surface water systems in several important ways. In surface water systems, raw water is transported to the treatment facility by aqueducts, which may be open or closed, or closed conduits running on the surface or below. Many medium and large systems have multiple treatment plants. Treatment of water consists in general of flocculation and filtration to get rid of solid matter and particulates that are frequent elements of debris in surface waters, followed by disinfection by gaseous chlorine, hypochlorites, chloramines, ozonation, or exposure to ultraviolet light (among other possible techniques) for destroying pathogens and potentially decomposing certain organic molecules.

In groundwater systems, dissolved minerals and salts and potential chemical and biological contaminants must be removed. Large debris is generally not a problem. There are two main treatment techniques for inorganics in groundwater. The first technique is in situ, or treatment within the ground, and the second is ex situ, or treatment after removing the groundwater from the ground.

The in situ treatment technique involves leaving the groundwater in place within the aquifer and adding reagents to the aquifer. The reagents react with the inorganic contaminants within the aquifer, lowering the contaminants to acceptable levels. In situ treatment is more aesthetically pleasing than ex-situ because it does not require large above-ground treatment systems. The costs of treating groundwater this way are variable. They depend on the contaminant constituents, control agents, hydrogeology of the aquifer, geospatial extent of the pollution, and the physical accessibility to the site. There are two main approaches to treating groundwater in situ: chemical detoxification and

[7] See: Critical Foundations: The Report of the President's Commission on Critical infrastructure protection, October 1997; PP A-44 et seq.

permeable treatment beds. Chemical detoxification uses the same process of neutralization and oxidation/reduction as mentioned above, as well as using natural degradation promoters. The neutralization and oxidation/reduction reagents are either injected through a series of wells installed at the head of the contamination plume or within the plume itself. In the case where the contamination is entering the groundwater by migration through the soil, the reagents can be applied directly to the soil. The reagents will then react with the contaminants in the soil and eventually reach the groundwater and treat it too. The main limitation to this method is that it can only be used where specific information about the contamination is known.

Permeable treatment beds involve excavating a trench through the aquifer, beyond the contamination plume, and filling the trench with a reactive medium. This treatment method is strictly limited to shallow aquifers. The theory behind permeable treatment beds is that the contamination plume travels up to and through the reactive medium. The contaminated water is treated as it flows through, and exits from the reactive medium cleaned. Many reagents can be used within the trench, depending on the contaminant removal level that one wants to achieve. Limestone is often placed within the bed to neutralize acid and precipitate heavy metals. Zeolite and synthetic ion exchange resins can also be placed within the bed to remove solubilized heavy metals. The trench must be constructed down to an impermeable layer or bedrock, and is effective for only a short time. There are some disadvantages to using permeable treatment beds.

- Plugging of the bed may divert contaminated groundwater.
- Contaminated groundwater may form a channel through the bed.
- Pollutant may be displaced if treatment chemicals are injected at a higher hydraulic head.
- Treatment chemicals may react with other waste constituents making more hazardous compounds.

The most common method of removing the groundwater for ex situ treatment is by pumping. The water, once removed, is treated in an above ground treatment plant similar to the one used in treating landfill leachate. The most common methods used to remove inorganics from the groundwater include:

- Reverse osmosis
- Neutralization
- Precipitation/flocculation/sedimentation
- Ion exchange
- Oxidation/reduction

Treated water from either ground or surface sources is then distributed to the system's users through the distribution system. An important part of the distribution system is its facilities for short-term storage of finished water. This allows capacity in the system for meeting peak water demands. They may be water towers (with capacities generally below one million gallons) or water reservoirs with capacities generally in millions to tens of millions of gallons). Many larger systems have the ability to add disinfectant to the water at several locations beyond the main treatment plant. Water is delivered

under pressure to a wide range of users that may include residences, businesses, industry, agricultural users, hydrants for firefighting, and facilities that serve persons who might be particularly susceptible to contaminated water such as schools, nursing homes, and hospitals.

The introduction of contamination is possible at nearly every stage in the treatment and distribution process, although some stages are more accessible and susceptible to intrusion than others. The source waters are generally large so that effective contamination at that stage requires considerable amounts of material. Some sources are navigable waterways upon which certain hazardous or toxic materials are shipped. Accidental or purposeful spills of these materials could significantly contaminate such a water supply.

Conveying raw water from the sources to treatment generally occurs over large distances and in unpopulated areas. Contaminants may be inserted at various points along the transport path, particularly if the aqueducts are open or the conduits above ground and easily accessible.

Treatment plants are generally in populated areas and frequently have fences and guards. Other intrusion detection and protection techniques are frequently employed as well. Nevertheless, the treatment plant is a point of vulnerability, particularly for an attack by an insider.

The distribution system is now generally acknowledged to be the most vulnerable segment of most water supply systems.[8] It is a complex system that underlies the entire served community. In general, the community water supply also supports fire fighting by delivering water under pressure to fire hydrants. These hydrants are among the many points in a typical distribution system where contaminants can be inserted. Of course, the further into the distribution system the insertion point is, the smaller the affected user community will be. Correspondingly, the less contaminant will be required. Contaminants can even be inserted at a customer tap under pressure so as to be moved back upstream and thereby contaminate the water for a somewhat larger group of customers.

## 1.1.1 Contamination Scenarios (Water Supply)

The following discussion probes some of the more important aspects of how a contaminant may enter the system. One could, as has been suggested by one reviewer, merely refer to the fact that there have been accounts of terrorist interest in and activities related to water system contamination reported in the open press.[9] This would serve to alert utilities to the reality of the threat. However, the authors believe that providing a somewhat more detailed discussion would assist in the later process of developing detailed guidance related to the design of an OCMS. Such discussion might also prove useful in the development of physical security enhancements designed to reduce the threat from contamination by reducing or impeding access to vulnerable points.

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[8] DRINKING WATER: Experts' Views on How Future Federal Funding Can Best Be Spent to Improve Security; GAO 04-29, October, 2003

[9] cf. Carl Cameron, Fox News July 30, 2002: http://www.foxnews.com/story/0,2933,59055,00.html; Associated Press, May 29, 2003: http://www.foxnews.com/story/0,2933,88100,00.html: US Filter News Nov 12, 2003: http://www.wqpmag.com/wqp/index.cfm/powergrid/rfah=%7Ccfap=/CFID/876822/CFTOKEN/89069973/fuseaction/showNewsItem/newsItemID/6056.

There are many different ways in which contamination may enter the drinking water supply system—some purposeful and some accidental. For example, contaminants can be dumped into finished water storage tanks, they can be injected into pipes under pressure through a bleeder valve, they can be forced upstream under pressure from any tap or fire hydrant[10]. The salient characteristics of a contamination scenario include: a) the particular contaminant species, b) the amount of contaminant inserted, c) the location of the insertion, and d) the rate at which or method by which it is inserted. The result of a contaminant insertion is a contaminant "pulse" whose duration and concentration profile vary with the insertion scenario and the properties of the water system.

Accidental contamination can occur through inadvertent spills of contaminant into the source waters (for example, from a barge on a navigable water way that also serves as the source for drinking water or from runoff or leaching of contaminant from lands near the source waters) or from effluent discharge upstream of a water supply abstraction point. It can also occur through breaks in pipes or leaks in tanks that are either underground or above ground. This is particularly important where leaking sewage lines are proximate to leaking water supply pipes. Contaminant may leak from buried storage containers and permeate the groundwater[11]. Another important source of accidental contamination is backflow from customer sites at which contaminated water at pressure higher than that in the delivery pipes (even for only brief times) can force contaminants upstream so as to affect a broader range of the distribution system.[12]

Intentional contamination can occur at a wide range of locations. Virtually any part of the system to which an attacker can gain access is a potential insertion site. Of course, some sites are more vulnerable than others. Among the most easily accessed sites in most water supply systems are: the source waters; many portions of the distribution system such as finished water storage facilities; some pipes, valves and pumps; and terminal appurtenances such as fire hydrants, backflow check valves and customer taps. While treatment plants are generally more difficult for an outside attacker to penetrate, a compromised insider could relatively easily attack there.

Contaminant added to a finished water reservoir or tank some distance from the outlet pipe will mix with the waters in the reservoir as water is drawn into and withdrawn from the facility.[13] The water drawn from the contaminated storage facility will then contain a concentration of contaminant that is determined by the location of the insertion and the hydrodynamics of the storage facility and will be a function of time. The resultant duration of the contaminant pulse will be longer than the insertion pulse by about the average water residence time in the tank/reservoir. This is typically on the order of two to four days in storage facilities that are properly configured and operated but can be much longer in many storage facilities. In other words, adding a contaminant to water storage would generally be expected to result in a contamination event lasting several days with contaminant

[10] Drinking Supply: Terrorists had eyes on water: Las Vegas Review-Journal Aug 12, 2004: http://www.reviewjournal.com/lvrj_home/2004/Aug-12-Thu-2004/news/24519286.html

[11] See for example, API Soil & Groundwater Research Bulletin, March 1998 (MTBE)

[12] See for a partial listing of backflow events of note: http://www.classicbackflow.com/incidents.html.

[13] Many water supply utilities still operate storage facilities with inadequate water exchange even though insufficient turnover of water in storage facilities can lead to stagnant water and serious problems with public health impacts. In such facilities, there may be very poor mixing and it is difficult to predict the "pulse" characteristics of the resultant contamination event.

concentration reaching a maximum somewhere in the mid-range of that time. This would be the case whether the contaminant is added quickly—in minutes—or over an extended period of many hours. If the contaminant is added over much longer times (for example, in the form of a dissolving matrix where the dissolution takes many days), that time factor could play the dominant role in the duration of the event.

Insertion of contaminant into distribution system pipes would likely produce a contaminant pulse that follows more closely the shape of the injection pulse. The edges would be somewhat modified by mixing and dispersion.[14]

Contamination of water supplies can directly bring about death or illness among the consuming public. The utility will also experience direct effects in that it will be unable to sell contaminated water, it may have to provide a level of decontamination of any water diverted away from the supply into the environment, and it may face the need to replace or clean up the contaminated portion of the system. Customers, particularly business, industrial, and agricultural customers, would likely face economic losses in using contaminated water. In addition, the utility may face legal liabilities in connection with damages resulting from the contaminated water and may experience loss of confidence by the public in the utility's ability to deliver potable water, support by the community, as well as criticism in the corporate audit process. There is the further danger that with a loss in confidence in the quality of water supply, consumers may seek water from other, perhaps unsafe sources, thus increasing the public health impact.

## 1.2 Wastewater/Stormwater

The wastewater system typically includes sewers, which collect and convey domestic and industrial wastewater to municipal wastewater treatment plants or facilities. Wastewater contains a variety of materials (both organic and inorganic in nature), including human waste, industrial wastewater, infiltration and inflow, and a wide range of chemicals and materials that are discarded into the system. Wastewater is conveyed to a treatment facility where the solids are removed and the wastewater is treated to produce an effluent that meets or exceeds limits on the concentrations of contaminants, which is summarized on the plant's discharge permit. Typically, a wastewater treatment plant consists of preliminary and primary treatment, which typically consists of screening and sedimentation for removal of large debris or objects. The water is then treated through a secondary biological treatment process to remove soluble organics. The final steps are removal of the biological solids and disinfection of the clarified effluent. The residual solids that are generated in both the primary and secondary treatment processes are further stabilized via digestion, and then the remaining solids are removed from the treatment plant as called for in its permit. Typical applications of the digested solids may include land application or land fills. The wastewater collection system is situated in the ground and consists of a network of gravity sewers, pump or lift stations, and force mains. Some communities combine their stormwater collection and disposal systems with their wastewater systems while others maintain them as separate systems. Because

[14] In theory, diffusion at the pulse boundary can also affect the contaminant concentration, but as a practical matter, given the flow rates and residence times involved, dispersion and mixing are much more dominant effects.

wastewater is inherently contaminated, it may seem an unlikely target for a contaminant attack. Nevertheless, there are contaminants that can wreak havoc in the wastewater and stormwater systems. For example, in 1981 Louisville, Kentucky suffered an explosion in the sewer system that ripped up more than two miles of street.[15] Apparently, it was caused by the accidental igniting of hexane fumes in the sewer. Thousands of gallons of hexane were illegally introduced into the wastewater collection system by a local industry and, it is thought, the fumes were ignited by a spark from a passing car. The explosion occurred early in the morning when the streets were nearly deserted and that may explain why there were no fatalities reported. A sewer explosion in Guadalajara, Mexico, in April 1992 killed 215 people, injured about 1,500 and damaged a number of buildings.[16] Some major cities in the United States have experienced sewer explosions that launched manhole covers many feet into the air. Such events happen a dozen times a year or more. Some of these cases involved the igniting of methane that is produced naturally in the decay of organic matter. Combined wastewater and stormwater systems allow easy entry of materials into the sewer system and may also allow direct venting of fumes or airborne pathogens to the street level, exposing pedestrians and motorists to significant risk.

## 1.2.1 Contamination Scenarios (Wastewater and Stormwater)

The effects of contaminants inserted at the treatment phase would be mainly environmental degradation and compromise of the biological breakdown of wastes in the process. Some contaminants are essentially untreatable in conventional wastewater plants or facilities. Wastewater contains a variety of materials (both organic and inorganic in nature), which includes human waste, industrial wastewater, infiltration and inflow, and a wide range of chemicals and materials that are discarded into the system by various manufacturers. Wastewater is conveyed to a treatment facility where the wastewater is treated to produce an effluent that meets or has less than the minimal concentrations of solids, BOD, as well as other constituents on the plants discharge permit. Typically, a wastewater treatment plant consists of preliminary and primary treatment, which typically consists of screening and sedimentation for removal of large debris, grit and other large objects that may damage downstream equipment or pumps. The wastewater is then treated through a secondary biological treatment process to remove soluble organics (BOD reduction). The final steps are clarification of the biological solids and disinfection of the clarified effluent. Some treatment plants also require tertiary treatment involving additional nutrient removal prior to discharging the effluent into the receiving streams. During the treatment of wastewater, sludge or residuals are produced. These residual solids are generated in both the primary and secondary treatment processes and are further stabilized via sludge digestion. The remaining solids after the digestion process are removed from the treatment plant to a level based on its permit. Typical applications of the digested solids may include land application or landfilling.

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[15] http://www.courier-journal.com/cjextra/2003projects/toxicair/0713/2wir-5-blast0622-7937.html

[16] http://www.corrosion-doctors.org/Localized/sewer.htm

Another possible location for the introduction of a contaminant is the wastewater or stormwater sewers. This may result in more severe and prompt local effects, depending on the type of contaminant used. Volatile contaminants could result in a potential for explosion as well as allowing volatile toxic materials to vent to pedestrian levels. Some pathogens that might also be introduced into the wastewater/sewer system could conceivably emerge into the air.

Significant points of vulnerability in wastewater collection systems are also found at lift stations. These are often readily identifiable to a trained eye and can be easily accessed through a locked hatch that is installed on the top of the lift station. The capital value for a lift station, which contains pumps valves, and piping, is much higher than a typical manhole or sewer. This in turn makes it a higher profile target, resulting in a higher risk for loss. A combination of contaminant insertion into the collection system and the subsequent failure of a downstream sewage lift station can surcharge the system, overflowing the contaminants from the system into areas where the public is vulnerable to exposure. Toxins inserted into surface drains that discharge to the receiving waters could contaminate water supply intakes that lie downstream in a river or small body of water.

The types of contamination events that could affect wastewater systems include:

- Disposal of byproducts from a decontamination event in the community (including decontamination of the drinking water itself as well as decontamination of persons and property following a chemical, biological or radiological incident).
- Discharge of contaminated drinking water into the wastewater system.
- Direct intentional contamination attack on the sewers or the wastewater treatment plant.
- Accidental discharge of contaminant into the sewers.
- A contamination event in the system's service area that could result in runoff of contaminant into the storm sewers.
- Disposal of byproducts from a decontamination event in the community (including decontamination of the drinking water itself and decontamination of persons and property following a chemical, biological, or radiological incident).
- A contamination event in the system's service area that could result in runoff of contaminant into the storm(or combined) sewers or infiltrating the system.
- When a wastewater process fails, the effluent may contain a high concentration of BOD and suspended solids due to the contaminant adversely effecting the wastewater treatment processes.

The concerns from such events include risks to health and safety of the general public and of utility workers; effects on wastewater treatment systems and their ability to adequately treat the wastewater and sludge; and possible environmental effects that arise from discharging contaminated effluent or utilizing contaminated sludge.

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SECTION 2

# Rationale for Online Monitoring and System Design Basics

Establishing and operating an OCMS can be an expensive proposition. It should be undertaken only if a) the benefits are expected to outweigh the costs and b) the system is needed to manage the risks of contamination.

## 2.1 Risk Reduction Alternatives

Contamination, whether accidental or purposeful, can jeopardize public health and safety and result in significant losses to the utility as well as to the served community. Completely and reliably preventing contaminants from entering a water system, except in a very few special circumstances, will not be possible. However, increasing physical security efforts could assist in mitigating the risks due to contamination by making it much more difficult for contaminants to be inserted into the system either accidentally or purposely. Measures as simple as using better locks, higher fences, surveillance cameras, etc., should be considered as techniques to reduce the risks due to contamination regardless of whether an OCMS is established.

Once all reasonable physical security enhancements are evaluated, the need for methods to detect and characterize a contaminant event can be assessed. The fundamental question to be answered in determining the need for contaminant detection of any kind is whether the potential costs resulting from a contamination event justify the costs of detection and whether the detection method results in an acceptable reduction in those potential contamination costs. Among the detection methods that should be considered, in addition to online contaminant monitoring, are: extensions or enhancements to the water or wastewater quality surveillance program already in use to meet regulatory requirements, and after the fact discovery from the medical and pharmaceutical community.

Contamination scenarios that result in relatively short but intense events, are likely to evade detection by a traditional grab-sample/laboratory analysis surveillance system unless it takes samples or measurements at key locations frequently enough to obtain at least one measurement (and preferably more) during the event. To detect events lasting only hours implies an extraordinary increase in sampling and analysis activity. Moreover, the time necessary for laboratory analysis of samples on a routine basis is generally on the order of days. Under emergency conditions this can be shortened, but to adopt such speedy analysis as a routine would invoke substantial costs, particularly in the human resources needed to take, transport, and analyze the samples. A detection scheme based on surveying the medical community and accounting for the pharmaceuticals, drugs, and medicaments sold assumes that the public has already been exposed to the contaminant. It is focused on a retrospective examination to characterize the event. Of course, the information resulting from such an analysis could be useful in treatment of those exposed and, therefore, valuable in safeguarding, at

least to some extent, the public health. However, it would not prevent exposure. In summary, these alternative approaches may be helpful, but do not constitute early warning in the sense that appropriate steps can be taken to limit or prevent the exposure of the public to the contaminant.

An online, near real-time, contaminant detection system can provide early warning. However, such systems involve a number of measurement platforms, each with several instruments located throughout the priority regions of the system and this can become a very expensive effort. An OCMS is justified if the likely costs that could arise from a contamination event (that is, the risks) exceed the sum of a) the costs (risks) of contamination that would remain even with an OCMS and b) the costs of establishing and operating the OCMS.

Detecting contaminants inserted deep within the distribution system implies an extraordinarily large number of monitoring locations. Furthermore, there is very limited opportunity for providing responses that would prevent exposure of the consuming public. If the purpose of the OCMS is detection to prevent exposure, rather than detection to assist in diagnosis and treatment of victims, monitoring deep in the distribution system would not be cost effective. Determining the point of diminishing returns for locating monitoring instruments is highly dependent upon the particulars of the water system.

A very difficult part of this calculation is valuing the public health impact. This involves not only valuing sickness and the loss of life, but also the subjective factors arising from public pressure and political posturing. In some cases the subjective factors may be more influential in determining whether an OCMS will be established, but that does not negate the basic cost-benefit or risk reduction arguments that are discussed here.

## 2.2 System Design Basics

The design of an OCMS is a complex problem in systems engineering. Ideally, the design would be done in a rigorous analytic mode, considering all details, all interactions and interdependencies, and established engineering principles. However, as is often the case in real world situations, not all the requisite scientific knowledge is available. In practice, therefore, the design of an OCMS is a combination of analysis and an intuitive approach based on experience and understanding of the particular utility and the community served.[17]

The first step in designing an OCMS should be the articulation of the objectives or mission of the system.

The objectives of an OCMS are:

- To provide an early reliable warning of a contamination event so that steps can be taken to reduce its effects by limiting exposure of the at-risk population.
- To indicate the location and travel of the contaminant to facilitate implementation of the appropriate responses.

[17] The very few online contaminant monitoring systems already established were designed largely through an intuitive approach based on intimate knowledge of the particulars of the water system.

- Insofar as possible, to identify the contaminant and determine its concentration so that the most appropriate response can be mounted and to alert and inform the medical community about the potential need for treatment.
- To provide information on the "normal" operating characteristics of the water supply or wastewater system.
- To support or supplement the existing regulatory surveillance activities.

The first three purposes are the most important from the point of view of contamination events as described in the first section. The last two are desirable but probably would not provide the justification for a substantial OCMS by themselves. That is, the last two purposes can be served with a much more limited monitoring system than the first three.

As an example, the following mission statement might be a useful model. This statement of mission explicitly recognizes that while the rationale for establishing the system is the mitigation of public health risks of contamination, there are other benefits that can be expected to accrue to the utility.

## 2.2.1 Sample System Mission Statement

The OCMS is to:

- Detect and characterize all "important" contamination events; distinguish them from benign excursions from nominal operating values.
- Where possible, identify contaminant(s) or class(es) of contaminant.
- Where possible, estimate contaminant concentration.
- Determine location, extent, and flow of contaminant through the system.
- Acquire sample for laboratory study when threshold is reached.
- Provide alarm or alert information to decisionmakers in sufficient time and detail to:
  - Eliminate all false negatives
  - Minimize false positives
  - Implement appropriate responses
  - Improve normal operations
- Develop good baseline data showing ways in which operations can be improved through deployment of an OCMS.
- Supplement existing surveillance system in meeting regulatory requirements.

## 2.2.2 Resources and Constraints

The second step in designing an OCMS should be the identification of all resources that can be brought to bear in establishing and operating the system and identification of all constraints or obstacles that affect its establishment and operation. Such constraints and obstacles are treated only very briefly in this section but are the substance of the rest of this document.

Resources include:

- Budget for establishing and operating the OCMS
- Personnel—numbers, capabilities, and time available
- Organizational, administrative, and management resources
- Equipment already on hand
- Facilities available (for example, SCADA[18] for handling the data)
- Other

Constraints or obstacles would include:

- Limitations in instruments that are available.
- Site conditions (for example, space, power, telecom, and environmental conditions).
- Model applicability and availability.
- Data analysis algorithms, and software availability and applicability.
- Response requirements—time and information.
- Communication subsystem to connect remote platforms with analysis center and support responses.
- Maintenance, housekeeping, and updating the system.
- Ensuring the system's readiness and level of personnel training.

## 2.2.3 Options

The next step is to configure and analyze realistic options within the available resources that meet the constraints. The options include choices for:

- Instrument suite for each platform
- Platform locations
- Data analysis software—off the shelf (unlikely) or developed specially for this problem
- Communications modalities and network
- Criteria and methods for setting alarm triggers
- Response options

The analysis should gauge the options against the constraints and the resources available. It should analyze pros and cons of each option in terms of how well the option meets the mission and is within the boundary of constraints and resources. The analysis effort should devise selection criteria for selecting the most appropriate option(s). And finally, the best option should be reexamined to ensure it is achievable and cost effective.

[18] Not all systems have SCADA.

### 2.2.4 The Detailed Design Process

To carry out the detailed design of the OCMS, a number of issues need to be addressed in some depth. Their resolution should then allow the full development of the system options and their analysis.

The remainder of this document raises and discusses the major issues that must be resolved in pursuing the design of the OCMS. Suggested guidance is presented under each section.

## 2.3 Water Supply

Some water supply utilities have assessed the risks that arise from threats of contamination in connection with their legally required vulnerability assessments.[19] However, it is clear from discussions with water supply utility representatives that many of them have not included contamination in their design basis threat and therefore have not paid adequate attention to the contamination problem. The applicability of standard assessment methodologies (such as RAM-W™ or VSAT)[20] to the large ensemble of possible contamination scenarios in the contamination problem is questionable and considerable adaptation may be necessary.

### 2.3.1 Contamination Risks (Water Supply)

The risks arising from contamination in water supply systems include:

- Public health risks that arise from use of contaminated water (including fire fighting).
- Economic risks to the user community that arise from the use of contaminated water (for example, in industrial processes).
- Economic risks to the utility from the loss of saleable water; loss of water for industrial, agricultural, and firefighting uses; potential legal liabilities; unfavorable audit reports; loss of public confidence; and cleanup and repair costs.

The primary concern is over the threat to public health from the exposure of people to the contaminant. This exposure can come about through a range of uses including but not limited to drinking tap water, using tap water in food preparation or for ice, showering, bathing, washing clothes and dishes, using a humidifier, watering lawns, washing cars, and fighting fires.

One also needs to consider the possibility that the target of an attack is a high value (to the attacker) customer, for example, government installations, schools, nursing homes, etc. That is, the target may not be the public at large but a specific segment that holds high value for the attacker.

Note that a precise quantitative evaluation of risk in this context is not possible. Many of the key factors that affect the calculation are not quantified. Furthermore, some important factors are

[19] Discussions with water utility operators.

[20] For more information on RAM-WTM see: http://cfpub.epa.gov/safewater/watersecurity/home.cfm?program_id=11. For more information on VSAT see: http://www.vsatusers.net.

subjective or highly uncertain. Nevertheless, rough estimates, similar to those made in some vulnerability assessment programs, are possible and useful.

## 2.3.2 Risk Assessment for Water Supply

The risks from contamination of water supply include risks to public health as well as a range of risks to the utility and the community. Risk is defined as the probability and severity of adverse effects.[21] The classical risk equation (from Lowrance) gives risk as the probability of an adverse event times the consequence of such an adverse event where p is the likelihood that an adverse incident will occur and I is the impact or loss that is expected if the adverse incident does occur.

$$\text{Risk} = p \times I$$

The units of risk are the units of the Impact. The probability function ranges between 0 and 1. Applying this equation to accidental or intentional contamination, the probability is a function of the threat of contamination and the vulnerability of the system to being contaminated.[22] While evaluating the threat is beyond the capability of most utilities, it can either be postulated or estimated from information that might become available from the federal government, particularly through the FBI or information sharing and analysis activities. Evaluating both system vulnerabilities and the impacts of contamination are within the grasp of the utilities.

Overall risk consists of public health and safety risk plus various other risks to the utility and to the community, as mentioned above. For purposes of determining whether an OCMS is justified, one should focus primarily on public health risk.

Public health risk assessment involves three steps:

- Identify the hazard (the hazard is the contaminant)
- Evaluate the exposure
- Determine response to dose

There are three exposure routes that need to be considered: ingestion, inhalation, and skin contact. Drinking contaminated water from the tap can cause illness and death if the dose of contaminant ingested is sufficiently great. EPA posits that a representative (and conservatively safe) value for water ingestion by consumers is about 2 liters (L) a day.[23] A more accurate average, of course varies by location, by other demographic factors, and by season. In general, most people today drink directly from the tap on average an amount of water that is less than 2 L a day (see footnote 18). However, people who are more physically active, for example, the military, athletes, or workers outdoors probably consume significantly greater quantities of water. When assessing risks and performing related calculations it is reasonable to assume for assessing effects on public health that a nominal person ingests of the order of 2 L of water a day.

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[21] Lowrance, William W. Of Acceptable Risk: Science and the Determination of Safety. Los Altos: Wm. Kaufmann, 1976

[22] Pikus, I.M. and Y.Y. Haimes Early Warning Contaminant Surveillance Systems: Fundamental Issues., UCOWR Conference, 2004.

[23] EPA Report: Estimated Per Capita Water Ingestion in the United States; EPA 822-R-00-008, April 2000

Water used in cooking or food preparation can also lead to exposure. Foods washed in tap water can retain some contaminant. Low temperature or brief cooking might degrade or destroy many contaminants, but some would likely survive that quite well. In other words, exposure by ingesting coffee, tea, and "instant" foods made by quickly heating water should be included in determining risk.

Although ingestion may be the main exposure path, one should not ignore inhalation of water vapor or aerosols from showering, from the use of humidifiers, (particularly in cold climates in winter), evaporation of water used in washing, and from other sources. EPA and others have programs to calculate exposure under a variety of circumstances and, in some cases, the exposure through inhalation of volatiles and aerosols while showering once a day is of the same order as that through ingesting 2 L per day.[24] Even in cases where the amount of toxic or pathogenic material inhaled is considerable less than what one would be exposed to by ingestion, many contaminants are an order of magnitude or greater more effective in causing illness or death by inhalation than by ingestion. Reasonable and agreed values for exposure via inhalation for the contaminants of concern in the context of this work are not yet available.

Similarly, exposure by contact can be important. Clothing laundered in contaminated water may retain some of the contaminant and cause the wearer to be exposed. Also, washing hands, bathing, and showering are potential exposure routes that need to be evaluated for the contaminants of concern in the context of this effort.

Fighting fires with contaminated water can lead to exposure through both inhalation and contact. Many contaminants would likely be degraded or destroyed from the heat of a fire but there may still be substantial amounts of contaminant exposure, particularly for the fire fighters or others in the immediate vicinity. Moreover, the chemical reactions of waterborne contaminants exposed to air at high temperatures has not been adequately studied. It is possible that some reaction products could also be toxic. Contaminated water used in fighting fires creates a significant runoff into storm sewers and can lead to further public health risk through that avenue.

The dose response of humans to the range of chemical, radioactive, and pathogenic contaminants generally is inferred from laboratory studies on animals such as mice, rats, and rabbits, among others. The correspondence between human and laboratory animal effects is not clear, so many practitioners invoke a safety or uncertainty factor usually of about 100 in adapting the dose response figures from laboratory animals to humans.[25]

For toxins, doses are generally given as milligrams (mg) of toxin per kilogram (kg) of body weight of the animal. To determine the equivalent dose for another animal one must know the animal's body weight. Dose values are cited for particular effects. For example, one very common value used is LD50. This is the dose that would be expected to kill 50 percent of the exposed and untreated population. Occasionally, other lethal doses are reported; for example, LD10 is the dose that kills 10

[24] Olin, S. S. (ed.), "Exposure to Contaminants in Drinking Water. Estimating Uptake Through the Skin and by Inhalation" book, International Life Sciences Institute (ILSI) Press (1999).

[25] International Food Information Council (IFIC), http://ific.org/publications/qa/adiqa.cfm.

percent of the untreated exposed population. Another commonly reported dose is the lowest dose at which an effect has been noted – (LOEL). The upper limit of the range of short-term doses in which no observable adverse effects occur is labeled NOAEL. EPA uses the maximum contaminant level (MCL) as a measure of water quality to meet regulatory standards. EPA also uses MCLG as the maximum contaminant level goal to indicate that level at which no adverse effects are expected from long-term chronic or short term exposures.

The relationship between LD50 and other lethal doses is not linear. In other words, LD1 is not necessarily one fiftieth of LD50. Furthermore, the relationship is different from one toxin to another. The dose-response curve for a typical toxin is an "ess" shaped curve so often found in biological situations[26] and illustrated in a qualitative fashion in Figure 2-1. At both the low end and high end of the curve the increase in response is less than proportional to the increase in dose. In the mid-range, however, the change in response can be considerably greater than the change in dose.

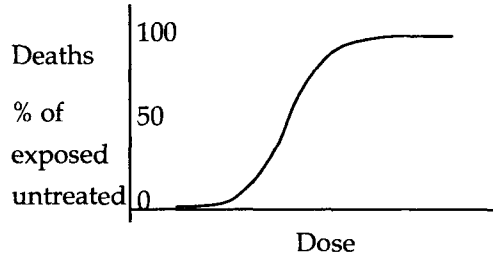


**FIGURE 2-1**
Typical dose-response curve (qualitative)

These evaluations do not usually take into account the different responses of humans whose health is compromised. Exposure of people in less than good health would likely result in significantly more illness and death than the dosage figures otherwise might imply. There is no scientific agreement on the appropriate level of response or how to treat numerically the exposure of persons with compromised health. Furthermore, that variation in dose response would depend upon the specific contaminant.

For pathogens, the dose is generally cited as the number of infectious organisms that must be inhaled or ingested (or if by contact, the number on a particular portion of the skin for a given time) to produce the disease. ID50 is the number of infectious organisms needed to produce the disease in 50 percent of the exposed untreated population. This dosage is not related to body weight *per se*, as is the toxic dose. However, health condition is very important. Here again, to translate between laboratory animals and humans a safety or uncertainty factor may be imposed. There is no substantial agreement in the literature as to what value would be appropriate. Again, a factor of 100 is suggested.

To arrive at the concentrations of contaminant in water that corresponds to given dosages requires knowledge of how much water usage corresponds to the dose. This depends upon the pathway for

[26] See for example, J.D. Murray, Mathematical Biology, Springer 1993, page 1 et seq.

exposure to the contaminant. The necessary calculation is not generally available in the literature except for exposure through ingestion. In that case, using the conservative figure of 2 L a day for consumption of tap water, to deliver a dose by ingestion in one day, a concentration of 0.5 dose per L or about 2 doses per gallon is implied.

## 2.4 Wastewater/Stormwater

The risks for wastewater and stormwater systems include:

- Public health and safety risks that arise from the potential for explosion of volatile materials discharged into the sewers or wastewater treatment plants and public health risks from venting of pathogens or toxic fumes carried in the wastewater sewers.
- Environmental risks that arise from degradation of the waste treatment process by contamination; this can result in contaminated effluent being returned to the environment (also a problem for downstream water supply systems that draw from the contaminated body of water).
- Contamination of the sludge to be used in agricultural, construction, or other processes.
- Economic risks to the utility that arise from a curtailment of service, the need to clean and repair damage to the process caused by the contaminant, legal liabilities for violating regulations concerning effluent and byproduct contamination, liabilities for damages caused, loss of public confidence, etc.
- Health and safety risks to utility workers.

In wastewater systems, the primary risk from contamination is taken to be the risk to the public health and safety arising from the potential for explosion of volatile fumes, the potential for inhaling toxic fumes or pathogens vented from the system and the effects of contaminated effluent on downstream waters.

Economic risks may indeed be important but for purposes of providing a basic rationale for the decision to establish an OCMS, the public health and safety risks are of paramount concern.

### 2.4.1 Public Health Risk Assessment for Wastewater Systems

Threats to public health from contaminants in wastewater arise from potential inhalation of toxic fumes or pathogens that are vented from the wastewater system to populated areas and from the potential for explosion of volatile fumes. No quantitative assessments relating degree of exposure of population to quantities of contaminant in the system have been found in the literature in pursuing this study. Moreover, the experts contracted to produce the white papers did not identify any such assessments. Calculations such as these require a detailed understanding of the wastewater utility in question, the flow of water within the system, the location of vents, the airflow from above the water surface to those vents, and the factors that relate vapor concentration to contaminant concentration in the water (for example, temperature and other factors affecting volatility).

# 2.5 Risk Assessment Methodologies—Water Supply and Wastewater/Stormwater

This pre-standards document does not intend to provide a methodology for assessing risks or vulnerabilities for contamination in either water supply or wastewater/stormwater systems. There are already several vulnerability assessment methodologies in use. For example, the Risk Assessment Methodology-Water (RAM-W™)[27], developed by Sandia National Laboratories in connection with AWWARF and with support from EPA has gained a number of practitioners and was used by many water supply utilities in their mandated vulnerability assessments.

VSAT is another well accepted and widely used—particularly among wastewater utilities—vulnerability assessment methodology[28]. It was developed by PA Consultants in connection with Association of Metropolitan Sewer Agencies (AMSA) and was supported by EPA.

Some consulting and engineering firms have developed their own assessment methodologies. Some of these are based on or adapted from either RAM-W™ or VSAT. Many are proprietary.

The applicability of these available assessment methodologies to water contamination, particularly by pathogens, has been challenged. In part, the problem in adapting the existing methodologies is the extraordinary span of potential contamination scenarios. It is probably not a valid approach to posit, as one does in many vulnerability assessments, a design basis threat. The variation in possible contaminant, possible concentration, location, and method of insertion does not lend itself to that kind of approximation. It may be that some sort of ensemble averaging and an understanding of the span of effects in the ensemble are needed.[29]

Aside from the wide span of potential scenarios, the risk or vulnerability assessment methodology for contamination would be very similar to the application for physical or cyber risks. No matter which methodology is used, the following key elements must be addressed:[30]

- Characterization of the water system, including its mission and objectives.
- Identification and prioritization of adverse consequences to avoid.
- Determination of critical assets that might be subject to malevolent acts that could result in undesired consequences.
- Assessment of the likelihood (qualitative probability) of such malevolent acts from adversaries.
- Evaluation of existing countermeasures.
- Analysis of current risk and development of a prioritized plan for risk reduction.

The vulnerability assessment process will range in complexity based on the design and operation of the water system itself. The nature and extent of the vulnerability assessment will differ among

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[27] www.sandia.gov/news-center/news-releases/2003/tech-trans/flcawardrams.html
www.sandia.gov/water/FactSheets/WIFS_RAnew.pdf

[28] http://www.vsatusers.net/

[29] See EPA's Threat Ensemble Vulnerability Assessment (TEVA) project

[30] http://www.epa.gov/ogwdw000/security/community.html

systems based on a number of factors, including system size, potential population affected, source water, treatment complexity, system infrastructure and other factors. Security and safety evaluations also vary based on knowledge and types of threats, available security technologies, and applicable local, state, and federal regulations.

The ensemble risk assessment should address the following factors for each type of scenario:

- For each location at which the given contaminant may be inserted either purposefully or accidentally, the ease with which contaminants can be inserted must be estimated.
- The criticality of each potential insertion site must be estimated from the number of people exposed and their susceptibility to illness or death from the exposure.
- The threat must take into account any available information on the intentions, capabilities, and experience of potential attackers, the potential sources of accidental contamination, and the availability, properties, and ease of use of likely contaminants.[31]

All existing protections and countermeasures must be taken into account.

# 2.6 Suggested Guidance

All water utilities, whether water supply or wastewater, should ensure that they have a current assessment of their risks due to contamination. However, it is recognized that packaged assessment tools accepted by the water community at large and tailored to the contamination problem are not yet available. Nevertheless, until such tools are available, utilities should estimate their needs for an OCMS by the following rough process that applies a standard risk assessment or vulnerability assessment methodology:

- Identify all practical potential points of insertion.[32]
- Identify the insertion points of highest criticality based on the population affected.
- Among the critical insertion points, choose the potential insertion points that are most readily accessible to an attacker or to accidental contamination.
- Postulate a contamination threat.
- Estimate the consequences.

If the risk assessment indicates that contamination poses a significant risk, the utility should consider a range of measures to reduce that risk. Among the measures that should be considered are enhancements to physical security, personnel security, and cyber security that would make the introduction of contaminant more difficult or more easily detected.

[31] This information is not generally available to utilities. However, federal agencies such as the FBI and the Department of Homeland Security could make available relevant information and judgments through an established forum such as the Water ISAC.

[32] The judgment of which potential points of insertion are practical from the viewpoint of an attacker is difficult but can benefit from the participation of persons intimately familiar with the operation of the system.

If the risk remaining after reasonable security enhancements are considered is still significant, the utility should consider establishing an OCMS. If the reduction in risk due to the OCMS is commensurate with its costs (development, establishment and operations) an OCMS is justified.

Design of the OCMS should then follow the standard engineering design principles as given.

SECTION 3

# Using Contaminant Lists and Determining Concentrations to be Detected

Water contaminants fall into three major categories: toxic chemicals (including biotoxins); pathogens; and radioactive materials. The number of potential contaminants is enormous and a comprehensive listing would be unwieldy and not very useful. The reasons for producing a list of potential contaminants include: to give the utility a sense of what might show up in its system; to provide the medical community a sense of what illnesses and afflictions might be seen from a contamination event; and to provide an OCMS designer specific contaminants that the monitoring system should be able to respond to. Lists of potential contaminants have been developed.[33] [34] Ideally, the listing should contain representatives of all priority categories of contaminant such that a system designed to detect the listed species will also be able to detect unlisted members of those categories.

This section discusses the use of contaminant lists and the setting of detection criteria for those contaminants.

## 3.1 Water Supply Systems

### 3.1.1 Chemicals (Including Biotoxins)

A fundamental premise of toxicology is that virtually any chemical is toxic to humans if the dose is high enough. Therefore, a list of possible toxic chemical contaminants would encompass virtually all chemical species. The determination of the chemicals that can be effectively added to water supply, either accidentally or by a purposeful attacker, and thereby cause illness, death, or economic loss, centers on several key parameters:

- Toxicity by all routes of exposure
- Solubility/miscibility in water – that is how well it is borne by water?
- Volatility – that is, does it stay in the water?
- Survivability (for example, half life) in water[35]

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[33] C.F. Burrows WD, Renner SE: Biological warfare agents as threats to potable water. Environ Health Perspect. 1999 Dec;107(12):975-84. See also USFDA Bad Bug Book http://vm.cfsan.fda.gov/~mow/intro.html

[34] Public Health Security and Bioterrorism Response Act of 2002, Title IV; HSPD-9 which says in part -
"The Secretaries of the Interior, Agriculture, Health and Human Services, the Administrator of the Environmental Protection Agency, and the heads of other appropriate Federal departments and agencies shall build upon and expand current monitoring and surveillance programs to: (a) develop robust, comprehensive, and fully coordinated surveillance and monitoring systems, including international information, for animal disease, plant disease, wildlife disease, food, public health, and water quality that provides early detection and awareness of disease, pest, or poisonous agents ..."

[35] This is often, but not always, a strong function of the reaction rate with residual disinfectant.

- Warning signs that should alert the public (such as taste, smell, or color)[36]
- The production of toxic byproducts through reactions in water or wastewater.

Toxicity is usually determined in laboratory studies of the responses of animals to exposure. The animals most frequently used are mice, rats, and rabbits although a wide range of other animals has been used. The most frequently reported measures of toxicity are the Lethal Dose that kills 50 percent of the exposed untreated population (LD50) and the No Observable Adverse Effects Level (NOAEL).[37] Extrapolating values obtained from animal studies is uncertain because the responses of an organism depend upon many variables and the precise relationships among those variables is not well understood. In light of the uncertainty, a safety or uncertainty factor is usually employed so as not to understate the effect on humans. A conservative value for NOAEL is estimated to be either $10^{-2}$xLD50 (where the value for LD50 is given for humans) or $10^{-4}$ xLD50 (where the value of LD50 is given for laboratory animals); the latter value includes an uncertainty factor of 100 (10 in going from animals to humans and 10 for intraspecies variations) in addition to the factor of 100 for the estimated extrapolation from LD50 to NOAEL.

Doses of toxic materials are usually reported as mg of chemical per kg of body weight, so the actual dose needed to produce a given effect is the reported dose/kg of body weight times the weight of the individual exposed. This is, of course, another approximation because the relationship between dose and body weight is not universal and there are other factors (for example, metabolic differences) that are important in determining an individual's response to a given dose. For a composite population, an average value gives a reasonable indication of the effects that might be expected across the population, but this can vary substantially in portions of the community.

The effects of exposure to toxic materials for laboratory animals is not necessarily a valid measure of the effects on humans for several reasons including: a) that animals respond differently (in some cases very differently) from humans to particular agents and b) the fact that usually the laboratory animals are healthy whereas human populations would include some fraction who are ill or whose health is compromised to a significant degree. However, in many situations where pharmaceuticals have been tested on laboratory animals and the results compared with later experience in use of the approved pharmaceutical, the correspondence has proved "reasonable."[38] It is usually assumed that using the safety factor of 100, there will be a reasonable correspondence between the effects of toxic materials on laboratory animals and humans. In some instances where people have accidentally been exposed to toxic materials the toxicities estimated from those experiences have not been very close to

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[36] Some suggest that utilities should adopt as a standard practice the use of taste panels and regular taste and smell tests (using smell bells)

[37] NOAEL is most frequently defined in terms similar to those in the glossary of this report; i.e., "the greatest concentration or amount of a substance, found by experiment or observation, which causes no detectable adverse alteration of morphology, functional capacity, growth, development, or life span of the target organism under defined conditions of exposure."—IUPAC Compendium of Chemical Terminology, 2nd ed. 1997

[38] Roche corporate position on animal testing: www.roche.com/pages/downloads/sustain/pdf/ropos_at.pdf

the values derived from laboratory studies.[39] Nevertheless, the traditional approach is to estimate toxicity on the basis of the effects on laboratory animals.

Toxicities range widely. Among the most toxic substances are many of the biotoxins, some of which require ingestion of only micrograms to cause death in humans. Chemical warfare agents are also highly toxic. More widely available materials such as pesticides and solvents generally are somewhat less toxic. And finally, the extraordinarily large number of industrial and common chemicals are toxic only if the exposure is to very large amounts.[40]

The solubility of a contaminant is a measure of the maximum concentration achievable in water. Solubility in water is affected by several properties of the water—temperature, pressure, and pH in particular. In some instances the presence of biological material or other chemicals can affect solubility. Volatility is a related measure and indicates how readily the contaminant will vaporize. This is of particular importance in the contamination of wastewater collection systems because of the explosive potential of many volatile materials and because of the venting of fumes to which people above ground might be exposed. It also is of concern in water supply systems where users may be exposed to the fumes while showering or using a humidifier.

Chemicals (as well as pathogens) used in warfare are usually delivered as airborne particles. Their effectiveness usually must be enhanced by "weaponizing" them, that is delivering them in aerosols within a narrow range of sizes so that they remain longer at levels where target individuals can breath them. If the aerosol particles are too small, they may tend to rise or be carried out of the breathable range. If they are too large, they tend to sink to the ground. However, for delivery in water systems, many of these chemicals or pathogens need not be specially treated or "weaponized." That is, they can be delivered effectively within water without any special preparation of the material.

Many potential chemical contaminants react with water or other constituents in the water. The primary reacting chemical is usually the disinfectant residual. The most commonly used disinfectants are chlorine, sodium hypochlorite, chlorine dioxide, chloramines, ozone and, in some systems, potassium permanganate, however, only chlorine and chloramines have significant residual disinfectant properties and react strongly with a number of contaminants.[41] The half-life of the contaminant is determined from the rate of reaction of the contaminant with the water and its constituents, the amount of contaminant, and the available reactants. Some contaminants are so highly reactive with chlorine that they are destroyed relatively quickly in water systems where chlorine is used as the disinfectant and a substantial residual is maintained. In such cases, reduction in the amount of residual chlorine may provide a good indication that such a chlorine "scavenger" is present in the system. Where the contaminant uses up the chlorine residual in a particular slug of water, the reaction stops and the remaining contaminant survives unless more residual chlorine is mixed in with the contaminant slug. Mixing in real water systems does go on continually at least to

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[39] U.S. Army, Medical Management of Biological Casualties Handbook, Fourth edition (Fort Detrick, MD: USAMRIID, February 2001) pp. 26-35. See also http://www.cidrap.umn.edu/cidrap/content/bt/anthrax/news/anconsensus.html

[40] cf. ATSDR toxicological profiles: http://www.atsdr.cdc.gov/toxpro2.html

[41] AWWA Government Affairs : Chlorine for Drinking Water Disinfection; May 1995 in AWWA Mainstream

some degree. However, it may be minimal in certain circumstances, for example, where flows are small and laminar.

Some chemical contaminants change the water's appearance, taste, or smell. While these observables might alert a user to contaminated water, they are unreliable as general indicators of contamination because many contaminants have little or no effect on these factors.

Some contaminants in reacting with water, chlorine, or other water constituents might produce reaction products that in turn are toxic. In principle, daughter products might even be more toxic than the original contaminant, although the authors know of no examples at this point. Therefore, the chemistry of the contaminant in the particular water system is important to know.

Another factor is the time over which a particular dose is received. Many but not all toxins are processed—that is, broken down—in the liver. Others are processed in other body organs. Many do not have a linear cumulative effect so that if the dose is spread out over a long time (several days) the body may have time to metabolize enough of the contaminant to keep the effective levels below those needed to cause prompt illness or death. In assessing the risks from chemical contaminants it is assumed that the dose is delivered in the course of one day.

However, concentrating a given amount of the contaminant into a short (of the order of hours) pulse of high concentration may, depending on the particular response-dose curve, actually increase the effectiveness of the contaminant as a weapon.

The effectiveness of a contaminant is very dependent upon the particulars of the system into which it is introduced as well as the way it is introduced. The chemical reactions depend upon the composition and other chemical and physical properties of the water as well as temperature and pressure. Laboratory experiments may be misleading in cases where these idiosyncratic aspects of the utility are important. This makes it difficult to formulate a master list of contaminant chemicals that is equally appropriate for all utilities.

## 3.1.2 Pathogens

Many pathogens have been developed and weaponized for airborne delivery and exposure by inhalation. There are several reasons for this. First, lungs are an excellent pathway to the bloodstream. There are few places where the barrier from blood to the outside world is thinner than in the alveoli in the lungs. Thus, placing pathogenic bacteria in the alveoli, by administration via an aerosol with appropriate characteristics, is an excellent way to establish septicemia. Septicemia is typically one of the most virulent manifestations of many diseases. Secondly, if pneumonia, or pneumonia-like symptoms, can be created, either by a pathogen or toxin, and these symptoms are severe enough, the affected individual will be unable to respire efficiently. Lack of oxygenation of the blood rapidly leads to death. Thus infecting the lungs, or poisoning them with a toxin, is an effective mechanism of killing.[42]

[42] The material for this paragraph was provided by an anonymous EPA technical reviewer.

Pathogens that are communicable, persist or grow in the environment, contaminate food or water, or are infectious through dermal contact enter into consideration for use as water contaminant weapons. In fact, in many cases the "raw" pathogens can be used without any special effort to weaponize them. In addition, there are many pathogens that are more effectively delivered in water. Many pathogens are produced in a broth or slurry. In this state, they are readily amenable to dispersion in water without further steps such as encapsulation, drying, milling etc. While selection and preparation of pathogenic organisms is not without difficulty, retaining them in the broth or slurry form greatly simplifies their use as water contaminants. Many pathogens are communicated from animal reservoirs to humans through excreta. For example, arena viruses are communicated to humans through urine and fecal materials of infected rodents. This class of virus contains a number of highly infectious and deadly hemorrhagic fevers.[43] Other pathogens are communicated by mosquito eggs or larvae. The survivability of such pathogens carried in water by excreta or other substances is very poorly known at present but should be kept in mind as a potential avenue for contamination of water supplies.

The main categories of pathogen are: bacteria, viruses, protozoa, and fungi. Rickettsia, rickettsia-like organisms, round worms, and other parasitic nematodes have also been suggested as pathogens of concern in water. Some classes of bacteria, fungi and protozoa go through a spore stage[44] and in many cases these spores are highly resistant to disinfection and to destruction by environmental conditions. However, bacteria not in spore stage may be more susceptible to disinfection. Nevertheless, some bacteria may be resistant to water disinfection even though they do not go through a spore stage. Viruses also present a mixed picture. Some are known to survive well in tap water and possibly proliferate in wastewater. For many, their susceptibility to disinfection and even some aspects of the mechanism of disinfection are also poorly known. Many of the most deadly viruses are transmitted primarily by mosquitoes or other insects; their survivability in water has not been studied and is not known. Protozoa are frequent contaminants of water because they exist in such proliferation in common circumstances such as farm animal waste. The biofilm lining water system components may be important in the survivability of some pathogens and may even promote their multiplication, although this has not been well enough studied to date.

Many pathogens do not survive well in chlorinated water. The precise mechanism of chlorine interaction with pathogens is not well understood and seems to be different among various groups of pathogens. It is important to know more about the fate of observable characteristics of water in interaction with pathogens to better understand the implications of measurements of these characteristics for identifying contaminants and inferring their concentrations. In addition, the interactions of disinfectants with pathogens in the biofilm can be quite different from those with free standing pathogens in water.

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[43] See for example, CDC's Special Pathogens Branch publications. Also, http://www.cdc.gov/ncidod/dvrd/spb/mnpages/disinfo.htm

[44] To be technically correct, one should say that some pathogens go through an environment resistant life-cycle stage. Some bacteria go through a spore stage, fungi have spores, protozoa may have spores, cysts have oo cysts, nematodes have ova, etc. For purposes of this document such stages are globally referred to as spores.

The measure of infectivity most often used is ID50 or the dose that will cause the disease in 50 percent of the untreated population exposed to that number of organisms. The infectious dose is strongly dependent upon the immune status of the exposed individual and probably a number of other factors relating to the status and behavior of the person exposed as well as characteristics of the pathogen. The infectious dose is expected to vary widely across a population. Averaging over a population may be misleading since some subsets of the community may be much more sensitive to lower doses.

There is a presumption in some cases that low level exposures to specific pathogens can engender specific immunity in a large proportion of individuals. Many of the specific instances of indigenous populations in endemic areas exhibiting "innate" or unexplained resistance may simply be due to the population continually bearing the cost of this "immunity" in high, but unexplained infant and elder mortality rates. The problem, if this technique is applied to frank pathogens (so called because they can initiate infection on their own as contrasted with opportunistic pathogens, which cannot), in a homeland security context, is that the introduction of a new frank pathogen, even at low levels, into an immunologically naïve population will generally result in some mortalities. In fact many, or perhaps most microbiologists would argue, if a curve of dose versus percent of the population developing illness were developed, the dose of one organism would cause disease in some proportion of the population for most, if not all, frank pathogens. Furthermore, for many frank pathogens, this proportion of the population infected by a single organism may be in the range of one or two percent. Thus, any exposure of this sensitive population to these pathogens may result in illness.[45]

For pathogens and individuals for which the specific infectious dose is greater than one organism, the time over which an infectious dose is received may be important in determining whether the body's immune system would be able to cope. Generally, it is assumed that the infectious dose is delivered within a brief period, for our purposes that period is defined as one day.

For a human population representative of normal communities, there will likely be some portion of the community that would contract the illness after being exposed to only one organism. Therefore, the target for detection should be one organism. This makes practical sense only if expressed as one organism for each measurement made. Of course, that would imply the potential exposure of water users to considerably more than one organism since the measurement is on a small sample of the water at a particular time interval. There is no way that a sampling system examining a small portion of the water passing a point over a small period of time could possibly detect a concentration that translates to an exposure of only one organism over a day's use of water. Even with the understanding that detecting a single organism in a sample measurement may imply a considerably higher exposure, the measurement is probably not a technically achievable goal at this time. However, anything above that target would probably be politically untenable as an objective. Even though current instruments cannot reliably detect the presence of single or very small numbers of organisms in a sample of water, until better sensors become available, the current instruments may still be useful if the concentrations of particles is higher and within detection limits.

[45] This paragraph was provided by an anonymous EPA technical reviewer.

It should be noted that there are many pathogens that would not be expected to affect properties of water such as conductivity, pH, residual disinfectant, etc. While measuring TOC could be a technique that detects the presence of substantial numbers of pathogens, such instruments are very expensive and would not have sufficient sensitivity to detect single or small number of pathogens at the current state of the art.

## 3.1.3 Radioactive Materials

Radioactive materials are found naturally in the environment, usually in extremely low concentration. They are also found in wastes from nuclear power plants, nuclear research organizations, and medical facilities. Radiation exposure can be external (that is, the source is outside the body) or internal (the radioactive material has been inhaled, ingested, adsorbed on the skin, or injected).

Because exposure to radioactive doses is generally very small, the main concern has been over long-term exposure and its implications for health problems such as cancer. But a purposeful insertion of radioactive material into water systems would most likely lead to higher exposure over a relatively short time. In this case, the concerns are somewhat different.

When radioactive nuclides enter the body, they move and lodge according to the chemical properties of the atom. That is, depending upon the particular nuclide, the effect may be concentrated in one organ or body system.

The radiation emanating from the radioactive decay may be a combination of electrons (beta particles), protons, helium nuclei (alpha particles), neutrons, nuclear fragments, and photons (x-rays and/or gamma rays) all at particular energies, depending upon the nuclide and its decay scheme. The most common damage mechanism is the ionization of atoms and dissociation of molecules in the path of the radioactive decay products. Because the effects, particularly of alpha and beta particles, are highly localized, the damage depends upon where the nuclide lodges or travels. The effects of radiation damage are generally delayed, depending upon where the damage is inflicted.

The measure of lethal dose for a radioactive material is usually expressed as the dose that is expected to cause death to 50 percent of an exposed population within 30 days of the exposure (abbreviated as, LD50/30).

## 3.1.4 Contaminant Concentrations of Concern

Most commercially available instruments measure parameters that are most directly related to properties of the water, not the contaminants. Some, perhaps many, of the contaminants of greatest concern affect certain properties of the water and in principle it may be possible to detect their presence through the measurement of such changed parameters. For example, a contaminant that reacts with chlorine could produce measurable decreases in chlorine concentration. The relationship between measured parameters and specific contaminants at specific concentrations has not been worked out analytically for real water systems. Therefore, when setting levels of concentration that must be detected, one will need to translate that into the changes in water properties that need to be

detected. Empirical studies have been done and the Appendix A paper on instruments and observables describes one such effort.

To determine the minimum level of concentration that would indicate a serious contamination event, one needs first to set the dose levels of concern and then to translate dose into concentration.

From the public health point of view, LD50 or ID50 are clearly not the correct criteria. That would imply that a dose resulting in the death or infection of less than 50 percent of the exposed population would be of no concern. However, detecting the NOAEL is probably not going to be achievable because it is generally about two orders of magnitude below the LD50 level (four orders of magnitude if the LD50 values given are for laboratory animals).[46] Nevertheless, it is recommend that the NOAEL be chosen as the target dose to be detected for chemical contaminants and one organism per measurement as the target for pathogens. In cases for which NOAEL is not reported, it can be estimated very roughly as $10^{-4}$ of the animal values of LD50 or $10^{-2}$ of human values of LD50.

To convert dose to concentration for chemical contaminants, one needs to make some assumptions. The first concerns body weight. In principle, it would be best to use a distribution of body weights that reflects the demographics of the community. In most cases, the effects of contaminants would be likely to be greatest on certain persons of lower weight who may be more susceptible to damage by the contaminant, such as children and sickly adults. Adults of lower weight, however, include those who are very fit as well as those in frail or sickened condition. In most communities, information at this level of detail is not readily available. Therefore, the best approach would be to make a reasonable estimate of average body weight. That generally would be of the order of 170 to190 pounds (lb) or 79 to 86 kg for men, 135 to 155 lb or 61 to 70 kg for women and roughly 40 to 80 lb or 18 to 36 kg for children. Infants obviously have even lower body weight of approximately 10 and 40 lb or 5 and 18 kg. For purposes of illustration in this document the overall average weight in a nominal community is taken to be 75 kg.

The next question is the route by which exposure to the contaminant is accomplished. In most cases ingestion is the most direct route. However, because for many contaminants exposure through inhalation is so much more effective, the possibility of inhaling vapors or aerosols while showering or from humidification of the air or other household and business uses cannot not be discounted. In addition, some contaminants are effective through contact with the skin, particularly if there are open sores or cuts, thus adding to the effective exposure.

To determine the minimum concentrations of chemicals that must be detected, one must convert the NOAEL dose for total body exposure to its corresponding concentration. For exposure through ingestion, one would have to know how much of the contaminated water is expected to be ingested. People ingest water by drinking from the tap or by using water in food preparation. The cooking process may destroy some toxins and pathogens but in general would not affect radioactive nuclides. For a rough estimate, an average consumption of tap water can be taken to be that taken in drinking fluids that have not been boiled for more than 1 to 3 minutes. This would include plain water, iced

[46] The Occupational Safety and Health Administration publish permissible exposure limits for workers to airborne or contact contaminants. However, these are not directly relevant to the contaminants of concern in water systems.

drinks, tea, and even coffee prepared in typical percolator or drip machines. In civilian communities, as noted above, EPA has estimated water ingestion to be approximately 2 L per day, on average. This may seem somewhat high but using this figure will give a conservative result. In other words, the error would be on the side of safety.

If the NOAEL dose by ingestion is to be delivered in one day in 2 L (~8 glasses) of water, that implies a concentration of (NOAEL mg/kg x 75 kg)/2 L in units of mg/L. Since there are about 4 L in a gallon, the concentration in mixed units would be 150 x NOAEL mg/gallon.

However, if the contamination dose is of short duration, say one hour, but the concentration much higher (for example, 24 times the concentration in a one day long pulse), the public health effect could be much greater. The probability of exposure for the short pulse is roughly one third that for the longer pulse (8 glasses of water assumed distributed over a 24-hour period compared to an assumed one of those glasses of water in the hour during which the water is contaminated. If the concentration of contaminant is in the range in which the number of deaths would be significant but well below 50 percent, then it may well turn out that although it is one third as likely that the person will ingest one glass of water during the one hour pulse as it is that he will ingest 8 glasses of water over the 24-hour period (which according to our assumptions is a certainty) the response to the 24 times larger concentration might well exceed three times the response to the lower concentration.

The calculation for exposure by inhalation or contact is considerably more difficult because there is no well accepted value for the average amount of the mixture of vapor and aerosol from humidifiers, showers, or other uses breathed in, or for average contact with contaminant residue on laundered clothing, or exposure through washing or bathing. The result of such a calculation would undoubtedly vary by contaminant. In other words, simply calculating the exposure by ingestion probably understates the actual exposure by an important factor. No accepted methodology has been found for calculating exposure by inhalation or contact in this context.

## 3.1.5 How to Use Contaminant Lists

There are many lists of potential water contaminants. Some have been prepared by professional or trade organizations, some by academic researchers, some by government researchers, and some by industry.

- EPA has an extensive list of contaminants whose maximum allowable concentrations in water are regulated. http://www.epa.gov/safewater/mcl.html#mcls
- CDC maintains a list of biological contaminants, many of which pose a water contamination threat. http://www.bt.cdc.gov/agent/agentlist.asp
- FDA publishes the Bad Bug Book on pathogens and biotoxins. http://www.cfsan.fda.gov/~mow/intro.html
- Several companies have produced proprietary lists used primarily in their own instrument and sensor design efforts.
- ATSDR maintains a large database on toxic chemicals. http://www.atsdr.cdc.gov

- Research organizations have published lists.
  http://www.mitretek.org/home.nsf/HomelandSecurity/Toxins
- Several engineering and consulting firms have prepared lists for their own use or for application on behalf of customers.

These lists have many common entries but are not completely congruent. Moreover, except for those that have been published in the open literature or in regulatory documents, these lists are sensitive or proprietary and not made publicly available.

Regardless of which list is available, certain modifications may be in order before it can be applied in the design of an OCMS. As noted in some detail above, the chemical and physical properties of contaminants are important on their own, but are also important in connection with the peculiarities of the water utility. For example, the particular disinfectant used, where it is introduced, its reaction rates and products with specific contaminants, system flow properties, and residence times all play a role in differentiating the importance of specific contaminants.

There may be contaminants on the list that are not particularly worrisome because they will not survive well in the specific system. Some contaminants that are unimportant when introduced a few days flow away from the tap may become very important when introduced a few hours away from the tap. Because of amounts needed, or properties of the contaminant, some points of vulnerability may be more important than other points so that where one looks for a particular contaminant is a function of system properties. For example, there may be potential contaminants that should be of concern to the utility, because they are readily obtainable in the area or are shipped on navigable waters that serve as the water source, but are not on the available list.

In the end, the utility or local government will probably bear responsibility in the eyes of the public (as well perhaps as in the courts) for ensuring that the OCMS can detect any significant contamination event. Therefore, the utility must examine the initial list to make sure that it contains all the contaminants of importance in its particular circumstances. No list prepared for general purposes can be expected to be applicable, as-is, to any particular utility. Furthermore, the lists of contaminants prepared and noted above are more pertinent to water supply than to wastewater systems.

## 3.1.6 Cooperation with Local, State and Federal Agencies

Utility operators, particularly those from small and medium sized utilities, expressed concern that they do not have the resources or in-house capability to resolve the key issues that underlie the development of an OCMS for their own utilities. Many of them suggested that there should be federal leadership on the issue in developing a master contaminant list and also in helping utilities adapt and apply the appropriate scientific and engineering information to the entire range of issues.

Some suggested that a hierarchy of efforts involving federal leadership by EPA and CDC and participation by state and local environment and health officials be brought to bear to help local utilities in this area.

### 3.1.7 Suggested Guidance

Utilities should have access to an official master list of potential contaminants, but must modify that list in light of the special circumstances of the utility (a list for water supply would be appropriate for water supply utilities, but a list of contaminants of concern for wastewater systems should be developed and would likely contain volatile hydrocarbons as well as volatile toxins and any pathogens that might be expected to become airborne in a wastewater environment). To determine the relative importance of a particular contaminant, the utility should examine a set of insertion scenarios for each priority insertion site. The scenarios would differ according to the method of insertion (for example, whether the contaminant is dumped or bled into the system). Also, the calculation of the amount dissolved, the amount vaporized, mixing, and chemical reactions will vary depending upon whether the insertion point is a water storage facility or a pipe. In each case the appropriate model should be run to predict concentrations of contaminant at the tap and at measurement locations.

Contaminants on the list that are considered not significant because of the specific characteristics of the utility can be removed from consideration, and contaminants that are more important for the particular utility, even though they may not appear on the list, should be added.

With federal leadership and participation by state and local officials, utilities should set target detection thresholds for contaminants. Even though currently available instrumentation may not be sufficient for reaching these targets, setting goals may assist the instrument manufacturers in developing appropriate sensing and measuring capabilities.

## 3.2 Wastewater and Stormwater Systems

### 3.2.1 Contaminants of Concern in Wastewater and Stormwater Systems

As stated in Section 2, it is intended that the primary risk from contamination in wastewater is the risk associated with the threat to public health and safety arising from the potential for explosion of volatile fumes and the potential for inhaling toxic fumes or pathogens vented primarily in the collection sewers.

For wastewater utilities, the contaminants of concern would include volatile hydrocarbons, volatile toxins, and pathogens that may easily become airborne in a wastewater environment. The concentrations of concern can be measured in the air above the wastewater surface. The instruments used to measure contaminants are summarized in Section 4 of this report. The VOC detection level should be set at a value below which it is unlikely to explode or burn in the presence of a spark or flame. This would be a function of the compound of interest as well as the geometry and hydrodynamics of the wastewater system or sewer. The volatile toxin detection level should be set at values consistent with an NOAEL level by inhalation at pedestrian positions. The level of pathogens in the air that serves as the target for a measurement aimed at pathogen detection is, by an argument similar to that for water supply systems, one organism.

No lists of wastewater system contaminants have come to our attention or the attention of the experts who developed the white papers for this project. Such a list should be developed but would have to be modified by the utility to take into account those materials that might be expected to show up either purposely or accidentally in the wastewater collection system. Local industry and trade should be taken into account as potential sources for such contaminants.

SECTION 4

# Selection and Siting of Instruments and Platforms

The OCMS is to achieve as many of the following objectives as possible: a) detect contamination events, b) locate the contaminant and c) identify and measure the concentration of the contaminant. While it would probably be cost effective if this could be accomplished in a single tier of instruments (and a) and b) might be accomplished by such a system), at the present stage of instrument development, it is likely that specifically identifying a contaminant and determining its concentration will require a different approach. That is, for the foreseeable future, until the state of the art in instrument design and manufacture advances appropriately, the approach most likely to succeed will involve one tier of instruments to detect contamination events and provide location information while a second tier—which will likely require laboratory analysis of samples—will be needed to identify and measure the contaminant.

For water supply utilities, the ideal instrument would detect any of the contaminants of concern, identify it and measure its concentration reliably and accurately down to at least its NOAEL value in the case of chemicals or to a single organism in a sample for pathogens, be fully functional in field operations, require minimal down time, maintenance and housekeeping, produce a digital data stream, and have the capability of some onboard processing in order to minimize data transmission and analysis requirements. That instrument does not exist and may not exist for a very long time.

For wastewater systems, instruments to measure volatile hydrocarbons exist in a fieldable form, whereas online instruments to measure the range of potential airborne toxins and pathogens under field conditions do not. An OCMS system for immersion in wastewater has distinct differences from one intended for water environments. Problems that may occur in a wastewater system include accumulations of grease and debris that may foul the probes. The background environment is both more diverse and more concentrated. Normal levels fluctuate more both at individual locations and between locations. Larger ports, tubes, and channels are required to prevent plugging.

The next best instruments would be tuned to detect specific kinds or classes of contaminants in water (and in air for the wastewater problem) and at least roughly indicate their NOAEL concentrations. Several research and development organizations are currently developing such instruments. The National Laboratories, several government labs (for example, NIST, NRL), a number of academic research organizations, and several companies are pursuing such efforts. However, there are very few such instruments now available on the market, and they have not been tested in realistic field circumstances.

# 4.1 Water Supply

## 4.1.1 Surrogate Parameters

Because it is not yet possible to field online instruments with the ability to detect, identify, and measure most individual contaminant species at the levels of concentration of concern, the presence and location of contaminants must be inferred from measurements of other parameters. While specific identification of contaminant species is expected to remain elusive to a fully field qualified system for some time, it is possible that the general class of contaminant might be inferred. At the present time, measuring concentrations of contaminants and precise identification of species will almost certainly require detailed laboratory analysis of samples.

There are many well-tested and understood instruments that measure a wide variety of water properties with good reliability and accuracy. However, the connection between these measured parameters and the identity and concentrations of contaminants of concern is not yet well understood. Nevertheless, these instruments will surely be among the constellation of devices to be employed in a contemporary OCMS.

Table 4-1 (adapted from the CSU white paper in Appendix A) shows potential surrogates that might provide indications of the presence and concentration of contaminants.

**TABLE 4-1**
Potential surrogates to monitor in detecting contaminants.

| Chemical Surrogates | Microbiological Surrogates | Toxin Surrogates | Radiological Surrogates |
|---|---|---|---|
| pH | Toxicity indicators | Total Organic Carbon | Alpha |
| Turbidity | Turbidity | Biomonitors | Beta |
| Total Organic Carbon | Phosphate | Toxicity indicators | Gamma |
| Chlorine Residual | TOC | | Toxicity indicators |
| Conductivity | Nitrate, Nitrite | | |
| Dissolved Oxygen | Chlorine Residual | | |
| Nitrate, Nitrite | Multi-angle light scattering | | |
| Phosphate | Fluorometry | | |
| Oxidation Reduction Potential | Biomonitors | | |
| $UV_{254/280}$[47] | Biological oxygen demand | | |

[47] USGS National Water Quality Lab Newsletter; July 1999 for a discussion of the utility of UV absorption measurements at these two wavelengths. See also Eaton, A.D., Clesceri, L.S., and Greenberg, A.E., eds., 1995, Standard methods for the examination of water and wastewater; Washington, D.C., American Public Health Association, American Water Works Association, and Water Environment Federation, 19th edition.

**TABLE 4-1**
Potential surrogates to monitor in detecting contaminants.

| Chemical Surrogates | Microbiological Surrogates | Toxin Surrogates | Radiological Surrogates |
|---|---|---|---|
| Biomonitors | Oxidation reduction potential | | |
| Toxicity indicators | Ammonia | | |
| Ammonia | | | |

## 4.1.2 Inferring the Presence of Contaminants from Surrogate Measures

Contaminants in water may affect measurable properties of the water and thus signal their presence through changes in those surrogate parameters. The kinds of changes that may be caused by contaminants include:

- Changes in chemical makeup of the water through chemical reactions.
- Changes in pH, oxidation-reduction potential and electrical properties through reaction of the contaminant with the water constituents or ionization of either the contaminant or water constituents.
- Changes in optical properties through absorption, emission or scattering of light at various wavelengths.
- Changes in biological makeup of the water.
- Changes in mechanical and acoustic properties of the water.

Some chemical contaminants hydrolyze in water, that is, they react with water by breaking one or more covalent bonds. This results in daughter products, which may or may not be less toxic than the original. In hydrolytic processes, the pH of the solution generally is changed because the ion concentrations are changed. This may also affect the conductivity of the water as well as the concentrations of other water constituents.

Other contaminants react with chlorine or other constituents of water to produce new chemicals that may or may not be more toxic than the original. Through such reactions there may result changes in pH, electrical properties, oxidation-reduction-potential, chlorine residual, dissolved oxygen, etc. The precise results of such reactions depend upon many factors and not all of the important factors are well enough known in any real system to permit an accurate and unique prediction of the changes expected in surrogate measures.

One practical approach, in view of the difficulty in analyzing the chemistry involved, is to develop empirically a set of fingerprints or signatures based on responses of a suite of instruments in tests of contaminants in a representative water sample. To do this, however, it is necessary to develop a good baseline for the measured parameters in the water system. These parameters in real water systems

undergo significant swings that turn out to be "benign abnormalities," and these swings must be differentiable from changes caused by the presence of contaminants.

Unfortunately, there are important potential contaminants that neither hydrolyze nor react in any significant degree with water. For such contaminants, only very minimal change, if any, in surrogate measures may be found.

The white paper on instruments, found in Appendix A, presents further discussion of the use of surrogate measures and the results of an experimental laboratory study on the subject.

## 4.1.3 Measuring Surrogate Parameters

### 4.1.3.1 Residual Chlorine

Chlorine or chlorine compounds frequently are present in water from the disinfection process. Some contaminants react with these chemicals resulting in changes in the level of residual chlorine or chlorine compounds and an increase in daughter products. Residual chlorine is one of the most sensitive and useful indicator parameters in water distribution system monitoring. All water distribution systems monitor (in many cases on a continuous basis) for residual chlorine concentrations as part of their SDWA requirements, and procedures for monitoring chlorine concentrations are well established and accurate. Chlorine monitoring aims to assure proper residual at all points in the system, helps pace re-chlorination when needed, and quickly and reliably signals unexpected increases in disinfectant demand. Many chemical and biological contaminants are known to combine with chlorine. Therefore, a significant drop in residual chlorine could be an indication of the presence of contaminants. Unfortunately, without a fairly accurate knowledge of the chemistry of the interaction of the contaminant with the water in the specific system, it is not possible to reliably predict the corresponding change in chlorine concentration or infer much information about the contaminant from a measured change in chlorine.

Not all potential contaminants react with chlorine. For example, some pathogenic bacteria go through a spore stage and often those spores are highly survivable in treated water.[48] Also, a number of chemical contaminants are non-reactive in drinking water. One of the key areas of concern is microbial adaptation to potable water treatment conditions or within distribution or collection systems. Microorganisms that develop resistance to water disinfectants would be much more problematic as emerging waterborne pathogens than those that are not resistant to chlorine. In addition, some chemicals (for example, sodium thiosulfate) can be added to water to eliminate residual chlorine and thus create a survivable environment for contaminants that are otherwise destroyed by chlorine.

To relate a change in chlorine concentration to particular contaminants in the water takes some rather sophisticated chemistry. Not only do the chemistry and hydrodynamics play a role, and they are not well enough known for any complex real system, but biofilm and other wall effects, again largely unknown in sufficient detail, can complicate the situation beyond analytic capability to deal with it.

[48] Lawrence Berkeley Laboratories, BioSafety Manual

Therefore, the only practical approach at this stage is an empirical correlation between changes observed and the results of investigation to discover the causes.

Many commercially available instruments measure residual chlorine. EPA's security Product Guide provides a more in-depth discussion of them.
(http://www.epa.gov/safewater/watersecurity/guide/chlorinemeasurementsensor.html)

### 4.1.3.2 Turbidity Meters

Particulate contaminants, for example, pathogenic organisms or microencapsulated contaminants, may be detectable using precision measurements of the water's optical properties. Turbidity instruments measure the average amount of collimated light scattering over a defined angular range. Both particle size and the concentration of suspended solids, as well as the level of dissolved solids can affect the reading. Turbidity is defined as an expression of the optical property that causes light to be scattered and absorbed, rather than transmitted in straight lines through the sample. Simply stated, turbidity is the measure of relative sample clarity.

Scattering is directly dependent upon the size of the particulates and the wavelength of the incident beam. In principle, then, one could design an instrument to detect and measure particulates in any size range. Multi-angle light scattering (MALS) technology is offering promise for detecting microbiological contaminants in water. This technology is based on laser scattering and motion analysis to determine the nature and amount of bacteria in a water sample. Adding pattern recognition techniques to the MALS technology has the potential to address the present shortfall in continuous monitoring for microbiological contaminants.

Turbidity is measured in Nephelometric Turbidity Units (NTU). Both particle size and concentration of suspended solids as well as dissolved solids can affect this reading. When measuring suspended solids, the instruments measure particle concentration, often as low as parts per million (ppm). Sensitivities of the order of 0.01 NTUs are achievable. For further information, see www.epa.gov/etv/pdfs/vrvs/01_vr_abb.pdf.

### 4.1.3.3 Toximeters

Rapid toxicity technologies do not identify or determine the concentration of specific contaminants, but serve as a screening tool to quickly determine whether water is potentially toxic. Rapid toxicity technologies use bacteria (for example, *Vibrio fischeri*), enzymes (for example, luciferase), small crustaceans (for example, *Daphnia magna*) or specific chemicals that either directly, or in combination with reagents, produce a background level of light or use dissolved oxygen at a steady rate in the absence of toxic contaminants. Toxic contaminants in water can be indicated by a change in the color or intensity of light produced or by a decrease in the dissolved oxygen uptake rate in the presence of the contaminants.[49] Other toximeters use measures of respiration rates or patterns or changes in behavior to indicate the presence of contaminants. Fish have long been used in water systems around the world as early warning sentinels for raw or untreated water quality. Other species have recently gained attention. Some of these approaches have been commercialized but development continues focused

[49] For a list of such instruments verified by ETV see: http://www.epa.gov/etv/verifications/vcenter1-27.html

largely on monitoring single cells of tissue or single microorganisms. The challenge is to find a sentinel that responds in a calibrated way to a broad range of contaminants —chemical and pathogenic—and that requires little maintenance and housekeeping. Some bacteria seem promising but there is still much room for improvement. While such devices are useful indicators of contamination, and in many cases the organism used is more sensitive to the contaminant than humans are, they do not provide the reliability and uniqueness of response needed. Therefore, when used they should be combined with other instrumentation.

Toxicity tests have traditionally been used to monitor wastewater effluent streams for National Pollutant Discharge Elimination System (NPDES) permit compliance or to test water samples for toxicity.[50] However, this technology can also be used to monitor drinking water distribution systems or other water/wastewater streams for toxicity. In such applications it may be necessary to remove free chlorine or chloramines as they can interfere with the response of the test organisms. Several types of toximeters are being used in water/wastewater security. The prime requisites for bio-monitoring or bio-sensors for drinking water or other water/wastewater security are rapid response and the ability to use the monitor at critical locations in the system, such as in water distribution systems downstream of pump stations, or prior to the biological process in a wastewater treatment plant. While there are several different organisms that can be used to monitor for toxicity (including bacteria, invertebrates, and fish), bacteria-based bio-sensors are better at this time for use as early warning screening tools for drinking water security because bacteria usually respond to toxics more quickly—in a matter of minutes. Methods that use higher-level organisms such as fish may take several days to produce a measurable result, although in some cases the response of fish to contaminants can be much more rapid—minutes. Bacteria-based bio-sensors have recently been incorporated into portable instruments, making rapid response and field-testing practical. The residual disinfectant can affect the response of certain organisms that might otherwise be useful in monitoring for toxicity. Therefore, removal of residual disinfectant may be necessary before the water sample is passed to the toximeter. These portable meters detect decreases in biological activity (for example, decreases in bacterial luminescence), which are highly correlated with increased levels of toxicity.

At the present time, few utilities are using biologically-based toxicity monitors to monitor water/wastewater assets for toxicity, and very few products are now commercially available. Several new approaches to the rapid monitoring of microorganisms for security purposes (for example, microbial source tracking) have been identified. However, most of these methods are still in the research and development phase.

In general, the commercial application of biological toxicity monitoring is quite new. Many biological toxicity-monitoring systems have been developed for site-specific applications, although the EPA ETV program has verified the performance of a number of these devices. Nevertheless, it is difficult to directly define sensitivities and detection limits of biological toxicity meters at the current time.

[50] See http://www.epa.gov/safewater/security/guide/biologicalsensorsfortoxicity.html

Biological toxicity monitors provide a kind of relative, nonspecific indication of water quality rather than precise, reportable measurements of specific parameters. The non-specificity is partly by design, because some biological toxicity monitors are typically used to provide a first-order screening test. Broad sensitivity to a wide range of contaminants is considered strength of a good bio-monitor.

At present, the main obstacles in the use of most approaches to field toximetry are that a) residual disinfectant must be removed prior to the toximeter and b) the time for sample preparation and measurement can be of the order of 20 to 40 minutes and therefore the toximeter is not a continuous monitor.

### 4.1.3.4 Total Organic Carbon (TOC)

Another measurement often made in water is TOC. This employs a well-defined and commonly used methodology that measures the carbon content of dissolved and particulate organic matter present in water. Many water utilities monitor TOC to determine raw water quality or to evaluate the effectiveness of processes designed to remove organic carbon. Some wastewater utilities also employ TOC analysis to monitor the efficiency of the treatment process. In addition to these uses for TOC monitoring, measuring changes in TOC concentrations can be an effective "surrogate" for detecting contamination from organic compounds (for example, petrochemicals, solvents, pesticides). Thus, while TOC analysis does not give specific information about the identity of the contaminant it can still be a valuable indicator of contamination events.

Generally, all TOC analyzers employ the same basic technique. A liquid sample is initially introduced to an inorganic carbon (IC) removal stage, where acid is added to the sample. At this point the IC is converted into carbon dioxide gas that is stripped out of the liquid by a sparge carrier gas. The remaining IC-free sample is then oxidized and the carbon dioxide generated from the oxidation process is directly related to the TOC in the sample. The analysis methods TOC analyzers use to oxidize and detect the organic carbon may be combustion, ultraviolet (UV) persulfate oxidation, ozone promoted, or UV fluorescence. With the combustion method, analysis is determined when carbon compounds are burned in an oxygen-rich environment, resulting in the complete conversion of carbon-to-carbon dioxide. In UV persulfate oxidation, the carbon dioxide is purged from the sample and then detected by a detector calibrated to directly display the mass of carbon dioxide measured. This mass is proportional to the mass of analyte in the sample. Persulfate reacts with organic carbon in the sample at 100 degrees Celsius to form carbon dioxide that is purged from the sample and detected. The ozone promoted method oxidizes the carbon by exposing it to ozone. UV fluorescence is a direct measurement of aromatic hydrocarbons in water. Fluorescence occurs when a molecule absorbs an "excitation" energy of one wavelength to be measured as concentration of the hydrocarbon.[51]

The response time of a TOC analyzer may vary depending on the manufacturer, but it usually takes from 5 to 15 minutes to get a stable, accurate reading.

[51] From: http://www.globalspec.com/learnmore/sensors_transducers_detectors/gas_sensing/total_organic_carbon_analyzers

Online TOC analyzers are designed to operate in remote locations without continuous surveillance by an operator. However, to operate reliably, the instruments require regular calibration, inspection, and maintenance by technically skilled personnel. Previous research recommends that, at a minimum, a weekly check should be done if the analyzer is in a remote location. See the EPA web page for more information, http://www.epa.gov/safewater/watersecurity/guide/chemicalsensortotalorganiccarbonanalyzer.html.

### 4.1.3.5 Radioactivity

Most water systems are required to monitor for radioactivity and certain radionuclides, and to meet Maximum Contaminant Levels (MCLs) for these contaminants, to comply with the SDWA. EPA requires drinking water to meet MCLs for beta/photon emitters (includes gamma radiation), alpha particles, combined radium 226/228, and uranium. However, this monitoring is required only at entry points into the system. In addition, after the initial sampling requirements, only one sample is required every 3 to 9 years, depending on the contaminant type and the initial concentrations. While this is adequate to monitor for long-term protection from overall radioactivity and specific radionuclides in drinking water, it may not be adequate to identify short-term spikes in radioactivity, such as from spills, accidents, or intentional releases. Thus, almost any intentional contamination event using radioactive materials would not be picked up under such a protocol.

In addition, compliance with the SDWA requires analyzing water samples in a laboratory, which results in a delay in receiving results. In contrast, security monitoring is more effective when results can be obtained quickly in the field. In addition, monitoring for security purposes does not necessarily require that the specific radionuclides causing the contamination be identified. Thus, for security purposes, it may be more appropriate to monitor for non radionuclide-specific radiation using either portable field meters, which can be used as necessary to evaluate grab samples, or online systems, which can provide continuous monitoring of a system. The focus should be on online systems that can be used in the field to provide quick, nonspecific measurements of radiation.

Ideally, measuring radioactivity in water in the field would involve minimal sampling and sample preparation. However, alpha particles can only travel short distances and they cannot penetrate through most physical objects. Therefore, instruments designed to evaluate alpha emissions must be specially designed to capture emissions at a short distance from the source, and they must not block alpha emissions from entering the detector. Gamma radiation does not have the same types of physical properties, and thus it can be measured using different detectors.

Measuring different types of radiation is further complicated by the relationship between the radiation's intrinsic properties and the medium in which the radiation is being measured. For example, gas-flow proportional counters are typically used to evaluate gross alpha and beta radiation from smooth, solid surfaces, but due to the fact that water is not a smooth surface, and because alpha and beta emissions are relatively short range and can be attenuated within the water, these types of counters are not appropriate for measuring alpha and beta activity in water. An appropriate method for measuring alpha and beta radiation in water is by using a liquid scintillation counter. However, this requires mixing an aliquot of water with a liquid scintillation "cocktail." The liquid scintillation

counter is a large, sensitive piece of equipment, so it is not appropriate for field use. Therefore, measurements for alpha and beta radiation from water assets are not typically made in the field.

Unlike the problems associated with measuring alpha and beta activity in water in the field, the properties of gamma radiation allow it to be measured relatively well in water samples in the field. The standard instrumentation used to measure gamma radiation from water samples in the field is a sodium iodide (NaI) scintillator. For further discussion, see http://www.epa.gov/safewater/watersecurity/guide/radiationdetectionequipment.html.

### 4.1.3.6 Biochemical Oxygen Demand and Respirometers

A biochemical oxygen demand (BOD) analyzer can be used to measure oxygen consumption as a surrogate for general toxicity. The critical element in the analyzer is the bioreactor, which is used to continuously measure the respiration of the biomass under stable conditions. As the toxicity of the sample increases, the oxygen consumption in the sample decreases. An alarm can be programmed to sound if oxygen reaches a minimum concentration (that is, if the sample is strongly toxic). The operator must then interpret the results as a measure of toxicity. It is difficult to define the sensitivity and/or the detection limit of toxicity measurement devices because limited data are available regarding this specific correlation between decreased oxygen consumption and increased toxicity of the sample. More information on this approach can be found at http://www.epa.gov/safewater/watersecurity/guide/chemicalsensorfortoxicitybodanalyzer.html.

A respirometer monitors the concentration of gas contained within an enclosed head space into which the material being monitored is respiring. Periodic sensing of the gas concentration, along with an equally accurate measurement of the volume of the head space, allows calculations of incremental and accumulated values for consumption and production. The system can be configured for single or multiple gas sensing. Oxygen, Carbon Dioxide, Methane, Carbon Monoxide, Hydrogen Sulfide and Hydrogen can be sensed over specially selected ranges. In aerobic testing, in most respirometers the measurement is actually a detection and quantification of the off gasses, demand gases or respiration byproducts. In some respirometers it is the change in pressure caused by the consumption of oxygen. Most are equipped with data collection and processing by computer. Most also share a common gaseous scrubbing system to remove CO2 from the reaction chamber, as that would over time poison the microbes. Respirometers are also used for anaerobic testing.

### 4.1.3.7 pH

The measurement of pH in water is one of the oldest and most useful measurements. Along with changes in conductivity measurements, changes in measured pH give an indication of changes in the ionic constitution of the water. While many benign additives can cause changes in these measures, combined with other measured changes, they can be very useful indications of a contamination event.

The EPA considers pH to be a secondary "contaminant," with an acceptable range of 6.5 to 8.5. This is a non-enforceable standard set primarily for aesthetic reasons rather than health-related reasons.

### 4.1.3.8 Oxidation Reduction Potential

Oxidation reduction potential is related to the concentration of oxidizers or reducers in a solution, and their activity or strength. It provides an indication of the solution's ability to oxidize or reduce another material. Because oxidizers and reducers are relatively unstable in solution, those present in a system have generally been intentionally added for a specific purpose. These chemicals have the ability to oxidize (accept electrons) or reduce (donate electrons). When present in a solution, the addition of an oxidizer will raise the ORP value, while the addition of a reducer will lower the ORP value. The greater the concentration of an oxidizer or reducer in the solution, the faster the rate of reaction will be. The actual ORP value of a solution depends on both the concentration and activity of the oxidizer present.

For most purposes, water is generally considered "neutral" with regards to its ORP value. Water solutions are actually very weak oxidizing solutions, a result of dissolved oxygen that is nearly always present. The ORP value of the solution quantifies the true ability or potential that the solution has to oxidize or reduce. In most applications, this property is more important than the absolute concentration of the oxidizer or reducer in the solution.

In water disinfection applications, the ORP value of the solution may be more meaningful than measurements of free residual or total chlorine. This is because the equilibrium between two forms of the chlorine in the water shifts with changing pH. The molecular form of free chlorine in water is HOCl, or hypochlorous acid, a strong, fast-acting oxidizer. As the pH increases, the HOCl converts to its ionic form, OCl (the hypochlorite ion), which is a weaker, slower acting oxidizer. As a result, the pH has a significant effect on the oxidizing strength of any chlorine solution. Monitoring chlorine alone would not indicate oxidation strength. Further, if the chlorine is combined with an amine or a stabilizer, the "total" chlorine concentration is also affected. These mixtures also do not provide significant oxidizing capability.

Hypochlorite (NaOCl/bleach) is added to the scrubbing solution to oxidize, disinfect or eliminate the odors. Acid or caustic may also be added depending on the specific gases involved. An ORP measurement system in the recirculation line can monitor the consumption of the NaOCl and automatically replenish when necessary.

The measurement of ORP is very similar to that of pH. Platinum is sensitive to the activity level of the electrons in the same manner as pH-sensitive glass is sensitive to the presence (activity) of the hydrogen ion. The electrode can be considered a battery, where voltage flows from the measurement side to the reference side of the electrode. The function of the reference electrolyte is to complete the circuit to the solution being measured. For this reason, it is important that the reference junction remain clean and free flowing. Maintenance of an ORP electrode is similar to that for a pH electrode. The electrode should stay in solution at all times; the system requires routine cleaning and calibration to compensate for electrode degradation; and, the electrode will have to be replaced on a regular basis (every 1-2 years, depending on the application).

### 4.1.3.9 Conductivity

Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum-cations. Some organic compounds do not conduct electrical current very well and have a low conductivity in water. Some organic molecules hydrolize or dissociate in water and some of those produce ions that lead to increased conductivity. Conductivity is also affected by temperature: higher temperature generally means greater conductivity.

Conductivity in water is measured in micromhos per centimeter (μmhos/cm) or microsiemens[52] per centimeter (μs/cm). Distilled water has a conductivity in the range of 0.5 to 3 μmhos/cm. For comparison, the conductivity of rivers in the United States generally ranges from 50 to 1500 μmhos/cm. Industrial waters can range as high as 10,000 μmhos/cm.

Measurement of conductivity is conceptually very simple. It measures the current between two electrodes across which is a known voltage. Conductivity measurements are generally very reliable.

### 4.1.3.10 Chloride, Phosphate, Ammonia, and Nitrate[53]

The breakdown of many pesticides and other organic molecules results in production of ammonia, chlorides and nitrates. As presented in the paper on candidate instruments in Appendix A, "phosphate, nitrite, and nitrate continuous monitoring is also available and is currently used in the wastewater industry. Applying this technology to drinking water monitoring offers another option to indirectly determine microbiological contamination in the distribution system. Nitrogen is a component of prokaryotic cells, composing 6-15 percent of the cell depending on cell type and nutrient conditions. Phosphorus is a required element for bacterial growth, is assimilated into cells, and found in nucleic acids, proteins, phospholipids, ATP, and coenzymes. When cells are lysed, phosphate is released. There is typically a stoichiometric relationship between nitrogen in a cell, and phosphate, with cells containing considerably more nitrogen. Utilizing nitrogen and phosphorus as water quality surrogates offer the potential to detect microbiological contaminants, and also to provide more specificity to detecting chemical contaminants. One key consideration for applying this technology to drinking water would be in lysing the cell before the solution was passed through monitors. Common ways to lyse cells include sonication and homogenization."

These indicators are measured with a number of traditional, wet-chemistry methods (titrations), instrumentally (colorimeters, UV absorption), or by correlation with electrical conductivity measurements. There are also a number of innovative instruments now available for online field use.

### 4.1.3.11 Spectrometry—UV

Recent advances in real-time UV-spectrometry allow this method to be added to the list of effective techniques for contaminant detection and identification.[54]

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[52] The mho has been relabeled as the siemen. They are equal in value.

[53] An EPA reviewer recommended adding these measurements since they may provide good indications of the presence of contaminants.

[54] See for example http://www.ecomonitoring.com

One strategy is to use the standard calibration algorithms for substances like T(D)OC, nitrate, turbidity, organic substances like aromatics, phenols, hydrocarbons, and others, and to monitor those substances over time. Although UV-Vis-spectroscopy is sensitive down to the low parts per billion (ppb)-range for many organic pollutants, it will not be selective enough to indicate the type of micropollutant at the drinking water level. Therefore, a closer analysis must follow in cases of elevated signals. However, the signal will often represent a sum parameter, but also as such, it will be orders of magnitude more sensitive than, for example, DOC measurements.

Another strategy is to use the UV spectrum as a whole, to detect even the smallest changes between the measured spectra and reference spectra at any wavelength, often changes that become only evident in differential spectra. As an example, variations of substance concentrations are derived from direct absorption values, and changes of the characteristics of water are detected from first and second order derivatives of the spectrum. Sometimes the detected changes cannot directly be correlated to known substances, but nevertheless may provide a sensitive alarm parameter.

There are several ways to exploit spectral information:

- Qualitative interpretation of spectral deviations from a site specific reference spectrum (peaks, shoulders, gradients, analysis of derivative spectra).
- Changes of spectral features over time (anthropogenic changes, for example, from spills are typically faster than natural changes).
- Compare spectral differences between measuring points of a measuring network—"delta spectrometry."

### 4.1.3.12 Luminometers[55]

Luminometers are luminescent toxicity screening instruments. They often use a freeze-dried reagent, to determine the inhibitory effect of water-soluble samples, including suspensions of solids, on the emission of light from the reagent. The reagent may contain naturally luminescent organisms such as Vibrio fischeri, which produce luciferase as a part of their metabolic pathway. Luciferase catalyzes the oxidation of a long-chain aldehyde and coenzyme, flavin mono-nucleotide. Substances affecting any part of the metabolic pathway of the bacteria directly affect the amount of light they emit. Toxic compounds interfere with this metabolic process, resulting in a reduction of light emission. To determine the toxicity of a sample, changes in light output are measured with the luminometer.

## 4.1.4 Selecting an Instrument Suite for Water Supply Monitoring

In a practical sense, a utility cannot be expected to incorporate all the instruments that may respond to the presence of contaminants. A subset consisting of those few (probably no more than 3 to 5) that

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[55] See for example, http://216.239.41.104/search?q=cache:huBHpwZnOSkJ:www.epa.gov/etv/pdfs/vrvs/01_vs_biotox.pdf+epa+luminometer&hl=en

respond most distinctly to the contaminants of concern would be deployed. At this time, however, there is insufficient information upon which to base a selection of those best instruments to detect the broadest range of likely contaminants.

Within the classes of instrument to be used, four categories of factors should be considered in selecting a suite of instruments for an OCMS:

- The capabilities of the individual instruments including: parameter measured, sensitivity, accuracy, reliability, fieldability, and cost.
- The capabilities of the set of instruments whose data are analyzed together: whether the measures are complementary and the ability to cross-correlate data.
- Characteristics and constraints of the site such as size constraints, power and telecom requirements and availability (for example, SCADA availability), environmental conditions such as humidity, temperature, and access to water flow and water disposition.
- Operational considerations particularly: maintenance, down time, calibration, testing, housekeeping (for example, reagents, etc.), and onboard data analysis.

For contaminants of moderate or low toxicity (most pesticides and industrial chemicals) changes measured in a laboratory simulation for residual chlorine, pH, conductivity, TOC and turbidity, taken together, were sufficient to indicate the presence of contaminant at levels well below LD50 values—although probably not at the NOAEL values. (See the white paper in Appendix A on instrument selection.)

For more toxic chemicals (for example, biotoxins) where concentrations of concern would be much lower, these surrogate measures might not give a sufficient indication.

Even for some pathogens, this suite of measurements is not likely to be sufficient to provide a reliable indication of the presence of contaminant.

A more comprehensive suite might include a toximeter. While that would extend the applicability of the instrument suite, it still is unlikely to be comprehensive in its coverage.

In addition to these measurements, to facilitate the use of models in predicting flow and fate of the contaminant, the suite of instruments should include measurements of flow/pressure and temperature.

### 4.1.5 Suggested Guidance for Selection of Instruments for Water Supply Systems

An OCMS for water supply should include a number of platforms containing instrument suites that can measure surrogate parameters with sufficient accuracy, sensitivity and reliability so that the correlation of contemporaneous measurements from the suite will indicate the presence of contaminant at levels at or above the NOAEL values and provide information on the location and extent of the contaminant in the system. An indication of the class of contaminant, if not its specific

identity as well as concentration, is desired but not possible with currently available technology except perhaps for a few select contaminants.

No analytic basis exists yet for understanding the specific relationships between contaminants and surrogate measures, although some partial empirical work indicates such relationships for a limited class of situations. From the limited empirical studies done and reported to date, it is recommended that for water supply, the candidate instrument suite should include instruments to measure:

- Flow/pressure
- Temperature
- pH
- conductivity
- residual chlorine
- turbidity
- TOC
- ORP
- Ammonia, chloride and nitrate
- Toxic materials (for example, a toximeter)
- Radiation (alpha, beta, and gamma)

From these, based on further laboratory and field study, a smaller set should be chosen. At present, however, there is no generally agreed basis on which the set can confidently be reduced. A better understanding of the relationship between surrogate measures and the presence of contaminants is necessary to enable progress.

As a general rule, in comparing options for particular instruments, the primary factor should be their performance characteristics. An instrument with higher sensitivity, accuracy and reliability is clearly preferred unless other characteristics of the instrument or site preclude its use. Because sample acquisition is likely to be a crucial aspect of verifying the contamination event as well as necessary for identifying and quantifying the contaminant, the ability to take a sample when a threshold is reached is an important characteristic.

Two specific resources should be monitored for current information on instruments:

- EPA's Environmental Technology Verification site, which verifies the performance of technology submitted by manufacturers. www.epa.gov/etv/verifications/verification-index.html
- EPA's Security Product Guide, which describes a number of sensors for water monitoring and gives vendor contact information. www.epa.gov/safewater/watersecurity/guide/tableofcontents.html#water.

## 4.1.6 Siting of Platforms (Water Supply)

Contamination events can affect any portion of the water system. In principle, the OCMS should provide coverage of all segments of the system in which contamination presents a risk. Table 4-2 lists the segments of the water supply and wastewater systems and indicates the advantages and disadvantages of locating instrument platforms at those locations.

**TABLE 4-2**
Potential Locations for Instruments—Water Supply

| Location | Advantages | Disadvantages |
|---|---|---|
| Source waters | Covers large segment or all of system<br>Long lead time for response<br>Long time for corroboration<br>For navigable source waters threat of contamination can be relatively high<br>To be of concern to public health, large quantities of contaminant needed—therefore easier to detect | Threat of intentional contamination of source waters is relatively low for source waters on which no commercial traffic flows |
| Raw water transport | Threat of intentional contamination is a bit higher than for sources<br>Covers large segment or all of system | Still a low threat for intentional contamination |
| Treatment plant | Threat of intentional contamination slightly higher than for source or transport.<br>Insider threat higher | Relatively low threat for intentional contamination because access is limited and there is potential for discovery |
| Finished water reservoirs | Threat of intentional contamination considerably higher | There may be many of them requiring coverage |
| Early distribution system | Moderate threat, particularly at sites to which access can be gained (for example, valves, pumps and check points)<br>R relatively long time available for warning and response | Need several platforms to cover entire system |
| Mid distribution system | Higher threat, covers many of the likely contamination entry points including valves, pumps and inspection/sampling ports | Need multiple platforms to get full coverage, moderate to little warning time |
| Entry pipes for likely targeted customers | Higher risk area; expect better cooperation from such customers | Locating so close to user leaves very little time for effective response |

Prior to the recent attention given to detection monitoring for intentional or unintentional contamination, monitoring has been mostly conducted for ambient/background water quality monitoring, regulatory compliance monitoring and operational purposes. For water utilities, background water quality monitoring sampling locations have been selected before raw water intakes or at well-heads to monitor raw water quality and adjust treatment as necessary. Similarly, for compliance monitoring, sampling sites have been located in clear wells prior to delivery into the transmission and distribution systems, and at distribution system locations identified through regulatory requirements. Because the objective has been compliance, the types of constituents

monitored have been known beforehand and the path taken by the water within the distribution network has been relatively predictable under expected flow conditions.

The problem becomes more complicated when intentional contamination is considered. In this case, the source, type, concentration and injection time and method are unknown, adding further complexity to the problem. The ideal solution would be to locate sampling sites at all possible nodes of a distribution system to detect contamination. Of course, this would be cost prohibitive, especially when sample collection has to be frequent or continuous, and instruments have to be a) highly accurate, and b) capable of detecting a wide range of contaminants at low enough concentrations. The use of intuitive methods for locating sampling sites may not be effective in meeting all these objectives. To address some of these concerns, academicians have typically used mathematical programming (optimization) methods, sometimes together with hydraulic/water quality network models, to tackle this problem. They have tried to identify the cost optimal sampling sites given certain constraints on the distribution system, and treating it as a form of "facility location" problem in mathematical programming and operations research. A main disadvantage in the use of such models by utilities has been the sophistication needed to develop them.

However, with the enhancements being made to current hydraulic/water quality network models, promising tools for identifying potential sampling sites have been emerging. Currently, there are a few integrated hydraulic/water quality network models with varying capabilities that can be used to develop strategies for locating sensors in distribution systems. These include EPANET/PipelineNet (from EPA), H2OMAP (from MWH Soft, Inc.), WaterCAD (from Haestad Methods, Inc.), MIKE NET (from DHI), AQUIS (from Seven Technologies A/S) and OptiMonitor (from OptiWater). These will be discussed further in the next section. In addition, there are many other engineering, analysis and software companies (for example, Wallingford Software Ltd. of the UK) that are developing or have developed interesting water system models.

## 4.1.7 Selection of Sensor Platform Locations

Among all the elements affecting platform location, the one that should have the biggest effect is the importance of the information to be gained by measurements there. For example, contamination in the part of the system that serves residential communities in general would be expected to have a greater impact on public health than a part of the system that serves mainly business or industrial customers. Locations that allow earlier detection in these more sensitive portions of the system would be expected to have a higher priority than those locations that are better suited to less sensitive portions.[56]

Some water system customers are at greater risk because they present higher value targets for a terrorist attack. These considerations pertain to such high priority targets:[57]

[56] For an example of a model to determine siting see: A Stochastic Early Warning Detection System Model for Drinking Water Distribution System Security Avi Ostfeld and Elad Salomons, Technion presented at EWRI Annual Mtg Salt Lake City, UT 2004

[57] Greg Welter, e-mail communication on review of draft, September 2004.

- The most knowledgeable attackers would likely choose an insertion point focused on their intended target, for greater certainty of impact and economy of use of a likely scarce resource (the contaminant). This would argue for the incoming supply line to such facilities (typically a high security government facility, or a target of high iconic value) to be a location of an OCMS instrument.
- However, if the attacker were seeking maximum, widespread impact, and again were knowledgeable about his craft, his most likely choice of insertion points would be at a pump station discharge. At such a location, he would have the greatest assurance of having the contaminant effectively and broadly distributed. This may well have been the intention behind the November 2003 contamination incident at the Ta'Kandja pump station in Malta, although it appears from the failed attack that this attacker failed to plan his attack fully. As well as the advantages to the attacker noted above, the pump station has some advantages to the utility in terms of power, telecommunications, and other infrastructure needed to support the OCMS. However, the utility would have to take particular measures to enclose and protect the sensor.
- The most likely point of attack (or of intrusion in which an attack might be suspected) would be at a storage facility. Because at some of these locations the water is not under pressure, contaminant introduction would be easier, although its effect less certain, particularly if the water exchange from the storage facility is slow.

In many cases, the convenience and cost issues associated with communication links, power and other environmental factors will be highly important in determining location. While the instrument selection is based on surrogates for the contaminants of concern, local conditions could preclude the use of some instrument platforms, in turn limiting the parameters that can be monitored. Thus, the type of instrument(s) that can be used as well as their location determines a) the parameters that can be monitored, b) the detection limits and accuracy of the data and information inferred therefrom, c) installation and operational requirements (periodic versus continuous sampling, data collection, communications, maintenance requirements, etc.), d) the integration of the instruments with existing water quality monitoring systems, and e) number of instruments that may be installed. When selecting sensor locations, both local site conditions and system wide considerations must be taken into account. The local site conditions that a utility should consider include:

- *Easy access to the instrument site by authorized personnel is important,* because all instruments require periodic maintenance, the frequency of which may vary with the particular technology, manufacturer, or the quality of the water being measured. For example, many chlorine analyzers require periodic replenishment of the various reagents that are necessary for their operation. Weekly to monthly service is required for this activity, depending upon the stored quantity of reagent. An instrument calibration should be conducted at the same time that reagents are refilled, and site access must facilitate this activity. This factor is directly related to the operations, maintenance and upgrading of the system. At the same time, the site should be secure against unauthorized persons.
- *Available space for the instruments and auxiliary equipment* (for example, within a utility-owned valve pit or manhole) must be considered. In some cases, early warning instrumentation may be

installed in appropriate host facilities. Municipal buildings, public schools, and fire or police stations may provide space for an instrument cabinet, a sample supply, and a drain for wastewater. Private, large-use facilities such as hospitals, hotels, sports arenas, or convention centers may be willing to provide space for an instrumentation cabinet, although some financial or water/sewer billing compensation may be requested in return. In selecting a host facility for an early warning system instrumentation cabinet, easy 24-hour access by utility technicians must be assured, as well as security against tampering.

- *Suitability of candidate instruments or sample collection method for the sampling site,* including the discharge of waste stream, access to electricity/power, and data transfer and telecommunication equipment, must be taken into account. Many of the important process instruments, such as chlorine analyzers, require a slipstream from the water supply pipe for injection of sample treatment reagents. These instruments generate a waste stream (although relatively small) that must be disposed of. Turbidimeters are generally configured as flow-through devices, and therefore require a slipstream, although the sample stream could be re-injected into the distribution flow. Other instruments, such as pH, conductivity, and dissolved oxygen sensors, as well as the multi-parameter probes, may be inserted directly into the distribution flow stream. To facilitate maintenance or avoid decontamination requirements, many utilities may elect to install these instruments in a slip-stream rather than into the actual distribution system flow. Thus selected locations for early warning system instruments will likely include consideration of waste stream disposal. In environments where sanitary sewers exist, it may be possible to route sample drains into the sewer with proper attention given to backflow prevention. In some suburban or rural environments, this may not be possible. In the absence of in-ground vaults, roadside instrument cabinets may be installed with a gravity drain to the sewer. Either option may result in significant costs for sample drain installation under sidewalks and roads.

  Another requirement is ready access to electric power. To host early warning system instruments in appropriately sized valve vaults, waste stream disposal may require use of a pump to move the liquid to the sewer. Electric power will be required for pump operation, but since some power will be required for operation of any instrument, power supply will be a consideration for all monitoring locations. Depending upon particular site conditions and installed equipment, solar/battery operation of the equipment may be possible or required at some locations.

  Similarly, communication methods for remote data collection and alarming must be supported. Suitability for SCADA communication must be determined, if applicable, including an assessment of whether required radio antennae will be feasible or permitted. Alternately, availability of telephone communications or fiber optic data lines must be considered.

- *Physical security of the instrument site* is important to guard against unauthorized access or tampering. The monitoring site must be reasonably secure to prevent tampering with the instrumentation, injection of contaminants, falsification of instrument data, and disruption of the power supply or data communications. Installation in or near areas that can provide some intruder deterrence such as police stations, fire departments, schools, etc., where suspicious activity can be more easily detected or prevented are recommended.

- *Hydraulic conditions at sampling sites* can affect the suitability of the site for the installation of instruments, because turbulence in the pipe might affect sample collection or measurement.
- *Existing sampling sites* for baseline or compliance monitoring may be good candidates for installing additional sampling instruments.

System-wide and topological factors include:

- *Potential areas or entry points of contamination* (such as reservoirs, blow off valves, pump stations:), ease of intrusion at these locations (perhaps due to lack of physical security) and ease of insertion of contaminants must be taken into account because locations closer to such sites are candidates for sampling locations. This factor also affects the type of contaminant that might be used by an intruder.
- *Likely contaminants* need to be considered by utility personnel. Water and wastewater systems can be contaminated by a wide array of chemicals, microbial contaminants, biotoxins and radioactive contaminants. In addition to acts of intentional contamination, unintentional events may also be the source of contamination and should be considered when designing monitoring systems. Sampling in an industrial area may, for example, include a stronger focus on sensing chemical contaminants, which is particularly important for monitoring wastewater collection systems. Monitoring for all potential contaminants remains necessary at all monitoring locations.
- *Contaminant transport time and concentration* also influence where and how many sensors need to be installed. Likely contaminant transport rates in the network (due to flow, dilution and decay), changes in contaminant properties due to bulk water properties, wall effects (pipe material, tuberculation, biofilm), and mixing all affect the time required for the contaminant to reach consumers at a certain concentration. This in turn determines the time a utility has to detect and analyze the situation and respond as appropriate. The delivery time and concentration also determine where and how many sensors need to be installed.
- *Vulnerable populations* (such as the elderly, ill, or children) at different parts of the network must be taken into account. Areas that serve such populations are candidates for siting instruments.
- *Relative water demand and associated flow characteristics* are critical in identifying sampling locations, because the temporal and physical characteristics of the network must be taken into account in selecting selected sampling locations. Temporal factors include diurnal (for example, morning vs. noon), daily (for example, weekday vs. weekend) and seasonal (for example, summer vs. winter) variations. Physical factors include pipe length, size, condition, material, appurtenances, bends, T-s, etc.
- *Frequency of sampling,* that is, periodic vs. continuous sampling, will impact both the number and locations of the instruments selected and the amount of data collected and analyzed. Sampling frequency constraints are determined to some degree by the expected contaminant pulse morphology and duration. In some of its research work, EPA assumes that a contaminant is introduced over a one-day period; this implies that sampling can be as infrequent as once every

several hours.[58] However, a credible scenario would have a contaminant inserted over a considerably shorter period—say an hour. In this case, the required sampling frequency would be substantially greater. The more common monitoring methods for microbiological contamination rely on periodic grab samples that typically take hours or days to analyze. These methods are usually sufficient for compliance monitoring but are inadequate for early warning systems because by the time the results are known, a considerable portion of the contaminants could be consumed. Thus, if periodic sampling needs to be performed, then the frequency of sampling and the number of sampling locations should be increased to improve the likelihood of detection and timely response.

- An assessment of the parameters discussed above and the literature lead to the identification of the following factors for consideration in the placement of instruments:
  - Minimize contamination detection time for a given number of sensors (or budget), versus minimize the number of sensors (or budget) for a specified time of detection.
  - Maximize monitoring coverage for all consumers versus maximize coverage for vulnerable (at risk) consumers such as populations at schools, nursing homes, hospitals, etc.
  - Continuous monitoring versus periodic monitoring.
  - Automated sampling versus manual sampling.
  - Use of few expensive monitors (for example, miniaturized gas chromatographs[59] or mass spectrometers) versus use of many less-costly instruments (for example, chlorine residual and other surrogate parameter analyzers).
  - Instrument life cycle costs.
  - Instrument ease of use and maintenance by utility.

## 4.1.8 Suggested Guidance for Locating Instruments in Water Supply

To the extent necessary to meet budgetary constraints and to address higher priority monitoring needs first, the placement of instruments should be based on a phased approach. Even before establishing an OCMS, the utility might consider expanding the existing surveillance system by increasing the sampling frequency, parameters monitored and number of sites. However, because some contamination events may be as short as an hour and most likely not extend beyond several days, it is very unlikely that expanding the existing surveillance system will reduce the risks of contamination to any sensible degree. Suggested phases in establishing an OCMS are described below.

A calibrated and relatively detailed extended period hydraulic model can be used as a tool to help a utility identify potential sampling locations. Functionality present in current hydraulic/water quality

[58] The EPA reviewer who made this comment referred to the TEVA research program but did not provide further reference.

[59] G.A. Eiceman: Instrumentation of Gas Chromatography, Encyclopedia of Analytical Chemistry
Edited by Robert A. Meyers. Ó John Wiley & Sons Ltd, Chichester. ISBN 0471 97670 9
See also: http://eetd.llnl.gov/mtc/Instruments.html

modeling packages incorporates GIS, CAD, and image data. GIS data should be available for use as base mapping or for overlay analysis to support the site selection process.

Several secondary benefits are provided by the hydraulic models now available from many commercial vendors. These models enable the user to trace the movement of constituents through the system, isolate portions of the system based on the extent of contamination, calculate volumes of contaminated water requiring flushing, and identify where system redundancy is not adequate in the case of a pipe break or isolation requirement.

See the white paper on siting instruments in Appendix A for more details on this methodology for locating sampling sites. It recommends a combination of ranking critical facility locations and performing hydraulic analyses such as contaminant source tracing, identifying contaminant pathways deemed most likely, and iterating to identify the best locations for monitoring.

It is important to note that the outcome of this methodology may suggest areas rather than specific locations that may be most appropriate for monitoring sites. The final step in the selection process would be to confirm the recommended locations through field visits to determine whether sampling equipment could be placed at or near the desired locations. The inability to physically locate monitors or to provide power or communications may disqualify some locations, and having areas in which to locate the equipment may provide more flexibility than specific locations.

Depending on the current monitoring capabilities and size of a utility, the guidance provided above can be implemented in phases. Prior to the identification of locations, though, the utility must decide which parameters to monitor, its budget (capital and operation and maintenance costs) for the early warning system, and its personnel resources (both number and skill level). The local and system wide conditions may limit the number and type of instruments it will be able to utilize, which then will determine how many sampling sites can be selected. Once these conditions are determined, then the utility can start with the phase that fits its conditions best.

- An initial phase might consist of establishing a pilot program using one or a small number of platforms each with a minimal set of instruments—for example, residual chlorine monitor, conductivity monitor, turbidimeter and toximeter. TOC instruments are substantially more costly but if the budget allows, adding one to the platform can be valuable. This will give the utility experience in handling the data, using a model, establishing an elemental communications system, handling the maintenance and housekeeping functions and getting some experience with the benign abnormalities that will likely characterize the water system.
- A second phase might consist of adding an instrument or two to each platform and/or adding a small number of platforms. State of the art equipment should be used even if it does not match the earlier installations. In this phase, the utility would upgrade some of the sensors to those that have superior capabilities such as monitoring a wider range of parameters, lower detection limits, fewer false negatives and positives, etc. Consideration might be given to working collaboratively with a research organization (government, national laboratory, university, instrument manufacturer) as a test site for a developmental sensor to be used in conjunction with the existing platforms.

- Subsequent phases would successively expand and upgrade the system.
- A final stage might have an optimal number of appropriately placed sensors tied to a central data analysis facility.

When selecting the sites, the following recommendations are offered:

1. The utility should identify as many candidate sites at the outset as practical. The beginning step is to identify, using the contaminant risk analysis methodology, the highest priority vulnerabilities to contamination[60]. This assessment would include evaluations of accessibility of the contaminant insertion point as well as the criticality of the affected population segment.
2. If the utility has a functional and well-calibrated network model, it should determine the dominant contaminant pathways. If the utility does not have such a model, then using its knowledge of the system, it should make educated guesses on where the dominant pathways might be.
3. For corroboration purposes during normal operations, the utility should choose existing compliance sampling locations close to the dominant pathways and start collecting samples there. Alternatively, with state regulatory agency approval, it might be able to move its compliance sampling points to locations that are better suited for contaminant detection monitoring. If the utility is not restricted in its resources, then it could select the best locations based on its hydraulic analysis.

The methods for selecting sampling locations to detect contaminants within a distribution system network have been either intuitive or analytically over-simplified. Intuitive methods cannot account for the variability and uncertainty inherent in the intentional or unintentional contamination of water distribution systems. However, more detailed analytic approaches such as mathematical programming are currently too complicated for water utilities to implement on their own. Furthermore, little guidance has been available to utilities that do not have the resources to develop such sophisticated approaches. Currently, for water distribution systems, hydraulic/water quality network models are the most practical tools for identifying candidate locations for monitoring instruments and sensors.

It is apparent that the identification of sampling locations is an iterative process involving many diverse sources of information and will be different for every utility. A utility will also be able to shape the analysis by identifying policy direction prior to the evaluation. Ultimately a series of steps would be undertaken based on the analysis described above that would allow the utility to identify a number of targeted sampling locations.

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[60] One EPA reviewer has commented that basing siting on the potential entry points of contaminant is a "weak design basis" since such information is very limited and highly uncertain and because distribution systems are widely vulnerable—i.e., many potential points of entry. This presumes that it would not be practicable to set priorities among the potential entry points. While this may be true for some utilities, the notion of setting priorities among vulnerabilities is inherent in all current approaches to vulnerability and risk assessment and is therefore adopted in this case as well. It remains to be seen in the application of appropriate vulnerability assessment methodologies whether such priority setting does or does not seem justified in any particular utility.

The number of sampling points recommended by the analysis will probably be higher than what a utility with limited budget can implement. In this case, additional prioritization will be required to identify the relative importance of each of the parameters represented by the steps. Several iterations may be required before an acceptable number of locations can be identified. Another option would start with a desired or target number of sampling locations. However, it may prove valuable for the utility to go into the process without any expectation of the target number of locations, allowing the process to identify an appropriate number.

A knowledge-based risk assessment of the local site conditions and system-wide factors discussed earlier is advised for each utility before conducting any detailed hydraulic analysis. Such an assessment will help narrow the number of iterations and analyses and, ultimately, the number of monitoring locations recommended.

It is also important to note that the quality of the predictive information from the utility's network model will be only as good as the investment made in developing that model and the skill and experience of those operating it. Of particular importance is a spatially accurate demand allocation and true model representation of operational settings. The quality of the network model is validated by performing comprehensive steady state and extended period calibration prior to any use of the model as a predictive tool.

## 4.2 Wastewater and Stormwater

The primary justification for an early warning system is to minimize the exposure of the public to contaminated water and its effects. However, early warning devices for sewer systems have been used primarily to avoid damage to receiving facilities or waters. These have included alerting for overflows and avoiding spills, avoiding treatment process upsets (particularly biological treatment systems that are susceptible to toxic contaminant overloads), and ensuring the safety of sewer workers. Additional concerns have included economic disruption and physical destruction of facilities and buildings (and associated loss of life). Because sanitary and storm sewers run near or beneath key buildings and public areas and are in close proximity to other utilities such as gas, water, communication, and transportation networks, early warning systems in sewer networks have to be part of the emergency response plans of wastewater utilities.

The wastewater and stormwater contamination problem is very different from the problem of contamination of water supply. As noted in earlier sections, the primary public health and safety concerns in wastewater/stormwater systems are:

- The potential for injury by fire or explosion of volatile materials in the collection portion of the system.
- The public health risk from toxic materials and pathogens in public places as a result of escaping from wastewater or stormwater in the collection portion of the system.
- Monitoring against toxic materials or pathogens in the wastewater/stormwater systems or sewers would be best served by instruments that detect such materials either in the wastewater

or in the air spaces within the collection system or the air space above the wastewater in the sewer.

## 4.2.1 Detecting Volatile Organic Materials

For wastewater collection systems, the monitoring system should include instruments to measure VOCs and either biological oxygen demand (BOD) or respiration in the wastewater and hydrocarbons above the wastewater surface. When appropriate instrumentation for online detection of pathogens in the wastewater and in the air spaces within the collection system becomes commercially available, it should be incorporated into the monitoring system.

VOC detectors detect, monitor or analyze volatile organics present in an environment. Detectors sense situations outside normal operating parameters and are set to alarm when these conditions are violated. Monitors are also set up to alarm, but their role is to determine which gases are in the stream being measured, and in what quantity they are present. Analyzers provide a breakdown of what is found, log the information, and can download it to a computer where further analysis and record keeping can be performed. Some instruments are designed to detect only one gas while others detect multiple species.

There are seven basic types of measurements that can be made on VOCs. Percent of the lower explosive limit (LEL) or lower flammable limit (LFL) of a combustible gas is defined as the smallest amount of the gas that will support a self-propagating flame when mixed with air (or oxygen) and ignited. In gas-detection systems, the amount of gas present is specified in terms of percent LEL: 0 being a combustible gas-free atmosphere and 100 being an atmosphere in which the gas is at its lower flammable limit. Another measurement is percent by volume, which measures the amount of a specific gas within a sample. The relationship between percent LEL and percent by volume differs from gas to gas. Trace measurement is usually given in units of ppm or ppb. Leakage and consumption rates can also be measured, as can gas density and signature or spectrum.

Specifications for VOC instruments are first, what type of gas requires sensing, and second, through how many channels does the instrument need to sense. This can be for multiple types of gas sensors, redundant sensors for the same gas, or for placing sensors throughout a location to get sampling at many different spots in the same general area. Other factors to consider are response time, maximum distance from the leak that the detector can detect gases, and flow rate through the sensor.

These instruments can typically be handheld, larger portable devices or permanently mounted instruments. They have four primary purposes: personnel exposure monitoring, air quality monitoring, confined space monitoring, and process gas monitoring.

Generally available features for these instruments can include temperature and humidity measurements, external or internal sampling "sniffer" pump, interchangeable probes, alarm settings, controller functionality, self-calibration, data storage or logging, and usability in hazardous environments.

Chlorine measuring instruments are among the most commonly used, robust and accurate instruments for water monitoring.[61] Sensitivities to 0.01 ppm are achievable with a number of commercial units suitable for distribution system and wastewater applications.[62]

Commercial systems exist that can identify airborne pathogens and spores, but they take days or, at best, hours to produce results and are not field-qualified.[63] However, the detection of pathogens in air is a topic of intense interest and a number of research and development efforts are underway in government labs, the national labs, academe and private industry.

A system being developed by Lawrence Livermore National Laboratory to identify such spores—the bioaerosol mass spectrometry system—recently demonstrated an ability to process a measurement in less than one minute. This mass-spectrometry technique can successfully distinguish between two related but very different spore species. It can also sort out a single spore from thousands of other particles—both biological and nonbiological—with no false positives. However, this instrument is not available commercially at present.

Another instrument under development at Lawrence Livermore and Los Alamos National Lab is called the Biological Aerosol Sentry and Information System (BASIS). It is designed to detect and locate an aerosol release of a biothreat organism quickly and accurately enough for an effective response. BASIS collects air samples at well-defined locations and at specified time intervals to help determine both the time and place of the release. Its mobile field laboratory rapidly tests samples for evidence of potentially lethal bacteria and viruses. Safeguards built into the system ensure a sample's integrity. BASIS is designed with extremely high sensitivity for detecting the most likely threat pathogens in a particular scenario. BASIS is designed for indoor or outdoor use. In 2001, the technology was successfully tested with live microbes inside a sealed chamber at the United States Army's Dugway Proving Ground. However, it is not yet available commercially.

Other national labs and government labs are developing sensors for detecting particular chemical and pathogenic species. Argonne National Laboratory, the Idaho National Engineering Laboratory, Oak Ridge National Laboratory, NIST, and NRL are among the most prominent.

## 4.2.2 Selecting an Instrument Site

Potential sites for wastewater system monitoring include major source locations as well as portions of the system near vents to public places.

[61] See http://www.epa.gov/safewater/watersecurity/guide/chlorinemeasurementsensor.html

[62] See for three examples: http://www.afcintl.com/water2.htm; or http://www.thermo.com/com/cda/product/detail/0,1055,1000001000223,00.html; or http://www.h20is.com/pro_9.htm

[63] http://www.llnl.gov/str/September03/Gard.html

**TABLE 4-3**
Potential Sites FOR Instrument Platforms—Wastewater/Stormwater

| Location | Advantages | Disadvantages |
|---|---|---|
| Wastewater collection | Would cover likely entry points for wastewater contamination | and would require fast response and many platforms |
| Wastewater treatment | Would require fewer platforms, would pick up contamination that would degrade the biological process performance or prior to discharging in the effluent | Would miss the collection system problem |
| Effluent and sludge | Would require few platforms | Would miss many contamination problems but pick up problems affecting effluent, sludge and treatment process too late for effective response. |

Major source locations should include wastewater streams from major industries from which VOCs might be more likely to accidentally or purposely flow. Significant amounts of VOCs can also be introduced to any wastewater or stormwater sewer, however, the cost of monitoring at all such locations would be prohibitive.

## 4.2.3 Suggested Guidance for Selection and Siting of Instruments for Wastewater and Stormwater Systems

For wastewater collection networks little information was found for basing decisions on locating sampling or monitoring stations for contamination. The current practice appears to be locating them in pump station wet wells, manholes, and at key facilities, but no guidance or explanatory information was found on the optimal selection of these locations. Regardless, the local site conditions discussed earlier for water supply should help identify locations for sewer systems also. Since the main vulnerability considered in this effort is the presence of volatile organics, volatile toxics and airborne pathogens, the measuring locations might be chosen based on likely entry points of such contaminants as well as areas that are relevant to the likelihood of explosion or where exposure of people to the toxins or pathogens is likely to be greatest.

For purposes of reducing the public health and safety risks from contamination of wastewater and stormwater systems, utilities should implement online monitoring to detect dangerous levels of a) VOCs (both toxic and flammable/explosive) and b) pathogens both in the water and particularly in the airspaces within the collection portion of the system.

Although the benefits have not been measured, appropriate instrumentation should probably include VOC monitors, residual chlorine monitors (post wastewater treatment) and BOD monitors. If and when appropriate instrumentation for detecting pathogens directly becomes available, such instrumentation should be incorporated in the monitoring system.

Priority locations for instrument platforms should include the most likely sources of these contaminants (for example, industries that use or produce VOCs in their operations) as well as portions of the collection system that vent to major public spaces.

SECTION 5

# Data Analysis and the Use of Models

Online contaminant monitoring raises several questions concerning best management practices for the collection, formatting, and communication of the enormous amounts of data expected to be generated. Given these large data sets, what is the best way to analyze this data to get the most from it? How would alarm triggers be established to prevent false positives or negatives, and to ensure that contamination events are detected at the lowest level of concern?

The objectives in analyzing the data obtained from the monitoring instruments are the following:

- Identify the presence and location of significant contamination in the system. *(essential)*
- Identify the contaminant or its class with sufficient specificity to allow appropriate responses. *(desirable)*
- Characterize the contaminant concentration profile (pulse morphology). *(desirable)*
- Determine time to tap (water supply systems) or time to treatment/disposal (wastewater systems). *(essential)*
- Eliminate false negatives and minimize false positives.
- Assess public health risk. *(highly desirable)*
- Provide timely information to decisionmakers. *(essential)*

The data to be analyzed consist of a time series of data points from each of the instruments on a particular platform and from all of the platforms in the system. The data from an instrument vary over time for several reasons. First, there may be noise in the instrument. This generally (though not always) can be characterized as stochastic and treated as a random variable following a particular intensity and frequency distribution. There may be non-stochastic variations in the instrument response (for example, drift) that need to be taken into account as well. Then there are variations in the actual properties of the water. For example, water age affects residual disinfectant levels as well as reaction product concentrations. Depending upon the sensitivity of the instrument, these variations may be at various scale sizes. For example, measurements of particulates in the water (by a turbidimeter or scatterometer, for example) at high sensitivity could show micro variations in particulate concentrations due to turbulence in the flow or variability in mixing in the water column. Finally, there are variations in the measured parameters that arise from changes in operating conditions (for example, opening or closing of valves, flushing of major systems, adding disinfectant, etc.). These changes would be registered as unusual but explainable and, from the point of view of contamination monitoring, benign.

To interpret a set of measurements as an indication of a contamination event, one must distinguish between such an event and all the other possible causes of the measured changes. The primary challenge here is to distinguish between the benign anomalies that arise in the operation of the system and potential contamination events. That requires a thorough understanding of these

benign changes and what characteristics can be used to differentiate them from contaminant events.

In every case in which an online monitoring of parameters in water supply distribution systems has been instituted, anomalies have been observed. Over a long time, expected to be at least a year but in some cases more, a utility can build a comprehensive catalogue of such benign variations and discover their causes. In principle, a benign anomaly can be characterized by the pattern of changes in various measurements and the time of occurrence (for example, every second Thursday at 6 am). That, however, does not guarantee that a contamination event will not produce very similar changes. It does suggest, however, that expected and understood anomalies can be verified quickly and thus distinguished from those that are unexpected, including contamination events. For anomalies that arise from utility actions, such as opening or closing valves, etc., the data analysis center can be notified in advance or at the time. For anomalies that arise from actions of customers, those customers can be contacted to verify their actions at the indicated time.

# 5.1 Water Supply

## 5.1.1 Large Signal Events

Some contaminants at concentrations that cause public health risks can be expected to produce large signals (for example, > 3 sigma from the mean noise). In such cases, the determination that a contamination event is underway can be made by comparing the responses of the instrument suite with a) benign anomalies that have been logged and b) expectations for contaminants of concern. If the pattern corresponds to a benign anomaly, the data analysis process must verify that the understood cause of that type anomaly is in fact the cause of the present measurements. If the pattern corresponds to the expectations for a contaminant, even if it looks the same as a catalogued benign anomaly, it needs further verification by either field testing or comparison with measurements at other platforms. Taking a contemporaneous sample for laboratory analysis can be a decisive element in the verification process.

There may be cases in which the pattern of instrument responses for a known benign anomaly is the same as that for an expected contamination event. In such cases, corroboration and verification of the event must be obtained.

## 5.1.2 Small Signal Events

The general case will be that the signal corresponding to a significant contamination event will be buried in the variations of the parameters measured. Extracting the signal from the "noise" requires a significant degree of data processing.

There are basically three strategies that can assist in data processing. First, if either the noise or the expected contaminant pulse can be characterized by frequency and amplitude distribution, several techniques can be used to filter the noise and extract the signal. Second, measurements by different instruments on the same platform can be cross-correlated (multiplied) to reduce the effects of random noise and accentuate signals due to real phenomena in the water. Finally, using models to

predict flow and fate of contaminant, predictions can be made and compared with measurements at other platforms.

## 5.1.3 Contaminant —Pulse Morphology—Water Supply

The time variation of contaminant concentration at a particular instrument location will be a function of the following:

- Where, how, over what time and in what quantity the contaminant is inserted?
- How the contaminant concentration changes because of reactions with the water?
- Flow, mixing and dispersion of the bolus of contaminant in the water.

Figure 5-1 depicts qualitatively the nominal pulse of contaminant some distance downstream of its point of insertion. For the purposes of this illustration, it is assumed that the contaminant is added in a short time (perhaps seconds or minutes).

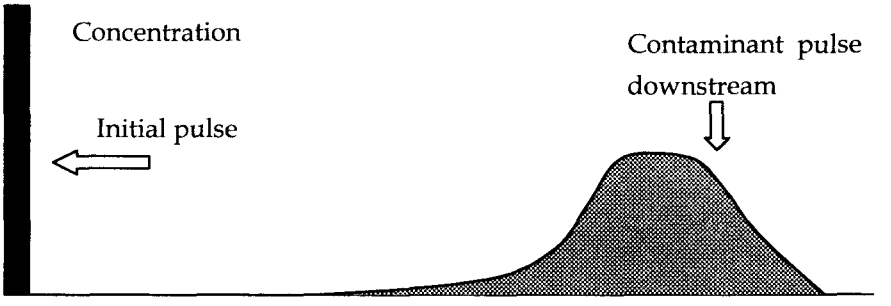


**FIGURE 5-1**
Contaminant Pulse Morphology

Contaminant added to storage water (for example, a finished water reservoir) even if added in a very short time, probably would produce a contaminant pulse at least as long as the mean water residence time in the reservoir (of the order of 3 to 5 days is a typical range). However, contaminant inserted under pressure into a water-carrying distribution system pipe would under most conditions produce a pulse that varies in morphology because of a number of factors such as inhomogeneous flow within the pipe, and the effects of mixing, turbulence, and chemical reactions. The overall duration of the pulse could be considerably different from the insertion pulse. If the insertion point is close to the measuring apparatus, the expected pulse will be closer to the insertion pulse. However, the pulse distortion effects will be increasingly important with prolonged travel times between insertion and detection.

If the total amount of contaminant is held constant and the injection time varied, a short duration pulse of high concentration that is timed to arrive at the tap to coincide with periods of highest water use for drinking, cooking, and showering would probably have the greatest impact.

## 5.1.4 Contaminant Event Signatures

A contamination event is expected to produce a pattern of instrument responses that is to some degree characteristic of the contaminant. If that pattern is uniquely associated with a contamination event and not with a benign condition of the water system, it should trigger an alarm.

A signature would consist of a set of time variant measurement signals from several instruments on a single platform that together characterize the contaminant pulse, its shape, and its effect upon the measured parameters. Later the report will discuss the implications of the analysis of data from several different platforms and methods of correlation of data and even perhaps signatures among different platforms.

To develop a library of signatures and their corresponding contaminants and insertion scenarios by analytic means would require a detailed knowledge of the flow and concentrations of reacting chemical constituents in the real system. This is beyond the state of the capability of current models. A rough but useful step toward developing such a library can be taken experimentally. At least one instrument company is developing such an approach in connection with the proprietary application of its instruments.

## 5.1.5 Models

Models have evolved over the years to meet water system requirements. The first models were based on steady-state hydraulic models. In the 1980s, increasingly sophisticated codes were developed, which included stand-alone water quality models. In the late 1980s, the first models able to simulate time-varying conditions were developed. Most of these were able to use the EPS. These types of models do not simulate the inertial effects due to rapid changes in velocity; however, they do simulate flow reversal and the reactivity of constituents and track conditions in tanks. Fully dynamic models and models that account for dispersion have been developed. For the last decade, the attention was focused on algorithms for use in modeling water quality in pipe systems. EPS models are currently the most advanced technique that is deployed widely for practical applications. Based on this, modeling water quality in water distribution systems is becoming a more widely accepted tool in support of water supply planning, design, operations, and research.

**TABLE 5-1**
Brief Summary of Hydraulic Models (see Appendix A, CSU Paper on Models for more information and detailed references)

| Software | Water Quality Analysis | Security Specific |
|---|---|---|
| AQUIS (7 Technologies) | Water age; network analysis | None |
| BRANCH 3.0/LOOP 4.0 | None | None |
| CROSS (WaterPac®) | Information not available | Information not available |

**TABLE 5-1**
Brief Summary of Hydraulic Models (see Appendix A, CSU Paper on Models for more information and detailed references)

| Software | Water Quality Analysis | Security Specific |
|---|---|---|
| EPANET (Version 2.0) | Water age, trace analysis, and constituent analysis. Constituent analysis allows various types of reaction coefficients to be input into the model. | Information not available |
| $H_2OMAP/H_2ONET$ | The program can conduct water age, trace, and constituent analysis. Constituent analysis allows various types of reaction coefficients to be input into the model. | Event/consequence management, vulnerability assessment, tracking contaminants to the originating sources, computation of purge volumes, event isolation, and customer report notification generation. |
| Helix delta-Q (Version 2.28) | Information not available | Includes "what-if" scenarios which allows closing pipes to view network effect. |
| InfoWater™ Protector | Same general capabilities as $H_2OMAP/H_2ONET$ | Models propagation and concentration of contaminants in system; assesses effects of water treatment on the contaminant; evaluates potential impact of unforeseen facility breakdown. Locate areas of contamination and calculates population at risk. Identifies valves to close to isolate a contamination event. Tracks contaminants to the originating supply source, computes purging volume, flushing strategies, result on fire-fighting capabilities, and prepares data for eventual prosecution. |
| MIKE NET 2002 | Water age, travel time, and constituent source tracking can be performed. Tracks movement and fate of water quality constituents. Allows different reaction coefficients. | Allows "what if" scenarios, allowing user-selected changes in network configurations, demand loading conditions, and changes in physical system characteristics. Can run several different scenarios on the same network. |
| OptiDesigner (Version 1) | Information not available | New update including stochastic behavior of the system and a method to determine the source of contamination. No release date has been set. |
| PIPE2000/KYPIPE (Version 2) | Automatic aging of pipes (roughness) and many other capabilities. | Information not available |

**TABLE 5-1**
Brief Summary of Hydraulic Models (see Appendix A, CSU Paper on Models for more information and detailed references)

| Software | Water Quality Analysis | Security Specific |
|---|---|---|
| PipelineNet | Water age, trace analysis, and constituent analysis. Constituent analysis allows various types of reaction coefficients to be input into the model. | Models flow and concentration of a biological or chemical agent within a city or municipal water system. Assesses effects of water treatment on the agent. Models flow and concentration of agent through the system and calculates population at risk. |
| Pipenet™ | The program has "What-if" scenarios, but is advertised for broken or blocked pipes. | Information not available |
| STANET® (Version 7.3) | Stationary mixing/tracking of contents (heating value, water quality, water age). | None |
| WADISO SA (Version 4) | Water age, trace, and constituent analysis. Allows different reaction coefficients. Constituent analysis allows various types of reaction coefficients to be input into the model. | Information not available |
| WaterCAD | Water age, trace, and constituent analysis. Allows different reaction coefficients. Constituent analysis allows various types of reaction coefficients to be input into the model. | Includes scenario for selection of valves for contamination isolation and developing flushing strategies. Simulates failure of critical water sources and identification of customers who will be impacted by the event. Predicts influence of these events and assesses possible impacts of correction actions. Prioritizes physical security improvements using component criticality and water system safety. |

Models can be used in a wide range of situations. Even when it is not possible to accurately model the behavior of a chemical or a microbe, models can provide a picture of how water moves throughout the distribution system and from this information, it can be determined which portions of the system are exposed to water from particular sources, tanks, or pipe breaks. One of the emerging abilities of models is to help utilities understand how the system will respond due to either accidental or intentional contamination. ESP models can be extremely effective in examining consequences of "what if" scenarios. Specifically, as applied to water system security, models have been used to examine three different time frames. First, they have been used as planning tools to assess vulnerabilities of the systems for various events. Second, they are used as a real-time tool during actual events for assistance in formulating responses. Third, they have been used for investigating events that occurred in the past. These three uses have also been defined as planning/design, operations, and forensics. Of course there are limitations to using models. Flow patterns in a water distribution system can be highly variable, and these flows can have a

significant impact on the way contaminants are dispersed in a network, and thus it is difficult to predict where a parcel of water will be at a given time. However, if a model is calibrated properly, these limitations can be minimized.

Hydraulic models can evaluate two different times: steady-state (system is not changing) or extended period simulation (system is changing with time but is represented as many different steady-state models running together). The steady-state analysis computes the state of the system by assuming the hydraulic demands and boundary conditions do not change. These computations include flows, pressures, pump operating valves, positions of valves, etc. The information typically obtained from such a model includes pressures and equilibrium flows. Steady-state models can be a reasonable first step to characterize the distribution of water quality in multi-source systems, but are less useful in terms of operation. It is basically a snapshot in time, used to determine the operating behavior of the system under static conditions. Steady-state models can be useful in determining the short-term effect of fire flows or average demand conditions within the system.

Because water systems are rarely in a steady state, these types of models are limited in handling transport and contaminant fate. Because of this, they are typically building blocks for other types of simulations or performed to analyze specific worst-case conditions such as fire demand, peak demands, and other system component failures that do not have a large impact by time.

Extended period water-quality models are used to simulate movement and transport of substances in water under time-varying conditions. They can be very effective for contaminant propagation studies. When combined with a flow-tracing algorithm, they have proven to be effective in modeling contaminant propagation in the drinking-water distribution system. These also model changes in water-tank levels, valve settings, storage tanks and pumps going on and off-line, flow reversal, and rapid demand changes. For these reasons, dynamic models have largely replaced steady-state models for water systems because they provide a better representation of the time-variant behavior of contaminants in distribution networks, particularly that arising from flow reversal in pipes.

Dynamic models involve a sequence of steady-state solutions linked by an integration scheme for the differential equation describing the storage tank dynamics. Each such time-dependent change in system boundary conditions refers to a hydraulic event and duration called a hydraulic time step, usually 1 hour. The time period for these models has generally been limited to periods of a day or a few days; however, longer time periods can also be completed. Longer time periods, up to weeks, months, or a year, can be completed with only minimal changes to the model codes.

The data requirements for these models are much greater than for steady-state models. This data includes water use patterns, more detailed tank information, and operational rules for pumps and valves. Additional information required includes start time, duration, and the hydraulic time step.

## 5.1.6 Water Quality Models

The water quality portions of many water quality models (H2OMAP, WaterCAD, PipelineNet, WADISO SA, Mike NET, Pipe2000, etc.) are based on the conservation of mass with incorporation

of reaction kinetics as calculated in EPANET. The basic equations used in these models are described in the Appendix A paper on modeling. The programs are based on the fact that a dissolved substance will travel in the pipe with the same velocity as the fluid in the pipe, and at the same time, it will react with its concentration either increasing or decaying. In most pipe systems, there is little longitudinal dispersion, that is, there is no intermixing of mass between adjacent parcels of water that are traveling down the pipe. This approximation breaks down in highly turbulent flow.

Where two or more pipes meet, the incoming flow is assumed to be mixed completely and instantaneously. This allows the substance concentration to be calculated through a flow-weighted sum of the concentrations from the in-flowing pipes.

The easiest (but not necessarily the best) method to deal with storage facilities is to assume the contents are mixed completely. It is reasonable to make this assumption for many tanks that operate under fill-and-draw conditions assuming that there is enough momentum flux imparted to the inflow. When these assumptions made, the concentration throughout the tank is a blend of the current contents and the entering water. However, at the same time, the internal concentration may be constantly changing because of reactions.

For these programs, the time steps are much shorter than the hydraulic time. This is done to accommodate the short travel times that can occur within the pipes. The method tracks the size and concentration of non-overlapping water segments that fill each link in the network. Throughout time, the upstream segment in a link increases in size as water enters. At the same time, there is an equal loss in size of the most downstream segment. The sizes of those in between remain the same. The contents of the segments are subjected to reactions and an accounting for total mass and flow volume entering nodes, as well as the contributions from external sources. The water positions are updated and new node concentrations are then calculated.

There are numerous models available, each with unique abilities in regard to not only hydraulic capacities but also applications in water security. These models are summarized in Table 1 of Appendix paper on models. A more in-depth description of these water models is provided in the appendix to that paper. Each of the water models has some similarities. These are discussed below.

The programs perform similar functions. Hydraulically, they all perform the same type of analysis: flow and velocity of water in pipes, pressure and head at nodes, height of water in tanks, discharge flow, and pressures from pumps. They all perform steady-state and extended period simulation analysis. Most use the same three common friction equations (Hazen-Williams, Darcy-Weisbach, or Manning's methods). Additionally, the programs have similar capabilities regarding modeling water quality. Each can perform water age, tracing, and constituent analysis. Additionally, they model constituents in the same manner: n-th order kinetics to model reactions in the bulk flow and zero or first-order kinetics to model reactions at the pipe wall. Wall reaction rate coefficients can be correlated to pipe roughness and the global reaction rates can be modified on a pipe-by-pipe basis. The constituents can grow or decay up to a limiting concentration. Also, they can perform four

different models of tanks. In regard to water quality, the three major types of analyses include age, trace, and constituent. These are explained in more depth below.

Water age analysis calculates the age of the water in the network at any node. Most of the models compute this characteristic based on EPANET calculations. This calculation is performed under constant hydraulic conditions and is a simple, non-specific measure of the overall quality of delivered water. The information required for age analysis is pipe velocity and flow rate, and therefore a reaction coefficient is not required.

The trace function determines the fraction of water that originates from a specified node over time, again with most models performing this calculation based on EPANET calculations. EPANET treats the source node as a constant source of non-reacting constituent, entering the network at the node with a concentration of 100. The analysis can be useful for analyzing systems with two or more raw water sources, thus showing how the water is blended over time. This analysis can only be performed using the EPS method and the only information required is pipe velocity and flow rate. Another similarity between the models is the mode of entry for the contaminant. The models allow any node in the system to serve as the source for a chemical constituent. Each modeling program allows several different methods to introduce the contaminant into the system. These are explained below:

- **Concentration**. This method fixes the concentration of any external inflow entering the system at a node. An example would be a reservoir or a negative demand located at a junction.
- **Flow Paced Booster**. This method adds a fixed concentration to the flow resulting from the mixing of all inflow to the node from other points in the network.
- **Setpoint Booster**. This fixes the concentration of any flow leaving the node. This can be used as long as the concentration resulting from all inflow to the node is below the setpoint.
- **Mass Booster**. This is used to add a fixed mass flow to the flow entering the node from other points in the network.

Tank mixing is another item that impacts the way a contaminant acts. Again, most models that complete this calculation use the EPANET method, which includes four options for tank mixing: complete mixing, two-compartment mixing, first in/first out plug flow, and last in/first out plug flow. These are described more in detail below.

- **Completely mixed**. This assumes that all water entering the tank is completely and instantaneously mixed with the water already in the tank. This is a reasonable assumption for many tanks operating under fill-and-draw conditions providing sufficient momentum flux imparted to inflow.
- **Two compartment**. This assumes that the tank storage is divided into two completely mixed compartments, both of which are assumed to be mixed completely. The inlet and outlets of the tanks are in the first compartment. As new water enters, it completely mixes with the first compartment. Overflow is sent to the second compartment. When water leaves the first compartment, the compartment receives an equivalent amount of water from the second compartment. The second compartment can have dead zones.

- **First in/First Out Plug Flow model.** This model assumes there is no mixing of water during the time it is in the tank. Water parcels are stacked effectively on one another, moving through the tank in a segregated fashion where the first parcel to enter is the first parcel to leave. This is most appropriate for baffled tanks that operate with simultaneous inflow and outflow.
- **Last in/First Out Plug Flow model.** This model assumes that no water mixing occurs in the tank. Water parcels still stack up one on top of another, and the last parcel to enter is the first to leave from the bottom of the tank. This is most appropriate for tall, narrow standpipes that have an inlet/outlet pipe at the bottom and low momentum inflow.

The water models use the EPANET calculation methods for modeling reactions. The EPANET method can model bulk and wall reactions, in regards to decay or growth. The bulk reactions used by these programs include simple first-order decay, first-order saturation growth, two-component second order decay, Michealis-Menton decay kinetics, or zero-order growth.

Substantial water quality changes can occur at or near the pipe wall interface. Wall reactions can be complicated, as they depend on temperature as well as pipe material and age. As metal pipes age, their roughness tends to increase with encrustation and tuberculation of corrosion products accumulating on the pipe walls. This in turn produces a lower Hazen-Williams C-factor or a higher Darcy-Weisbach roughness coefficient that results in greater frictional head loss through the pipe. Dissolved substances are transported to the pipe wall and react with materials such as biofilm or corrosion products ( for example, iron oxides) on or near the wall. Several variables will influence this reaction. One of these is the area available for the reaction, which is simply the surface area per unit volume. Another variable is the rate of mass transfer between the fluid and the wall. The factor is represented by a mass transfer coefficient. The value of this mass transfer coefficient depends on the reactive substance's molecular diffusivity as well as the Reynolds number of the flow. Unlike bulk reaction rates, wall reaction rates cannot be measured directly —they must be back-fitted against calibration data collected from field studies. This involves trial and error to determine the coefficient values that will replicate the field data best. The type of pipe will have a large impact on this coefficient. There is not any expected wall demand for disinfectants for plastic and relatively new lined iron pipes.

## 5.1.7 Model Applications

There are several distinct uses for models in security applications. To be useful, the model must be calibrated for a wide range of alternative scenarios and be ready to apply rapidly in the EPS mode. The model must be set up in an automated mode so that operation is represented by a series of logical controls established for the current operating procedures. Such an evaluation is possible, including the required data, but only limited demonstrations of this type of operation have been accomplished so far. The obvious key to this is that the model must be ready immediately because there would not be time to establish the model in an emergency. Security applications of distribution system hydraulic models include the following:

- **Instrument placement.** Models can be used to help determine the optimum placement of monitors. As discussed in Appendix A, there are different approaches for using models for determining where instruments should be located within the distribution system.
- **Pre-event response scenarios.** Extensive modeling could be conducted before an event occurs to facilitate response planning. Various scenarios can be input to a model and then run to determine the extent of the contamination and to develop and test response plans that will minimize any impacts. There are many variables that could impact this use, and using professional judgment for these variables will be an important factor to obtain the best type of responses. The response plan will be analyzed much quicker in the model.
- **Design/upgrade of water systems.** After the model is run and the possible contamination areas are highlighted, the next step will be to identify the weak points in the water system. There are two aspects to this use. First, flow patterns through sections of the network can be seen in the model. System design modifications may be able to alter these flow patterns, thus preventing flow from re-entering the major distribution lines and spreading to other areas. Second, optimal system design will include methods to isolate and flush the contaminants., all the time ensuring the contaminant water is handled properly. No water system will be perfect in regards to isolating and flushing the contaminant without further impact to additional users; however, evaluation of the system through this method will allow utilities to pinpoint areas that need improvement.
- **Identifying location of contamination.** During an actual contamination event, a model could be used to determine and predict the location of the contaminant bolus. When there has been a confirmed response, the model could be run with the data available to determine the input location of the contaminant as well as its future trajectory. While this can be stated simply, the solution to deconvolution of any practical model to yield such information is very difficult and the subject of ongoing research.
- **Confirmation of positive event.** One positive alarm from a monitor may not necessarily indicate contamination. There could be numerous causes that would result in a false positive, and therefore a reasonable approach for confirming a positive alarm must be developed. It would be unreasonable for a utility to immediately react as though the system was being sabotaged on only one reading; however, due diligence must be practiced to ensure a proper response is initiated to limit the number of casualties. After a positive alarm is detected, there would be a mobilization to verify the field monitors with other monitors. At the same time, another verification could be done with the model. This would be performed through predicting where the contamination, if truly in the system, would travel to next and the appropriate reading that would be expected at that point. After the water reaches that point and the monitor responds in the model-predicted manner, the second positive response has been found. Depending on how the utility decides to respond (depending on whether two or three positives are required prior to initiating a response), the response can be initiated.

Note: in this scenario, the reaction equations will become important. If the constituent is assumed not to decay, then there may be a substantial overestimation of the level of constituent. If field

measurements do not match model predictions with these conservative reaction kinetics, it may lead to the conclusion that there was not a contamination event even though there was one.

## 5.1.8 Suggested Guidance (Water Supply)

Water utilities should model their systems not only as a prerequisite to establishing an OCMS but to understand and better manage normal operations. A model that has the capability to include insertion of contaminants at the appropriate locations and to model not only flow but also chemistry should be selected. The utility will need some experience in applying, validating, and tuning the model to the particular circumstances of the system to ensure its validity under all anticipated operating conditions.

After a model has been tuned for use in the system, it can be accommodated in the data analysis scheme.

- Data analysis must be automated. The analysis program should be written to address contamination scenarios ranging from very short insertion pulses (of the order of a few minutes) to long-term bleeds (on the order of a few days) and cover most likely potential insertion points. It should allow for weighting (prioritizing) the scenarios and insertion points according to threat information received (most likely from external sources) and the results of the utility's vulnerability assessment. It should be able to characterize the measurement noise spectrum and apply appropriate data analysis filtering or other techniques to facilitate signal extraction.
- A catalogue of potential pulse characteristics should be developed, and the data analysis program should apply the library of pulse shapes to the task of signal processing.
- The OCMS responses to benign variations in operational characteristics must be registered and a library of such variations constructed. It is desirable to have an analysis program that can learn from experience which variations are likely to be benign.

The analysis program should have *a* built-in decision tree that directs corroboration and verification activities under circumstances that differentiate between the following:

- Event signatures that have been seen before and previously determined to be benign.
- Event signatures that have been seen before but for which the cause has not been determined to be benign.
- Event signatures that have not been seen before.

Event signatures that have not been seen before should be treated as potential contamination events and the analysis program should trigger the appropriate confirmatory responses.

The analysis program should provide for the comparison and correlation of measurements from different instruments on the platform (including signature computation) as well as the measurements from instruments on different platforms.

# 5.2 Wastewater/Stormwater Systems

## 5.2.1 Wastewater/Stormwater Models

There are several models applicable to wastewater and stormwater systems. Some of these programs are described below. Note that all information, particularly pricing information, is subject to change and is offered here only for information purposes.

| HYDRA V6 | |
|---|---|
| Scientific Software Group<br>P.O. Box 708188<br>Sandy, UT 84070-8188 | Telephone: (866) 620-9214<br>Fax: (801) 302-1160<br>Email: info@scientificsoftwaregroup.com<br>Internet: http://www.scientificsoftwaregroup.com |
| **General Description:** HYDRA is a comprehensive hydraulic model designed specifically for the unique challenges of storm and sanitary sewer modeling. It can be used to model almost any collection system.<br>HYDRA combines powerful hydraulic analysis and GIS features with a user-friendly interface for the municipal engineer. Important "what-if" questions that affect the capacity of the system can be answered by HYDRA software. | |
| GIS: HYDRA can exchange data with ESRI ArcInfo and ArcView Shapefiles.<br>CAD: Imports and exports data to AutoCAD using DXF files. HYDRA also works directly with AutoCAD 12, 13, 14, or 2000.<br>Model Size: Information not available.<br>OS: Microsoft® Windows™<br>Head-loss Equations: Information not available.<br>SCADA Link: Information not available.<br>Presentations: Information not available.<br>Security Specific: Information not available. | |
| **Water Quality Analysis:** Information not available. | |
| Price: See chart below for pricing.<br>Support: Information not available. | |

| | | |
|---|---|---|
| HYDRA 6—200 pipes | First Year License | $1,245 |
| | Annual License Renewal | $250 |
| HYDRA 6—Unlimited pipes | First Year License | $4,495 |
| | Annual License Renewal | $1,250 |
| HYDRA SWMM Module | First Year License | $495 |
| | Annual License Renewal | $125 |

| SewerCAD | |
|---|---|
| MethodsHaestad<br>37 Brookside Road<br>Waterbury, CT 06708 | Telephone: (800) 727-6555<br>General: info@haestad.com<br>Support: support@haestad.com<br>Internet: www.haestad.com |
| **General Description:** SewerCAD is an advanced design, analysis, and planning tool, handling both pressurized force mains and gravity hydraulics with ease. It has features such as steady-state analysis using various standard peaking factors, extended period simulations of complete collection systems, and advanced automatic system design.<br><br>SewerCAD allows users to construct a graphical representation of a pipe network which contains pipe data, pump data, loading, and infiltration information. It has the flexibility to mix gravity and pressure components, enabling the user to model the systems exactly as they are in the field. | |
| Comes with Haestad Methods' Engineering Libraries and Library Managers, which allows specification and modification objects, components, or common materials, which include materials, minor losses, and constituents<br><br>GIS: Can link with GIS applications in any format and in any units.<br><br>CAD: Can be stand-alone or fully integrated. SewerCAD elements are fully accessible to all AutoCAD.<br><br>Model Size: Unlimited.<br><br>OS: Microsoft® Windows™ (2000, XP)<br><br>Head-loss Equations: Darcy-Weisbach, Chezy-Manning, Hazen-Williams, Kutter's<br><br>SCADA Link: Can link with SCADA applications in any format.<br><br>Presentations: SewerCAD can create detailed reports for any element or group of elements. System-wide summaries and project inventories can be generated. Input and output from different scenarios can be compared with tools like comparative annotation. Reports can be copied to be included in any word processed document or spreadsheet.<br><br>ArcVIEW: Information not available.<br><br>Scenarios: The scenario management system allows the user to track "what-if" conditions and design alternatives. Scenario management allows for minimal data entry with its data inheritance. All changes to "parent" data are automatically passed down to the "children" and that data are also updated with the same changes.<br><br>Security Specific: Information not available.<br><br>Calibration: Information not available. | |
| **Water Quality Analysis:** Information not available. | |
| **Price:** See charts below for pricing.<br><br>Support: ClientCare™ Program offered by Haestad includes the following: free upgrades, unlimited professional support any time throughout the year, discounts on software, books, and training. The cost of the program is based on the level of support and is a percent of the software cost. The purpose of ClientCare is to keep the user up-to-date with the technological developments as well as access to technical and engineering support. If not subscribed, Haestad offers technical and engineering support on an emergency basis per incident. | |

The chart below shows the pricing of the SewerCAD software, based on the model size:

| # Pipes | 10 | 25 | 100 | 250 | 500 | 1000 | 2000 | 5000 | 10000 | Unlim |
|---|---|---|---|---|---|---|---|---|---|---|
| EZPay | $26 | $117 | $224 | $332 | $547 | $869 | $1,084 | $1,407 | $1,622 | $2,159 |
| Standard | $195 | $995 | $1,995 | $2,995 | $4,995 | $7,995 | $9,995 | $12,995 | $14,995 | $19,995 |

EZPay allows purchase to be divided into monthly installments that are billed automatically. Each payment includes a processing fee.

Support for the program is included below:

| | **One-Year Renewable Subscription** | **Two-Year Subscription** |
|---|---|---|
| Gold Subscription Fee | 35% | 55% |
| Silver Subscription Fee | 32% | 52% |
| Bronze Subscription Fee | 29% | 48% |

The percentages above are based on the software's current list price.

| **TOXCHEM+ V3** | |
|---|---|
| ENVIRONMEGA | Telephone: (905) 689-4410 |
| 50 Dundas Street East | Fax: (905) 689-7040 |
| Suite 200 | E-mail: support@enviromega.com |
| Dundas, Ontario Canada L9H 7K6 | Internet: http://www.enviromega.com |
| **General Description:** A model that can be used to estimate emissions of organic and metallic contaminants from wastewater treatment and collection systems. It also has a "backsolve" feature that enables the user to work backwards to an allowable headworks concentration by specifying a contaminant concentration of a liquid, air, or solids streams in downstream processes. TOXCHEM+ allows for the modeling of activated sludge, fixed film, lagoon, closed tanks and industrial pretreatment systems, and also collection system effects and spill flows.<br><br>The new Version 3 of TOXCHEM allows users to execute multi-contaminant model runs, and view the results on screen. It also gives the user the ability to create a grouping of contaminants for modeling runs. With these new features, TOXCHEM Version 3 is at the forefront of predictive fate modeling.<br><br>Version 1.1 allows dynamic modeling of slug flows. | |
| **GIS:** Information not available.<br><br>**CAD:** Information not available<br><br>**Model Size:** Information not available<br><br>**OS:** Microsoft® Windows™ (3.1, 3.11, 95, NT)<br><br>**Head-loss Equations:** Information not available.<br><br>**SCADA Link:** Link to SCADA systems. The model can accept signals from flow meters, temperature sensors, or suspended solid probes to provide online estimates of contaminant fate, VOC/HAP emission | |

| TOXCHEM+ V3 |
|---|
| rates or loadings of contaminants in solids for off-site disposal.<br>**Presentations:** Data can be presented in a number of user customizable reports.<br>**ArcSDE/Geodatabase Compatibility:** *Information not available.*<br>**Scenarios:** Information not available.<br>**Security Specific:** Information not available.<br>**Calibration:** Information not available. |
| **Water Quality Analysis:** Information not available. |
| **Price:** See pricing chart below.<br>Support: User guide and contact available for one year after date of purchase. |

| Purchase | License | First Copy | Additional Copies |
|---|---|---|---|
| Regular | Single-User | $4,000 | 2-5: 30% Discount |
| | Network** | $5,900 | |
| Academic* | Single-User | $1,350 | |
| | Network** | $1,950 | 6+: 60% Discount |
| Upgrade from V2 | Single-User | $1,500 | |
| | Network** | $2,000 | |

Academic purchases are licensed for non-commercial use only and may be used for instructional purposes at educational institutions such as colleges and universities.

** Local Area Network (LAN) License—up to 10 users. Wide Area Network (WAN) licenses are currently not supported.

| Water9 | |
|---|---|
| United States Environmental Protection Agency<br>Ariel Rios Building<br>1200 Pennsylvania Avenue, N.W.<br>Washington, DC 20460 | Telephone: (202) 272-0167<br>Internet: www.epa.gov |
| **General Description:** *Water9 is a wastewater treatment model that estimates air emissions of waste* constituents in wastewater collection, storage, treatment, and disposal facilities. Water9 can provide a model for a full facility and has the ability to produce reports about constituent fates, including air *emissions and treatment effectiveness. It can be used to obtain emission estimates for individual* compounds. The total air emission then can be obtained by summing the individual compound estimates.<br>Water9 can be used to estimate air emissions from site-specific water treatment plants for common wastewater treatment units. It utilizes theoretical models and correlations of data from Enviromega and the University of Texas at Austin for its collection system components and is updated as new data becomes available. | |
| GIS: Water9 does not have any direct linkages to external GIS.<br>CAD: Water9 does not have any direct linkages to external CAD. | |

| Water9 |
| --- |
| Model Size: Information not available. |
| OS: Microsoft® Windows™ (95/98/NT) |
| Head-loss Equations: Information not available. |
| SCADA Link: Information not available. |
| Presentations: Information not available. |
| ArcSDE/Geodatabase Compatibility: Information not available. |
| Scenarios: Information not available. |
| Security Specific: Information not available. |
| Calibration: Information not available. |
| Reports: Reports are generated into a simple text file. |
| **Water Quality Analysis:** Information not available. |
| **Price:** Free—public domain. |
| Support: Provided through the Air Emissions Model Hotline (919) 541-5610. |

## 5.2.2 Suggested Guidance (Wastewater/Stormwater)

Utilities should model their systems not only as a prerequisite to establishing an OCMS but to understand and better manage normal operations. A model that has the capability to include insertion of contaminants at the appropriate locations and to model not only flow but also chemistry should be selected. The utility will need some experience in applying, validating, and tuning the model to the particular circumstances of the system to ensure its validity under all anticipated operating conditions.

EPA's Water9 model may be particularly relevant for the wastewater/stormwater monitoring system because it includes a calculation of emissions of contaminants from the water.

After a model has been tuned for use in the system, it can be accommodated in the data analysis scheme.

Data analysis must be automated. The analysis program should be written to address all the relevant contamination scenarios including both accidental and purposeful addition of contaminants and including VOCs as well as pathogens. It should allow for weighting (prioritizing) the scenarios and insertion points according to threat information received (most likely from external sources) and the results of the utility's vulnerability assessment. It should be able to characterize the measurement noise spectrum and apply appropriate data analysis filtering or other techniques to facilitate signal extraction.

The OCMS responses to benign variations in operational characteristics must be registered and a library of such variations constructed. It is desirable to have an analysis program that can learn from experience which variations are likely to be benign.

The analysis program should have a built-in decision tree that directs corroboration and verification activities under circumstances that differentiate between :the following:

- Event signatures that have been seen before and previously determined to be benign
- Event signatures that have been seen before but for which the cause has not been determined to be benign
- Event signatures that have not been seen before

Event signatures that have not been seen before should be treated as potential contamination events, and the analysis program should trigger the appropriate confirmatory responses.

The analysis program should provide for the comparison and correlation of measurements from different instruments on the platform (including signature computation) as well as the measurements from instruments on different platforms.

## SECTION 6

# Communication System Requirements

An OCMS would be expected to consist of a number of instrument platforms located throughout the water system—whether water supply or wastewater—operating continuously and producing large quantities of data. The data would be sent to a central data analysis facility at which they would be processed. Under normal conditions, the results of the data analysis would not trigger any of the contamination alarms or responses but certain results might be available to illuminate the operational aspects of the utility. Under conditions recognized as a possible contamination event, certain information and alarms would be provided to a decisionmaker and possibly certain other actions would be triggered as well (for example, taking samples or initiating a corroborative investigation). The decisionmaker would then evaluate the situation and take further appropriate actions. To transport the data and conduct these actions effectively, there must be a communications system in place that is reliable, effective, and secure. This section deals with the design of such a system.

Communications system design is best done by professional communications engineers who are familiar with standard telecommunications design principles and the state-of-the-art equipment in the field. This section is not intended to supplant the role of the communications engineer, but rather to provide guidance to utility operators of which water system and OCMS factors are pertinent to the telecommunications system design.

Figure 6-1 illustrates the role of the communications system in linking the monitoring platforms, the data analysis center, decisionmakers, response personnel, etc. The monitoring instruments provide

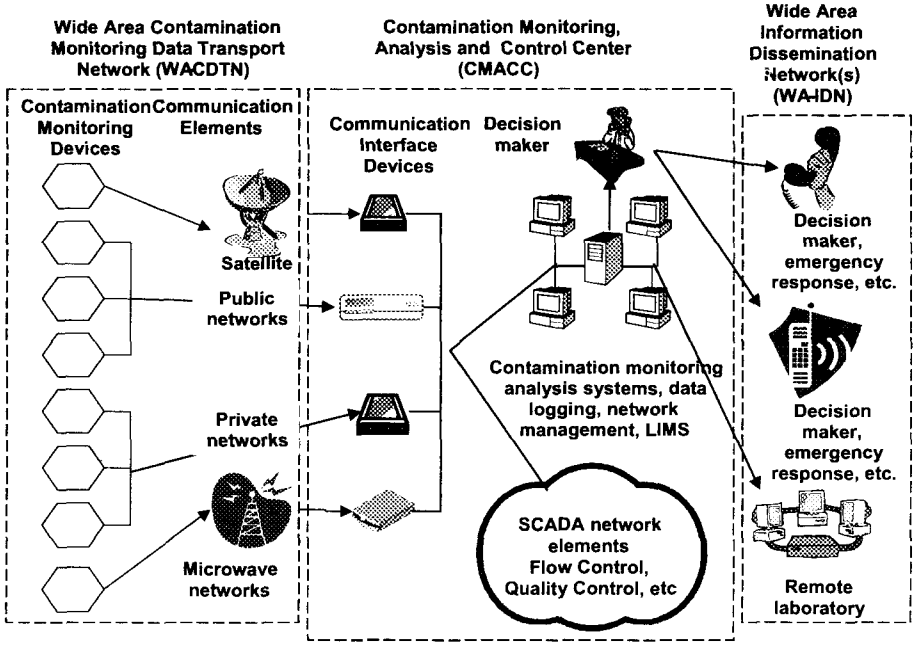


**FIGURE 6-1**
Communications System Linkages (from A. Kolnik, Appendix paper on Communications)

data in a transmissible form and standard format. For purposes of this section, the data are presumed to be all in digital format and represent samples taken with an appropriate frequency – nominally once every 30 seconds, but that figure can be varied over a wide range. Each data point would contain the value of the measured parameter and unique identifier information that notes the specific instrument from which it originated. The data would be encrypted to provide a measure of security, and would likely contain check digits to ensure authentication.

The data can be transmitted to the data analysis center over existing SCADA linkages (hard wire, public switched network or radio frequency) or over separately configured and managed linkages. Most utilities would most likely prefer to use an existing SCADA system for OCMS communications. However, to make sure that the OCMS system is secure, the better practice would be to encrypt its data which. would make it more difficult to ensure compatibility with an existing SCADA. In addition, since SCADA systems are themselves potential targets, it is a better practice to maintain firewalls between the OCMS and the SCADA. While that may still allow for a combined communication system, greater care must be taken in designing and implementing the SCADA to preserve the necessary degree of security for the OCMS.

# 6.1 Communication System Design Strategy

As a general proposition, the communications engineer must design a network that meets the overall objectives of the facility, or business, that it serves. Therefore, to design communications for an online contamination monitoring system, the designer will need to answer questions such as:

- What policies and regulations will affect the design and implementation?
- What are the key management, functional, and operational objectives?
- What devices will be attached to the network?
- What information will be transported over the network?
- What are the physical characteristics of the network
  - Where will the network elements be located?
  - What distances must be covered?
  - What terrain conditions must be accounted for?
  - How will the network equipment obtain power?
- What technologies are available to use in the network, and which are most appropriate for each part of the network?
- How will the network be managed?
- How will the network be secured?
- Who will need access to the network, and who will need to be contacted via the network?

The designer could use the systematic design approach illustrated in the Figure 6-2.

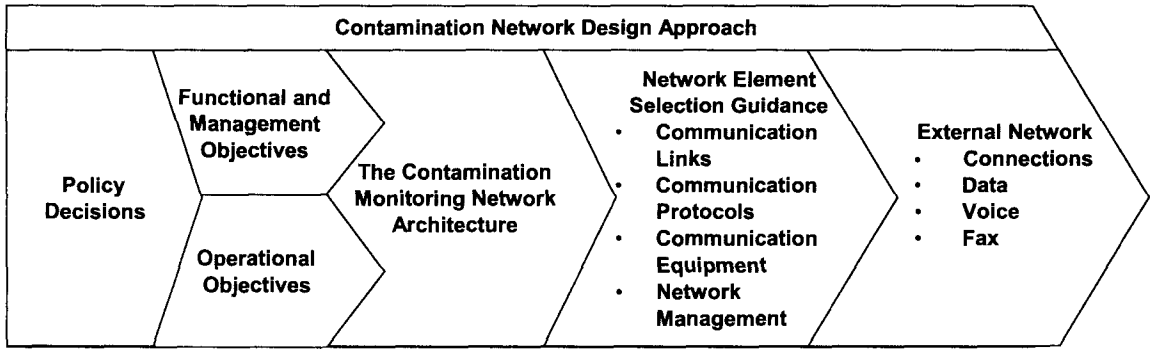


**FIGURE 6-2**
Contamination Network Design Approach (see A. Kolnik, Appendix paper on Communications)

The contamination-monitoring network must also meet the objectives of those responsible for the proper operation of the facility and proper direction and monitoring contamination and response activities in the event of a contamination event.

Guidance should be provided to the network designer regarding policy issues that will govern the network's functionality, and the trade-offs of cost versus performance.

Once the policy issues are identified, it is possible to establish the network requirements (architectural, management, and operational objectives) that will result in a design which provides the required functionality.

The contamination monitoring system designer should obtain comment from "policy makers" that include at least the personnel who:

- Establish the operational, response, and mitigation policies for the contamination monitoring system and the facility as a whole.
- Operate the facility and network.
- Analyze the contamination data received over the network.

The designer should conduct a set of interviews with decision-makers and operational personnel to elicit answers to all policy matters that affect the design and functionality of the network. Table 6-1 provides examples of the decisionmakers and operational personnel who should be consulted to define the high-level policies that the network designer should consider before work begins on the actual technical design.

The list is unlikely to be exhaustive, especially as new contamination monitoring challenges arise and response requirements evolve. Each facility may have specific and special additional policy requirements that could affect the network design. The network designer should account for these specific needs in developing the network design and evaluating the tradeoffs that will inevitably have to be made.

**TABLE 6-1**
Sources the Network Designer Should Interview (from A. Kolnik, Appendix A, Paper on Communications)

| "Policy Makers" | Typical Roles and Responsibilities | Typical Policy Guidance Inputs |
|---|---|---|
| Human Decisionmaker(s) | Implements Critical Infrastructure Policy<br>Ensures regulatory compliance<br>Prepares operational plans<br>Prepares mitigation plans<br>Decides whether to initiate mitigation plans<br>Validates action in the field | Acceptable mitigation methods<br>Methods for initiation of response<br>Methods for communicating with/escalation to other HS responsible organizations<br>Use of automated responses to contamination events |
| Facility manager | Operations<br>Budgets<br>Maintenance<br>Upgrades<br>Training<br>Hiring<br>Regulatory compliance | Operational requirements<br>Budget constraints<br>Staff capabilities<br>Maintenance methods and constraints |
| Control room/network operator | Monitors the network<br>Responds to communications alarms<br>Conducts routine maintenance and equipment replacement or upgrade<br>Provides input to policy and network design on requirements and functionality | Technical network monitoring policies<br>Control system requirements<br>Escalation policies<br>Maintenance policies |
| Contamination evaluation expert | Analyzes contamination event data from the field devices<br>Notifies decision-maker(s) if a contamination event has occurred | Monitoring requirements<br>Local analytical devices required (for example, in a laboratory at the facility)<br>Remote communications required (for example, to decisionmakers and/or to a remote laboratory or response team) |

# 6.2 Design Objectives

Six design objectives are proposed that are at the functional and management levels. The findings on Policy Decisions will be critical in establishing the appropriate architectural and management

strategies for each network implementation. Examples of appropriate design strategies to achieve these six design objectives are given in Table 6-2.

**TABLE 6-2**
Design Strategies to Achieve the Functional and Management Objectives (from A. Kolnik Appendix A paper on Communications)

| Design Strategy | Functional and Management Objectives | | | | | |
|---|---|---|---|---|---|---|
| | Geography | Scalability | Maintainability | Cost Effectiveness | Regulatory Compliance | Staffing Needs |
| Wireless technology | X | X | X | X | | X |
| Fiber technology | X | X | X | | | X |
| Copper technology | | | X | X | | X |
| Public networks (PSTN, Frame Relay, etc.) | X | X | X | X | X | X |
| Shared SCADA links | | | | X | ? | X |
| Multiple vendor sourcing | | | X | X | | |
| Dedicated network management system | | X | X | | X | |
| Shared network management system | | X | X | X | ? | X |
| Standard protocols | X | X | X | X | | X |
| Network performance logging | | | X | X | X | |
| Redundant network links | | | X | | X | |
| Remote site connectivity | X | X | | X | ? | |
| Mobile and terrestrial communications | X | X | X | | ? | |
| Fax communications | X | X | X | X | ? | |

Five operational objectives for data transfer that the network must meet if it is to provide the functionality required by the contamination monitoring system are presented later and Table 6-3 provides a set of design strategies to achieve these objectives.

Taken together, these define a set of functional requirements for the network.

The network design should address six high-level functional and management objectives:

- **Geographically sufficient.** It must connect all the required monitoring devices, many of which will be remote from the operations center, off-site laboratories or other related facilities, maintenance staff, and decisionmakers and response teams, who will generally be (initially) remote from the plant site.

**TABLE 6-3**
Design Strategies to Achieve the Operational Objectives (from A. Kolnik Appendix A Paper on Communications)

| Design Strategy | Operational requirements[64] | | | | |
|---|---|---|---|---|---|
| | Accurate | Complete | Real-time | Secure | Reliable |
| Public networks (PSTN, Frame-relay, etc.) | X | X | X | ?[65] | X |
| Redundant network connections | | X | X | X | X |
| Digital communications[66] | X | X | X | | X |
| Well-proven network protocol stack | X | X | | | X |
| Encryption | X | X | | X | X |
| Multiple transmission media | | X | | | X |
| Equipment polling/heartbeat | X | X | | X | X |
| Connection to control elements managed by the SCADA system | | | X | | |
| Multiple contact mechanisms to decisionmakers—phone, cell-phone, e-mail, fax, pager | | X | X | X | X |
| 24 x 7x365 control room | X | X | X | X | X |
| Additional training in communications for technicians | | | | | X |

- **Scalable**. Since there is the potential to add more devices after the initial network installation (for example, devices that detect additional contaminants, or devices located in other sections of the physical system), the network must scale easily, without the need to invest in large scale equipment replacement.
- **Maintainable**. It should be easy to detect and repair problems, and carry out equipment upgrades, moves, and changes.
- **Cost effective.** The design should account for the budgetary constraints of the facility.
- **Compliant with regulatory requirements.** For example, maintenance of records of network availability, maintenance or other performance characteristics.
- **Staffing.** The network should use commonly available equipment and protocols to avoid the need for very specialized network technicians.

[64] Accurate—transports data exactly as received; Complete—does not lose data due to communication errors; Real-time—transports data immediately when received; Secure—is secure against penetration (e.g., by hackers or other malfeasants); Reliable—is available at a defined level of availability—typically 99.9999 percent up-time.

[65] The public networks are secure, in many senses, but are vulnerable in terms of permitting a remote user to find ways to access a utility's network.

[66] Monitoring equipment that generates analog signals should be equipped with an interface to convert them to digital form.

Table 6-2 indicates which design strategies best meet the architectural and management objectives.

The network must provide for data transfer that is:

- Accurate – transports data exactly as received
- Complete – does not lose data due to communication errors
- Real-time – transports data immediately when received
- Secure – is secure against penetration (for example, by hackers or other malfeasants)
- Reliable – is available at a defined level of availability – typically 99.9999 percent availability[67]

A number of strategic design choices are available to accomplish these objectives. Some choices are purely technical (for example, the choice of an encryption method, or a protocol, or type of connection link) while others will influence the ability to control and monitor the network, and report contamination events reliably, immediately, and securely.

Further detail on the design of communications systems is provided in Appendix A in the paper by ARK Associates.

# 6.3 Suggested Guidance

If the utility decides on a phased approach, the first stage could piggy-back on the existing SCADA system or, if no SCADA exists, a simple rf- microwave link (with appropriately licensed spectrum) could be established.

Ultimately, the connection between the remote measuring units and the data analysis center should be established on a link that ensures very high reliability of service, the ability to encrypt the signals and that will protect the instrument-data transport – analysis connection from outside interference or tampering. The options are using the SCADA system, public switched network (such as telephone lines), satellite, microwave, or running new land lines.

The full OCMS might require communications links beyond the utility's SCADA system in which case the utility should decide whether to invest in an entire new communications link or the expansion of the SCADA network to include new instrument locations.

In any event, since some possible responses will require communications with utility personnel or assets, the OCMS communications system will have to connect with the SCADA and management networks.

Also, the communication system should include the protocols and equipment necessary to communicate with the media and with other outside organizations such as local emergency response teams, and state and federal organizations as appropriate.

[67] This level of reliability or availability may seem excessive, but is necessary for a secure network. It represents downtime of about 31 seconds per year. Reducing the availability to 99.999 percent would permit an acceptable downtime of about 5 minutes—enough for someone to tamper with the network without exceeding any alarm guidelines. The goal can be achieved using redundant connections to each monitoring device.

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## SECTION 7

# Responses to Contamination Events

This section is not meant to be a comprehensive discussion of the possible responses to a contamination event. Rather it is a reminder of the main categories and their features. For a fuller discussion of responses, see EPA's RPTB and related emergency response guides.[68]

The objective of response actions is to minimize the exposure of the public to contaminants, or the effects of contaminants, while providing additional time to evaluate the nature and severity of the event. In general, containment of the contaminated water would be a desirable option for an operational response. However, containment is not always a realistic possibility. Other options can also be pursued. For example, elevating the disinfectant levels or adding materials to counteract the contaminant in a targeted area may be considered.[69] In cases where the contaminated water supply cannot be stopped prior to the tap, public notices or advisories to boil the water not drink the water, or not use the water may be issued.[70]

The *Public Health Security and Bioterrorism Preparedness and Response Act of 2002* requires that **community** drinking water utilities serving more than 3,300 people update or revise their Emergency Response Plans (ERPs). The update is directed to consider the various types of incidents that could occur as a result of malevolent acts (for example, intentional contamination of water supplies, cyber attacks, physical assaults, intentional release of hazardous chemicals, etc.). The update should also address risks discovered during the utility's Vulnerability Assessment that was mandated under the same Act. An emergency response plan is a good idea for water supply utilities outside the mandate as well as for wastewater systems.

According to EPA, "protecting public health is the primary goal of community drinking water systems, and having an up-to-date and workable ERP helps achieve this goal in any crisis situation." The Public Health Security and Bioterrorism Preparedness and Response Act of 2002 amends the SDWA by adding a requirement that community water systems serving populations greater than 3,300 either prepare or revise an ERP that incorporates the results of its Vulnerability Assessment. The ERP must include "plans, procedures, and identification of equipment that can be implemented or utilized in the event of a terrorist or other intentional attack." The ERP must also include "actions, procedures, and identification of equipment which can obviate or significantly lessen the impact of terrorist attacks or other intentional actions on the public health and the safety and supply of drinking water provided to communities and individuals."

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[68] EPA's Response Protocol Toolbox: http://cfpub.epa.gov/safewater/watersecurity/home.cfm?program_id=8#response_toolbox

[69] The real crux of the matter is having appropriate materials close at hand for the large number of probable and immense number of possible contaminants which may be used. Detection time plus identification time plus acquisition plus application time will likely exceed the window of opportunity. If the system is shut-down to gain time, dispersion and mixing will be difficult. The pre-positioned injection ports necessary are in themselves new vulnerabilities.

[70] Notices to boil, not drink, or not use water are relatively easy to issue but can have costly and undesirable effects upon the served community. Utilities should be reluctant to issue such notices unless determined to be necessary.

EPA has developed a RPTB that is composed of an overview and ) six interrelated modules that focus on different aspects of planning a response to contamination and other threats and incidents, long before they occur. The RPTB is primarily concerned with drinking water contamination threats. Module 1 is an overarching document that serves both as a primer on contamination threats to drinking water systems and an overall guide to utility planning for such incidents. Module 2 is the hub of the toolbox; it addresses the overall management of a contamination threat. The remaining modules support Module 2 by presenting information and protocols for investigating the contamination threat or implementing actions in response to a contamination threat or incident.

Most emergency responses are handled within the Guidelines of the NRP by the utility with assistance from local and state responders. The NRP is the overarching document that helps provide coordination between local, state and Federal Agencies responding to a disaster. The plan determines the roles of each participating agency and provides common language, communication, and actions among the first responders. This plan was utilized in the 9/11 events in New York City and at the Pentagon. Other uses of the plan included the Winter Olympics at Salt Lake City and for the emergency response to Hurricane Isabel in Virginia, North Carolina and Maryland. The development of coordination between local, state and federal agencies resulted in the ICS which provides disaster management including use of common terminology, modular organization, integrated communications, unified command structure, action planning, manageable span of control and comprehensive resource management.

While this document is not intended as a guide to developing response plans or strategies, the subject is important for several aspects of the design of an OCMS. In particular, the time needed between the identification of an emergency situation (such as a contamination event) and the effective implementation of an appropriate response, is important in determining priorities for placement of monitoring instruments. If there is too little time between the detection of an event and the implementation of a response that will safeguard the public, the investment in the monitoring capability has been ineffective. Also, the response options need to be taken into account in the design of the communications system and in stockpiling adequate quantities of materials to counteract the effects of the contaminant in the water.

Response options fall into three main categories:

- Notices to the public
- Utility actions
- Outside emergency response.

# 7.1 Notices

For water supply, three primary types of notices can be provided to the public. The most common is a "boil water" notice. This advises the public to boil tap water for a minimum length of time before using. It is usually invoked when pathogens are suspected in the water. Boiling water for ten minutes or more has a very strong likelihood of killing or disabling most pathogenic organisms. However, boiling water containing some pathogens may not be advisable because it may result in carrying

them into the air through steam without destroying them. Anthrax spores, for example, might become airborne within steam droplets before being destroyed by the heat in the boiling process. It may also decompose many toxic chemical species but it has no effect on radioactive materials.

A boil water notice can be provided to the broadcast and print community media—in relatively short time once the utility management has agreed upon issuing it, and can be made known to the public within a matter of hours or less. The impact of a boil water notice is relatively low. People can still use the water for nearly any purpose, and because the issuance of such notices is not very rare, the psychological impact and loss of confidence by the public is manageable.

Notices to not drink or not use water also can be issued quickly. These notices are much less often used and they may cause some loss of confidence in the system. Their impact on the user community would be moderate. Alternate sources of water particularly for drinking and sanitary purposes would have to be found if the notice were expected to be in effect for more than a day. Typical contamination event scenarios are likely to be two or three days in duration, so if boiling the water or other measures are not effective in countering the contaminant, alternate sources of water supply should be sought. A do-not-use notice would also affect the use of the contaminated water for fire fighting, unless specifically exempted.

If an explosive potential or toxic/infectious emanations from a wastewater collection system are identified, the area at risk should be closed off to vehicular and pedestrian traffic and the public notified to avoid the area. Such actions can be taken in a matter of hours or less and in general would be expected to have low impact on the community but a high impact on businesses in the closed area.

## 7.2 Utility Action

For water supply, the best action, in theory, would be to divert the contaminated water to a holding facility in which it could be decontaminated. This would imply that water under pressure would be unavailable to users for a period of time, that is, until the contaminated water is clear of the delivery path. In practice, containment and decontamination is not likely to be a possibility. In some cases, diversion in the form of discharge to the environment (into rivers or other bodies of water), or directly into the wastewater or stormwater system, is more practical. These actions can be taken relatively quickly but they would have at least moderate and perhaps high impact or cost.

In principle, some contaminants can be countered by adding specific material to the water. Some pathogens can be killed by temporarily increasing the disinfectant residual. In any case, the additive must meet the following requirements:

- Reduce the infectious or toxic potential significantly.
- Must not have or create byproducts that have, a significant public health risk.
- Be acquirable and storable for long times.
- Able to add to the contaminated portion of the water.

Utilities for the most part do not have the capability to identify such materials and leadership at the federal level is needed to make this an effective response option. The time needed to institute this option is moderate and the cost may be high.

For wastewater systems, contamination by volatiles in the collection system can be treated by forced venting, which would substantially reduce the explosive potential. Toxic or infectious materials can be mitigated through the addition of a higher concentration of disinfectant or by materials that counteract the toxin or pathogen. Again, this would require a moderate length of time to be implemented and it cost could be high.

## 7.3 Implications for OCMS

In light of the range of possible responses, in general, it will not prove worthwhile to install monitoring platforms using currently available instruments closer to the customer taps than the distance it takes flow to travel two hours.

## 7.4 Suggested Guidance

The utility should include the OCMS in its emergency response plan. This means that the contact list and functional assignments should reflect the appropriate information.

Deciding what, if any, materials can be added to water supply or wastewater systems to counteract the effects of certain contaminants without causing a public health risk is probably beyond the capability of all but a very few of the largest utilities. It would be helpful to have, associated with the contaminant list, an indication of what materials would accomplish the purpose of destroying the contaminant or its effects without causing further problems. In addition, if such materials can be identified, it would be helpful to have information on their acquisition and storage.

SECTION 8

# Interfacing With Existing Surveillance Systems

The CWA gives states and territories the primary responsibility for implementing programs to protect and restore water quality, including monitoring and assessing the nation's waters and reporting on their quality. However, under the SDWA, EPA is authorized to set water quality standards. Some states often adopt even more stringent regulations.

To meet these regulations, water supply systems conduct surveillance programs based on taking water samples at specific locations and testing them in a laboratory to determine the level of specific contaminants. The number of regulated contaminants in drinking water is very large—over 90—and likely to grow. Regulated contaminants include pathogens, toxic chemicals, and radioactive nuclides. The list includes many contaminants that are unlikely to be involved in short-term intense contamination events but may have long-term consequences through chronic exposure.

## 8.1 Strengths and Weaknesses of the Grab Sample/Laboratory Analysis System

The grab sample-based surveillance system has been designed to meet the regulatory requirements for contaminant monitoring in drinking water. Samples are taken from a relatively small number of locations, which can vary from time to time, on a schedule of relatively infrequent sampling. For contamination events that may last only a few days, the grab sample process is likely to miss the contamination. That is, this type of program has a very low potential for detecting such contamination events. The samples are handled to preserve their in situ properties and to protect the sample grabbing personnel from exposure to potentially harmful contaminants. The samples are then sent to a laboratory that may be within the utility or may be run by an outside organization. The laboratory studies are performed on high quality, often state-of-the-art, instruments and the results are generally highly accurate and reliable. The process generally incurs a time delay on the order of days or weeks from the time of the sample to the return of results from the laboratory. In emergency situations, some labs can provide analyses within 24 hours. The process is labor intensive and moderately costly when the initial investment in laboratory equipment and the personnel costs are taken into account.

## 8.2 In Situ Monitoring

Some utilities employ online monitors for specific water properties. The most common include chlorine, pH, and conductivity. These instruments are generally placed at strategic locations to provide confirmation of proper operations and indication of deviations that should be addressed through the addition of appropriate materials or other changes in operations.

## 8.3 Strengths and Weaknesses of the Online Monitoring System

The OCMS will operate nearly continuously, therefore it should be active during any significant contamination event. The monitoring instruments will be installed at relatively permanent locations; but there may be many of them. Most utilities do operate limited OCMS- style systems today. Continuous monitoring for flow, pH, turbidity, chlorine, fluoride and many more parameters is routine within the plant operation. Therefore there is a nucleus to develop for use in collection systems Unfortunately, because at this stage in the development of instrumentation the presence and properties of contamination must be inferred from changes in surrogate measures, the sensitivity and accuracy with which the contamination event can be described are questionable. The initial cost of a full-scale OCMS is high but because it is technology intensive, the operational costs may be less than for the grab sample system.

## 8.4 Administrative Matters

Both the OCMS and the grab sample system are focused on water quality. The purpose of the OCMS is to detect significant contamination events and provide an appropriate alarm. The purpose of the grab sample system is to ensure that the water system meets regulatory requirements that are focused mainly on long-term chronic exposure to specific contaminants.

In establishing an OCMS, one question is its relation to the existing surveillance and monitoring system. From a management perspective, it would be best to have the two systems functioning in cooperation rather than in competition. Suggesting that they should both be operated and maintained by the same group within the utility. Because the skill sets required for each systems are somewhat different, there may be limited opportunities to share staff. If the utility operates its own in-house laboratory facilities, there may be some commonalities in personnel who maintain the instruments. Likewise, field trained sample takers could be used for some housekeeping functions for the OCMS.

The two systems have some commonalities:

- They both seek evidence of the presence of contaminants.
- They both involve expertise in dealing with instruments that detect and measure parameters related to toxic chemicals, biotoxins, pathogens and radioactive materials.
- They both provide information to system management that may relate to a range of responses that can be taken by the water utility.

This suggests that there may be advantage in combining the operations so that at least some expertise among staff can be shared more easily.

## 8.5 Suggested Guidance

The two monitoring approaches could complement each other. The grab sample system might provide back up and corroboration for OCMS measurements. This is particularly the case where the OCMS instruments have the ability to take samples in suspicious circumstances.

Also, the online system could provide information that would help trace the source of problems discovered in the sample surveillance system.

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SECTION 9

# Operations, Maintenance, Upgrades, and Exercise of the System

System operations and maintenance must be considered and planned to ensure the highest possible system reliability and water quality. It should be assumed that security monitoring of drinking water will advance in technology and practice, and equipment will need to be upgraded over time to incorporate advances. Finally, the system must be exercised, along with the personnel involved, to maintain the best level of preparedness and training.

Installation of an OCMS would serve two purposes: detection of a contamination event and improved operation of the water utility. By some estimates, 85 percent or more of water utility assets are invested in the distribution system. Increased monitoring and control of water quality in the distribution system is prudent to protect these assets and to improve water quality for the utility's customers.

If one assumes the common use of the equipment is for monitoring and improving water quality, then system reliability standards could be somewhat more relaxed. But it is prudent to assume the worst-case scenario.

Therefore, instruments selected for deployment in this application must have a proven track record of analytical performance, electronic and mechanical reliability, minimal maintenance (cleaning, repair, calibration), and ease of use by persons with minimal formal training in analytical measurements. Failure on one or more of these points will lead to limited system availability and performance, as well as loss of operator confidence.

## 9.1 Suggested Guidance

### 9.1.1 Acceptable Up-Time, Mean Time Offline

The monitoring system should be designed for minimal downtime for repair and routine maintenance—replacement of limited life components, replenishment of reagents, and calibration. A target for average up-time should be at least 99.9 percent.[71]

If a monitoring system is offline for more than 10 minutes, substantial amounts of toxic materials could flow past a site without detection. Consider the consequences if the monitored site is one of the primary transmission mains in the distribution system. That implies a Mean Time OffLine of not more than 10 minutes. This has significant implications for methods of notification, getting people to the site for repair/replacement, spare part availability and service modes. These new requirements are so different from previous maintenance norms that revolutionary thinking and planning will likely be needed to achieve success.

[71] If an OCMS is established and known to the public, it may act as a deterrent, thus reducing the risk of a terrorist attack . If the risk is expected to be significantly reduced, some of these criteria may be relaxed.

## 9.1.2 Scheduled Maintenance

Security monitors must not be allowed to run until they break—preventative maintenance procedures should be considered mandatory. Scheduled maintenance will be essential for such systems, and the operations staff must plan for maintenance regardless of the size of the installation.

Such maintenance costs will not be trivial. To minimize these costs, the utility should select instruments that typically require not more than bi-weekly or, ideally, monthly maintenance. If the downtime for maintenance is 0.1 percent of the time, that translates to 40 minutes per month. Based on instrument selection, the down-time should be not more than 30 minutes. The implications of being off-line for that much time should imply re-thinking the maintenance procedures so that time off-line is minimized. Consideration should be given to hot-swapping components or systems, or having redundant systems so that no down-time is needed.

Consideration should be given to scheduling maintenance at random times rather than in a predictable pattern that might facilitate planning by attackers.

## 9.1.3 Service Agreements

One option to using in-house scheduled maintenance is to contract with an external service company. Only service companies with technicians trained by the manufacturer should be considered for contract services. This may be advantageous depending on the size and resources of the system, but introduces complications with security. Anyone coming into contact with the system, whether utility employees or a contractor, should have a background check and perhaps a security clearance.

## 9.1.4 Built-In Test Equipment

It would be useful if a monitor had Built-in Test Equipment (BITE) —to enable online testing. BITE or diagnostic information is beneficial because it can decrease the time spent in troubleshooting a failed piece of equipment.

To the extent possible with current technology, instruments should have built-in self-diagnostics to assist maintenance personnel in identifying the probable cause of instrument malfunction. The manufacturer should be required to provide a comprehensive operations manual clearly describing and defining the meaning of the diagnostic codes, probable cause, and suggested course of action for remedying an instrument malfunction.

Instruments with predictive diagnostics that can estimate time for service or remaining sensor life would be especially useful so that system downtime can be minimized, or scheduled at times of low use.

## 9.1.5 Communication Requirements

Data from distribution monitoring devices must be continuously transmitted to a central location that is monitored by operations staff 24 hours per day. Although digital data are preferred, there may be an advantage to having instruments capable of both analog and digital communication. Digital communication should be employed whenever possible. Most modern instruments with digital

communication capability will transmit analytical measurement values and also critical diagnostic information about performance of the instruments. Older analog systems provide very limited, if any, ability to communicate instrument diagnostic information.

Whatever hardware and software are selected, it should be designed to use commonly available hardware and software interfaces so that it is compatible with typical HMI (SCADA) systems. System manufacturers must be able to accommodate data transmission over one of the commonly used "BUS" methods (MODBUS, PROFIBUS, etc.).

The need for digital communication may dictate the need to upgrade communication systems to replace older style analog systems. The method of data transmission—radio, satellite systems, hardwired networks—will vary by utility and even at different locations within the same utility.

Whatever means is employed to continuously transmit data, the primary concern should be system reliability. The monitoring system should include local data logging to permit access, analysis, and download of data onsite if necessary.

## 9.1.6 Manufacturer Support

The monitoring equipment manufacturer should be required to provide support for a monitoring device for an adequate length of time.

All instruments supplied for the system must be of current manufacturer's design. In the event that an instrument becomes obsolete, the manufacturer will warrant that repair parts to maintain proper function of the instrument will be available for a reasonable period, for example, a minimum of seven years after the date of obsolescence. If the instrument becomes unserviceable before the seven years, the manufacturer should be required to make available a replacement instrument of equal or better analytical and performance specifications. The discount amount, if any, of such replacement instruments should be stipulated at the time of purchase of the original system.

## 9.1.7 Supplies and Limited Life Components

An assessment of supply needs must be done to ensure that supplies and expendables are available on a timely basis. Stocking some supplies at the measuring site may be necessary. However, the utility should avoid stocking replacements for long-life components such as circuit boards, unless recommended by the manufacture, as manufacturers often upgrade designs of such components. Those items should be ordered as needed. It is prudent to stock a two-month supply of limited life components and reagents. As with long-life components, the utility should avoid stocking a large supply of limited life components and especially reagents. Stocking a large supply of reagents creates unnecessary warehousing costs and can lead to degradation and possibly contamination.

The instrument supplier should be required to offer an automatic reagent replacement program. Such a program will ensure reagents are in stock when needed as well as to ensure the reagents are fresh. Such plans may simplify re-stocking of reagents and materials that are needed to keep the systems running.

If reagents or other supplies must be disposed of, plans for disposal services or treatment should be made in advance of the equipment being installed.

## 9.1.8 Spare Parts

It is prudent for the utility to stock a two-month inventory of spare parts and limited life components (such as lamps, replacement electrode elements, analytical reagents) to effect repair of the instruments for normal maintenance and calibration procedures. To accommodate more serious maintenance needs, the utility should maintain a service agreement with the instrument supplier to dispatch a factory service technician with all necessary repair parts within 48 hours. Such a service agreement should be considered for all monitoring sites considered 'mission critical.'

Depending on the system design, it may be prudent to stock spares for items that have long procurement lead times. For certain critical monitoring sites, it may be prudent to install instruments in replicate or have a complete replacement elements of the monitoring system available.

A utility should consider mounting one or more monitoring systems in mobile platforms (for example, a trailer) capable of being deployed on short notice to any location in the distribution system. Such platforms should be self-contained, including an on-board power supply.

## 9.1.9 Human Factors

At a minimum, crews of at least two persons should be trained for system operation and maintenance. Having two crews will allow at least one crew to be on call all of the time. The total number of crews trained should be that number necessary to respond to all system maintenance needs within 2 hours in any part of the OCMS.

Utility personnel assigned to operation and maintenance of the monitoring systems will be senior employees of the utility with a proven track record of reliability. The need for additional security clearances should be addressed on a case-by-case basis, based on how critical a particular monitoring location is to security considerations. A less stringent policy may be practical in low risk environments.

In areas where there are a number of significant political targets (government facilities, for example) it may be prudent to conduct more extensive background checks of employees. It may also be prudent to require security clearances for manufacturers' service personnel.

The system hardware and software must be designed to anticipate attack. Such attack could be crude, seeking the physical destruction of the equipment. Any monitoring system should report, or be polled on a frequent basis to assure that it is still there and functioning.

Another method of system attack would be to tamper with connections and signals coming into and leaving a monitor. False signals could be supplied while a system attack was taking place. Monitoring system hardware and software should be designed under the assumption that the system will be attacked, and should be able to recognize and report the condition. If data transmission is interrupted for any reason, the monitoring system should include local data logging to permit onsite access, download and analysis of data if necessary.

The utility must train in anticipation that their system will be attacked, and an effective response must be planned and practiced. Operators will need to be trained on the monitoring equipment, and its emergency replacement (such as portable analytical instruments or grab sample programs).

Instrument manufacturers should be required to offer training assistance for operating and maintaining their equipment. In as much as practical, it is prudent to standardize on a single manufacturer's equipment to minimize training needs and to make supply and parts inventory as simple as possible.

Municipal water systems have traditionally utilized very little continuous online monitoring. Monitoring, if any, has been with hand-held portable instruments, or samples have been gathered and transported to a laboratory. Persons conducting this testing may occasionally be water distribution technicians, but more typically are water treatment plant or laboratory personnel who are familiar with the instrumentation and test techniques. Hence, few water distribution personnel are familiar with the instruments, proper analytical techniques, sampling techniques, or intricacies of the analytical methods used.

Considering the foregoing, instrumentation placed into the distribution system must be rugged, require little operator intervention, and be reliable. They must also be easy to install, service, and use since little if any experience in installation, maintenance, or use of the instruments is present in the majority of distribution system crews. It is impractical in the long-term to utilize laboratory or treatment plant personnel for a wide area distribution-monitoring network.

In the interests of security, personnel should follow procedures that will not compromise system operation or reporting.

During maintenance or repair procedures, the maintenance personnel will notify a central control manager of the off-line status of the system, and the system should be capable of providing automatic notification at the time it is taken offline for maintenance.

During maintenance, the system will be configured to hold all digital and analog signal values that existed when the maintenance was initiated. Maintenance personnel must report to the central control manager when maintenance is complete and the system placed back in service. To assure the system is again communicating to the central control system, the maintenance personnel will not leave the site until cleared to do so by the central control manager.

If a system will be offline for any significant length of time, the maintenance staff should notify critical personnel of the system status and implement grab sampling at a frequency established by the utility (based on the current knowledge or suspected threats to the system and/or the area being monitored by the analytical instrumentation).

Most troubleshooting should be possible with common hand-held diagnostic tools and common hand-tools. When a specialized, proprietary instrument is available for diagnosing common problems, the utility personnel must be trained on its proper use and at least one such device must be owned by the utility.

A broad list of items in connection with human factors is given below.

- How many monitoring sites are appropriate in the distribution network? Consider high profile targets, such as federal buildings, as well as areas of greatest concern, such as schools, hospitals, and power utilities. Additionally, consider primary storage locations of water supply, such as tanks and reservoirs, and primary interconnections. It may be useful to think about monitoring in terms of blocks of population, or in square miles, depending upon the system.
- Will the most advanced technology be used at some or all sites?
- What is the lowest cost alternative for a monitoring site, while maintaining the level of surveillance necessary to provide the desired level of activity detection?
- It is prudent to consider the expected working life of the instrumentation, and to budget for replacement instruments and backup instruments accordingly?
- Replacement parts and consumable parts and reagents must be taken into consideration for budgeting purposes.
- Service and maintenance considerations must be included in budgeting. This may include personnel and related expenses, or service contracts.
- Updates to the system to maintain the desired level of surveillance capability should be included in budgeting considerations. Examples may include updated information on potential attack agents, or additional parameters that may be available in the future.
- Communication devices and upgrades to the devices must be considered. This could range from simple upgrades to establishing a major new communication system for the utility.
- Additional training in the event of personnel turn-over, and security/background checks of new personnel.
- In considering the cost of deploying the monitoring network, it would be prudent to consider the cost of doing nothing.
  - What will the cost be in loss of confidence in the utility?
  - What will be the public health cost?
  - What will the cost be in loss of commerce Water quality concerns play a key role in commerce. When it was thought Sydney, Australia had a serious waterborne disease outbreak (later determined to be laboratory error) just prior to hosting the 2000 Olympics, moving the Olympics to an alternate site was considered.
  - And, in the worst-case scenario, what will be the cost in life lost?

## 9.1.10 Upgrades in Technology

It is understood that technological improvements to instrument design and analytical performance may become available. The manufacturer should be required to notify the utility of the availability of any such improvements. It may be prudent for the utility to enter into an agreement with the manufacturer in advance, so when upgrades become available, they will be expeditiously implemented.

To the extent possible when new designs become available, they must be backward-compatible with existing instrumentation including communications protocols and software interfaces.

Just as with hardware, it is assumed that software will advance and that the system will benefit from software upgrades. If the software has information in the form of agent libraries, decontamination procedures, or treatment, such libraries could be upgraded much like computer anti-virus software.

If such software can be installed in the field, there must be security provisions within the system that will prevent the installation of a null set, or phony set of information.

Algorithms for data analysis should be extensible to accommodate the addition of information from new sensors added to the system.

## 9.1.11 Exercising the System

To maintain an effective level of readiness, it will be important to exercise the system and, in the process, maintain the training level of utility personnel. There are several ways to exercise an OCMS.

Tabletop simulations are useful tools for training as well as for testing policies and procedures. In this technique one posits a scenario and challenges the operational and policy staff to deal with the situation. Such exercises can be done without even involving the OCMS at all—just start with the scenario that the OCMS has detected an event. However, a tabletop exercise could incorporate the use of signals on the communications system that simulate the presence of a contaminant to see how the data analysis part of the system works and exercise the "down stream" portions of the OCMS apparatus.

Another approach would be the use of benign contaminants. That is, the utility would inject a substance into the water supply or the wastewater system that causes one or more of the instruments to register a change that would be interpreted as a contaminant event. The injectant must, of course, be something that does not cause a public health or safety risk.[72]

A third exercise strategy would concentrate on exercising one or another part of the system. For example, one set of sensors could be focused on a test chamber in which a known contaminant has been placed. The signals coming from those instruments would then be fed to the data analysis center and should cause an alarm to be generated. Or the data analysis system could be isolated and tested using simulated data from a set of instruments. Or the communications system could be tested by an attempted hacking or through observing the fidelity and reliability of is transmissions under a given set of signals and stresses.

[72] National Sanitation Foundation's standard for Drinking Water Chemicals (NSF/ANSI Standard 60).

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APPENDIX A

# White Papers

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# Appendix

This appendix presents the white papers done under contract for this project by several experts. The contracts were awarded under a competitive process in response to a request for proposals issued by ASCE.

The papers are presented as submitted to ASCE. They are:

**Methodology and Characteristics of Water System Infrastructure Security 5.1 Contaminants and Concentrations: (Highsmith)** ..... **A-3**

**Candidate Instruments and Observables (CSU)** ..... **A-31**

**Instrument Database Appendix (CSU)** ..... **A-73**

**Candidate Instruments and Observables (Hach)** ..... **A-183**

**Appendix I. Site Sensor and Analyzer Characteristics to Consider (Hach)** ..... **A-193**

**Placement of Monitoring Instruments in Water Distribution and Wastewater Collection Networks (CH2M HILL)** ..... **A-201**

**Data Analysis (CSU)** ..... **A-219**

**Models (CSU)** ..... **A-247**

**Appendix - Models (CSU)** ..... **A-293**

**Response (Highsmith)** ..... **A-317**

**Communications (ARK)** ..... **A-337**

**Operations, Maintenance and Upgrades (Hach)** ..... **A-394**

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# Methodology and Characteristics of Water System Infrastructure Security 5.1 Contaminants and Concentrations:

Submitted to
American Civil Engineers Society

GRA-SEW-RFP-01

Prepared by

Anita K. Highsmith, Stephen Margolis, William J. McShane.
Highsmith Environmental Consultants, Inc. Atlanta, GA 30329

April 27, 2004

Highsmith Environmental Consultants, Inc.
Attention: Anita K. Highsmith
P. O. Box 2943 1691 Mason Mill Road
Decatur, GA 30031 Atlanta, GA 30329

Phone: 404-636-6886
Email: akhwater@aol.com

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# Methodology and Characteristics of Water System Infrastructure Security 5.1 Contaminants and Concentrations:

Anita K. Highsmith, Stephen Margolis, William J. McShane.
**Highsmith Environmental Consultants, Inc. , Atlanta, GA 30329**

## Executive Summary

Improvements during the early-and mid-Twentieth century in water treatment greatly reduced the burden of waterborne diseases that remain killers in the developing world, i.e., cholera, typhoid fever and dysentery. The advent of the twenty-first century has led to the emergence of chemicals and biologicals that are resistant to standard methods of water treatment. Recent studies have reported: (1) in some communities up to 40% of episodes of diarrheal illness may be associated with "finished" or treated tap water, the characteristics of the distribution system and the proportion of the population who have diminished disease resistance due to age and/or heath status; (2) in San Francisco, 85% of Cryptosporidium infections acquired by HIV/AIDS patients in the late 1990s were acquired by drinking tap water; (3) about 80% of rivers and streams contain trace amounts of antibiotics, steroids, synthetic hormones and other commonly used drugs; and (4) information on digital devices that allow remote control of U.S. water pipelines has been recovered from Al Qaeda computers seized by U.S. authorities in fall, 2002, (CDC, 2003).

The federal Centers for Disease Control and Prevention (CDC) have proposed a series of goals in "Healthy Water: CDC's Public Health Action Plan. One specific goal focuses on homeland water security: "Enhance public health preparedness to detect and respond to illness caused by deliberate contamination of water, as part of the government-wide effort to ensure homeland security." CDC will work with local partners to ensure early detection of intentionally caused microbial or chemical contamination of water, providing guidance on how to use surveillance data to distinguish terrorist events from hoaxes and naturally-occurring changes in water quality. In partnership with the U.S. Environmental Protection Agency (EPA), CDC also will encourage coordinated biological and chemical terrorism preparedness, response and recovery planning among water utility, public health partners, healthcare providers, and law enforcement officials. CDC will support research to determine how long agents can survive in water, how susceptible they are to common water treatments, and what quantity an individual must ingest, or absorb, to become ill. Finally, CDC will also develop and reevaluate rapid methods for detecting biological agents in water (G-2).

The United States water distribution system is highly fragmented with 168,000 water systems nationally. The FBI has identified water systems as a logical target for a chemical (CT) or biological (BT) strike by terrorists or serious pollution/ toxic industrial materials (TIM) release (C-1, C-2). However, in 1996, the National Research Council stated in a report that greater than 20% of the water systems (or

greater than 33,600 systems) failed to meet Safe Water Drinking Standards for microbial contamination (C-3).

These systems serve more than 20% of the US population. This number translates to potential exposure of more than plant operations or laboratory testing support. Given the recent recession, this condition is likely to have persisted or worsened.

Potential threats to water supplies can arise from a variety of sources. For example, severe pollution by industrial and municipal chemical and sewage wastes; industrial accidents resulting in chemical spills into surface and sub-surface water sources; deliberate chemical or biological attack on water sources, processing, storage, and distribution infrastructure. These threats can exhibit a wide range of chemical, physical, radiological, toxicological, and biological properties. This enormous range of properties presents the analytical chemist and microbiologist with a substantial scientific challenge in terms of problem definition, choice of techniques for agent identification, and methodologies.

Most water treatment systems in the U.S. were built decades ago and have undergone limited or no improvements. Distribution lines have been modified to meet user demands. Reconstruction creates dead-ends in the distribution system, increasing the presence of biofilms already in place.

Utilities in the U.S. serve various-sized communities. Surface and groundwater supply source water. Source water may contain high organic and inorganic materials, some naturally occurring, others not. Water column profiles are not uniform. In some cases, the source may be influenced by water run-offs from climatic events, agricultural, or from industrial wastes. For example, a number of geographic locations in the U.S. have high levels of naturally occurring chemicals such as arsenic, while others may have toxic materials in the ground that leach into the source water.

Private wells are more likely to be influenced by contaminated groundwater leaching in from the surface. Agricultural run-offs from non-point source waters are examples of contaminants contributing to elevated levels of animal waste products and or pesticides in the source water. In other cases, industry waste poured into waterways have contributed to "drugged" source water.

Methods of treatment vary and, in some cases, such as well water, are consumed without treatment. Microbial agents and chemical agents including, by-products and toxins, may potentially contaminate water. The next generation of indicators may be in the form of physical recognition, such as an in-line or out-of-line device that can measure multiple prints of materials and alert operators and officials of unusual intrusion(s).

Technology, using operator assistance and recognized by standard methods has been developed. It is used extensively to monitor selected chemical and physical parameters on site and in the field.

It is anticipated that new devices under design can be placed in-line, at-line, and/or out-of-line of the distribution system with read-back to central locations with capabilities of detecting groups or types of contaminates. In order to accommodate this effort, more than one device may be needed to detect multiple groups of contaminates including microbial agents. In-line monitoring for chemical(s) has not been as challenging as monitoring and detecting of microbial populations.

This paper will focus on contamination and concentration(s) of selected agents as a means to develop guidance for the design of on-line, at-line, and/or out-of-line contamination and concentration monitoring system(s) for water distribution systems. The following approach is suggested: (1) understanding the contaminants of interest and levels of detection [microbial, toxin, and chemical]; (2) establishing concentrations posing a human health risk; and (3) providing supplemental indicators of distribution system contamination.

## Background

The ability to identify and evaluate threats is paramount to the protection of the water supply infrastructure and to the health and safety of the community. How we recognize a potential threat to the water infrastructure will depend on several things including day-to-day surveillance and response. Protection of water infrastructure requires a utility be prepared on multiple levels. Given present and recent global conditions, staff must be trained for response in the best and worse circumstances. This training requires a higher sense of awareness.

Understanding and ranking contaminants of concern then becomes the first order of work in designing a prototype device followed by developing sensitivity capabilities, as well as, a means for capturing contaminants and by-products for laboratory analysis and confirmation.

**Database Repositories:** Existing databases serve to provide guidelines upon which to measure other pathogen types or unknown etiologies. Drinking water quality data are available from a number of groups that have different responsibilities and needs. Four primary groups maintain information on water quality: the federal government, the state government, public water systems, and the water supply industry. While each database has specific purposes, data on public health outcome is less well-studied and documented. Contaminant groups are divided into four groups: microbials, inorganics, organics, and radionuclides. Contaminants of concern dealing with water quality infrastructure vary by groups (government, research organization, and utility). Three levels of guidance are published: regulations, standards, and guidelines.

**Quality Assurance/Quality Control Programs:** In the event of an unusual event, such as a terrorist attack, management will be required to assess the situation, activating a more specific and tailored response. A plan must be in place to evaluate a water supply and appropriately notify officials and the public. (See Section 5.7: Responses).

**Standardized Procedures:** A standard operating procedure is critical in the collection of data and transfer to appropriate officials. Regardless as to whether a technique is simple or sophisticated, in-line, at-line or on-line, fast or slow quality must be attained and maintained. Each laboratory/system that performs microbiological, chemical and or toxin analysis must adopt a quality assurance/quality control system. All methods must be written, validated, and subjected to performance testing and challenges. Laboratories that are compliant with U.S. EPA CLP guidelines should be fairly conversant with quality assurance requirements (C-35). Those that are not will need to start a steep learning curve. Again, it will be the smaller systems that will be most heavily impacted by the necessity of establishing a formal quality assurance/quality control program.

**Indicator Systems:** In the design of any indicator system, i.e. analytical methods for identifying groups or specific etiologic agents, or physical device, the investigator needs to consider: what will be measured, the ease of operation and maintenance, the upkeep, and cost. In addition, a method needs to be developed to ensure successful information-gathering for decision-making products. However, it is important to recognize that in addition to detection of an agent (microbial, chemical, toxin, or particulate), it also is necessary to determine a means by which the agent can be isolated and identified on-line or in a laboratory.

No one test measures all etiologic agents, microbial, chemical, toxin or by-product. Certain surrogates tests, such as turbidity and pH changes, can act as indicators of changes in water service or quality. Chemical contamination is easier to monitor and analyze than microbial contamination. Microbial populations have various rates of survival, persistence and proliferation qualities within the aquatic environment.

**Health Impact:** In addition to etiologic agent selection as indicators of water quality, consideration needs to be given to public health impact. The publication, *Control of Communicable Diseases Manual* provides a brief but thorough review of 136 groups of diseases (G-4). It is estimated that individuals drink approximately two-liters/person per day. Illness associated with drinking water exposure is based on a number of factors. These elements include virulence, pathogenicity, and infectious dose rates, carrier status, and secondary infection exposure. The impact of exposure to contaminated water varies by populations, age, and dose response. Dose response studies have been conducted by evaluating retrospective information for selected etiologic agents following outbreak investigations as well as numerical modeling.

Although human clinical trial data may be limited, epidemiological studies associated with waterborne disease provide an understanding on how healthy and unhealthy populations are effected, i.e. specific dose responses. Some epidemiologists regard exposure to an agent equivalent to an infective dose. Certainly, some agents have a more potent dose response level than others.

Waterborne disease (WBD) is transmitted by one of three routes: ingestion, dermal and inhalation. The literature contains publications that deal with a wide spectrum of data that would benefit the decision-making process in developing instrumentation for detection. Most publications have reported on actual cases associated with epidemiologic investigations, while others have projected outcomes through the use of numerical analysis (modeling). Risk assessment is another method that provides information on contamination(s) and concentration(s).

Outbreak investigations also demonstrate the difficulty of determining the causative agent. In over half of the outbreaks investigated, the causative agent is of unknown etiology. In cases of illness associated with parasites such as Cryptosporidium, the indicator coliform test may or may not be positive.

**Source Water Contamination:** Untreated, as well as treated water, is not sterile; many types of material (chemical, microbial, and particulate) are part of the water column profile, including the biofilm that develops on the interior surfaces of the distribution system. Generally, microbial populations are products influenced by the source water and the treatment and delivery process.

Data on contaminants is extensive for community water systems and less so for private wells. The EPA requires various periodic testing. The testing is based on the number of persons served. Data from communities served by private wells may be more limited.

The EPA has expanded these regulations to include disinfection by-products, organic chemicals, including herbicides and pesticides, and inorganic chemicals such as metals. Water utilities are required to monitor water at the treatment facility, as well as in the distribution system based on the Surface Water Treatment Rule (SWTR) enacted in 1986 and the Total Coliform Rule (TCR). The SWTR establishes maximum contaminant level goals for viruses, bacteria, and the protozoan, *Giardia lamblia,* while the TCR sets limits for the number of coliform bacteria that can be present in distributed water (G-3).

The EPA CCL list of contaminants has been established to aid in priority setting for the EPA's Drinking Water Program. The CCL is critical to understanding the quality of drinking water and protecting public health. Data from utilities provides regional and historical information on drinking water quality over time. As part of the SDWA, EPA requires the *National Drinking Water Contaminant Occurrence* to store data on the occurrence of both regulated and unregulated contaminants. While this database provides valuable information in the design of a device(s) to monitor water quality, other resources also are important and should be considered.

In 1998, the EPA required all community water system owners, except for private well users, to inform customers of contaminants detected. Larger systems test for agents listed in the EPA Contaminant List (CCL) (M-1). While the coliform bacteria are used as indicators of contamination events, outbreaks of illness and disease have occurred in the absence of these indicators.

Lists of etiologic agents have been produced by various groups as materials of concern. Selecting a suite of agents to incorporate in a detection device (in-line/out-of-line) also will also be dependant on geographic site location, taking into consideration those agents that are naturally occurring in the source water.

Monitoring for intrusion is a difficult task. The first indicator may be a physical breach in the system followed by illness or disease. Knowing how to respond to a suspect event is equally difficult. Testing for all contaminants, (known, potential or emerging) is costly and labor intensive. Implementing a program for understanding potential contaminants and the concentrations that would impact on human health

during routine day-to-day operations will greatly support recognition of unusual conditions leading to contamination of the water supply.

## Microbial Agents

**Indicators of Contamination:** Historically, coliform bacteria have been used as the sanitary index of drinking water quality. Although EPA has established a sampling regiment for microbial water sampling and analysis, state government may elect to vary this regiment. Periodic testing varies by size of population served. The coliform group of bacteria (Family *Enterobacteriaceae*) has been detected during most outbreaks of waterborne disease caused by bacterial, viral, and unidentified agents, but not all. Thus in cases such as these, the utility would not have violated either the 1975 or 1989 maximum contaminant level for coliform results.

Information on occurrence and recovery of microbial organisms is found in reports that provide baseline water profiles for regional surface and groundwater and those associated with a health effect. However, this data is subject to change with the recognition of emerging disease agents.

Very closely tied to the ability to recognize a potential contaminant is the need to have a plan for collecting the water samples, transporting and retaining materials for chain of custody. In addition, a written plan is necessary for water utility personnel that covers knowledge of the laws and regulations that require planning, training and use of protective equipment used by first responders.

Microbial agents associated with water quality include bacterial, viral, protozoan and algae. In some cases, analytical testing for these groups of organisms has evolved from cumbersome procedures to rapid methods that include molecular technology. Standard microbiological techniques have an inherently slow cycle time (incubation in multiple media). Molecular methods have an advantage over other procedures in that very specific targets can be recognized that collectively result in definitive identification of the agent. These methods also may provide laboratory capability to measure within a meaningful range. Some of these methods have led to nomenclature reclassification of agents. The most widely used system of classification and nomenclature is the U.S. is *Bergey's Manual of Determinative Bacteriology* (M-5).

A revolutionary DNA/RNA chip design for detecting waterborne agents is under development. The DNA/RNA probe will have exquisitely high sensitivity and specificity and allow for the measurement of waterborne microorganisms at levels lower than now possible. The system is being field tested in selected U.S. metropolitan cities in order to select DNA/RNA probes and perfect the identification software. The high resolution DNA/RNA chip technology represents the opportunity for a highly reliable and fast screening for any type of waterborne microbiologic agent. The chip system works by matching up to 400,000 programmed genetic codes. It allows the water plant operator, or homeland security personnel, to quickly and

accurately identify waterborne agents, at lower concentrations than currently possible (C-33).

**Concentration:** It is difficult, if not impossible to project levels or minimum levels of concentrations for all microbial contaminants that are associated with health effects. Initially, a new design prototype may be limited to a presence or absence of indicator followed by a presumptive/confirmatory report. At any rate, to be effective, data obtained by an inline device will need to be transferred to actual laboratory confirmation.

**Sensitivity to Disinfection:** A threat to water supply may become ineffective or limited due to the agent's sensitivity to the disinfection used or to the multiple barrier systems (filtration, sand, etc.). For example, coliform bacteria are less resistant to water disinfectants than are protozoan such as Giardia or Cryptosporidium species.

**Survival in the Aquatic Environment:** Bacterial species survive for different periods of time. Some species persist in water; others have the ability to proliferate in water. Viruses, another group of agents isolated from water, are not comparable to bacterial organisms in cell structure and their mode of replication is fundamentally different. Enteric viruses are not normal flora in the intestinal tract, but are excreted by infected persons. Enteric viruses multiply only within living susceptible cells. These agents may be present in sewage-contaminated surface and ground waters that serve as a drinking water sources. Viruses known to be excreted in relatively large numbers with feces that cause acute infectious nonbacterial gastroenteritis include enteroviruses, adenoviruses, reoviruses, rotaviruses, the Hepatitis A virus, and the Norwalk-type virus. Infection rates vary considerably.

Fungi are present in diverse water sources, treated and untreated. Species have been isolated from treated water and on inner surfaces of distribution lines. It is not fully known if they survive water treatment or enter the system.

**Dose Response:** Some epidemiologists consider any exposure to an agent of high concern to be equivalent to an infective dose. A bacterial genus may contain up to several thousand serogroups. Therefore, the presence or absence of one serogroup does not imply the absence of other pathogens. Risk increases when mass feeding and/or poor sanitation coexist. Others have reported in risk analysis studies that low numbers of enteric viruses present in a drinking water supply could pose a significant risk of infection.

**Biological Agents Representing Potential Risk to Health and Safety:** CDC, EPA and other groups have complied lists of agents that are considered to pose a threat to national security. Groups (government, utilities, and industry) have selected etiologic agents to be considered potential risk to public health and safety. For the purpose of this document, all lists were not available for public use. In some cases, these lists are duplicates. CDC has placed agents in three categories in order of priority. High priority agents include organisms that pose a risk to national security: For example,

CDC designated Category A. "The U.S. public health system and primary healthcare providers must be prepared to address various biological agents, including pathogens that are rarely seen in the U.S. High-priority organisms that pose a risk to national security because they: (1) can be easily disseminated or transmitted from person-to-person (2) result in high mortality rates and have the potential for major public health impact (3) might cause public panic and social disruption and (4) require special action for public health preparedness."

CDC designated Category B. The second highest priority agents include those that are (1) moderately easy to disseminate (resulting in moderate morbidity rates and low mortality rates and (3) require specific enhancements of CDC's diagnostic capacity and enhanced disease surveillance.

CDC designated Category C. The third highest priority agents include emerging pathogens that could be engineered for mass dissemination in the future because of (1) availability (2) ease of production and dissemination and (3) potential for high morbidity and mortality rates and major health impact.

## Toxins

In addition to performing chemical tests and evaluating physical parameters, toxicity tests need to be considered. The development of a device, or devices for monitoring the presence of toxins requires an understanding of toxins and their characteristics. Currently, water treatment facilities may conduct routine toxicity testing using aquatic organisms as natural monitors. Toxicity terms for dose, exposure time, acute toxicity, chronic toxicity, lethal concentration, effective concentration, inhibition, asymptotic LC50, median tolerance limit, no observed effect concentration and lowest observed effect concentration are defined in Standard Methods (G-1).

There are three acceptable methods for water purification against toxins: reverse osmosis; coagulation/flocculation; and chlorination. Reverse osmosis is effective against microcystin, saxitoxin, staphylococcal enterotoxin B, and T-2 micotoxin. Coagulation/flocculation is effective against staphylococcal enterotoxin B. Chlorination with 5mg/L, or 5 parts per million for 30 minutes also is effective against staphylococcal enterotoxin B (T-1).

According to the Textbook of Military Medicine, Part I, *Medical Aspects of Chemical and Biological Warfare,* as a general rule, direct contamination associated with toxin product in the water supply would have to be accomplished downstream of the water processing plant and near the consumers' taps (T-2). Ordinary chlorination methods used at water treatment plants are effective against the most toxic toxins. Human illness is unlikely due to the dilution effect in a water supply at the reservoir or plant's storage tanks. The natural occurrence of algae in stagnant water bodies could produce enough toxin, i.e., microcystin, to cause human illness.

**Characteristics:** Toxins are biological agents produced by living organisms such as animals, plants, or microbes. Toxins differ from replicating agents – viruses, mycoplasma and bacteria – in that toxins cannot replicate or be replicated in a human system. At times, toxins have been claimed to be "chemicals," i.e., saxitoxin, and are treated as if they are chemical agents of concern.

Toxins are divided into two categories based upon molecular weight and structure: "low-molecular weight" toxins and "protein" toxins. The former are usually 10 amino acids long and/or less than 1,000 daltons, and the protein toxins are generally greater than 10 amino acids. The mechanism of action for a toxin does not correlate to the molecular structure, size or its production source. There are two general categories of human interaction: neurotoxins directly impact primarily the peripheral nervous system, with temporary and reversible effects; and membrane-damaging toxins damage and/or destroy tissues, or organs and the effects are less reversible.

**Routes of Transmission:** Toxins are not volatile as compared to chemical agents, and with rare exceptions do not cause dermatological effects. Thus, for a toxin to be effective it would have to be prepared in a respiratory aerosol, allowing contact with the inner surfaces of the lung. Aerosol particles between 0.5 and 5 um in diameter are retained in the lung, and aerosolized particles smaller than 0.5 um can be inhaled, but most are exhaled. Toxin particles larger than 5-15 um lodge in the nasal passages and do not reach the lung. Finally aerosolized toxin particles bigger than 15 um drop to the ground. Thus, the human risk could come by exposure to shower water or hose sprays containing aerosolized toxins.

**Analysis of Toxins in Water Samples:** Swabs taken from water should be placed in sealed glass or Teflon (polytetrafluoroethylene) containers and kept dry and as cold as possible until analysis. Handling a toxin sample can be dangerous because the toxin can be inhaled. Immunological, analytical and/or assays methods are, or will become available for most of the toxins known. The enzyme-linked immunosorbent assays – ELISAs – are sensitive to 1-10 ng/mL and take 4 hours to develop. Chemical methods are available for toxins at the low microgram to high nanogram level and require two hours to develop. The polymerase chain reaction – PCR – can identify the genetic material of a toxin from any living organism – bacterial, animal or plant. In addition, extremely small quantities of toxins can be detected by a combination of immunoassay and PCR analysis.

**Detection Methods:** Aside from activities directly carried out by or for the water supplier, there also is a broad array of detection systems and diagnostic decision support systems for bioterrorism response. Bravata, et.al., (C-23) evaluated the available detection and diagnostic decision support systems for bioterrorism response including 55 detection systems and 23 diagnostic decision support systems. The authors report "only 35 systems have been evaluated: 4 reported both sensitivity and specificity, 13 were compared to a reference standard, and 31 were evaluated for their timeliness. Most evaluations of detection systems and some evaluations of diagnostic

systems for bioterrorism responses are critically deficient." For example, only eight of the 55 detection systems available had published evaluations (Table T-1).
In order for a bioterrorism detection system to be effective, it must have a very high sensitivity (how many of the samples that are positive report positive) and very high specificity (how many of the samples that are negative report negative).

## Table T-1: List of Detection Systems

| |
|---|
| BioCapture |
| Digital Smell/Electronic Nose |
| Fluorescence-based array immuno-sensor |
| LightCycler |
| Ruggedized Advanced Pathogen Identification Device, [RAPID II] |
| MiniFlo; Model 3312A Ultraviolet Aerodynamic Particle Sizer and Fluorescence Aerodynamic Particle Sizer-2; Sensitive Membrane Antigen Rapid Test (SMART) Antibody-based Lateral Flow Economical Recognition Ticket [ALERT]). |

Reference: Bravata DM, Sundaram V, McDonald KM, Smith WM, Szeto H, Schleinitz MD, Owens DK. 2004. Evaluating Detection and Diagnostic Support Systems for Bioterrorism Response; Emerging Infectious Diseases 10#1 100-108.

**Impact on Public Health by Age and Dose Response:** A terrorist event in a city will impact on an entire community – men, women, infants, children, seniors and even domesticated pets. People do not respond in similar manners to chemical agents, environmental toxicants and pharmacological agents. Infants, children and seniors, because of their unique physiological differences from the "average adult," will respond differently and have to be evaluated in a risk assessment and/or risk evaluation differently. The factors responsible for differences in risk assessment between children and adults include, as presented by the Conference on "Differences Between Children and Adults: Implications for Risk Assessment ":

- Growth and development
- Time between exposure and manifestation of effects
- Parameters of toxicity assessment
- Biochemical and physiological responses
- Drug and chemical disposition

Growth and development: Infants (birth to six months) and children (six months to six years) have a tremendous potential for adverse effects during growth and development. The full complement of mature cells does not occur until several years after birth. Time between exposure and manifestation of effects can be a major determinant of toxic outcome.

**Parameters of Toxicity Assessment:** Toxicity can represent an accumulation of multiple agents and/or events which interact to result in an adverse outcome. The functional ability of infants, especially, and children generally, is different from that of adults, which necessitates a different approach to toxicity assessment.

Communication skills, motor skills, and intellectual skills of newborns are such that the known toxicities of many agents cannot be monitored adequately using approaches acceptable for adults, i.e., dizziness, ataxia, slurring of speech, and hearing impairment.

**Biochemical and Physiological Responses:** How children respond to toxicants can be uniquely different from adults, or even older children. This is well known for many drugs and can be true for toxic agents. For example, phenobarbital is a sedative-type drug for adults, but produces hyperactivity, as a side effect, in children. These paradoxical responses must be considered in any risk assessment or evaluation. Drug and chemical disposition: refers to movement of agents through the body, including absorption, distribution, biotransformation, and excretion. For example, the kidneys clearance of foreign compounds is reduced at birth and matures to adult capacity in the first few years of life (T-7).

**Risk Evaluation and Risk Management:** Risk management is a holistic approach to planning, evaluating and executing an action. It is a term used by the military and by those responsible for preparing for, responding to and directing the recovery from a terrorist event. The military, since 1995, considers risk management " a fully integrated element of planning and executing operations...helps us preserve combat power and retain flexibility for bold and decisive action." (General Dennis J. Reimer, US Army Chief of Staff, 27, July, 1995). The term "risk assessment" has been utilized by different agencies in different ways. EPA has used the "risk assessment" of toxic environmental chemicals by evaluating the toxicity and lethality of those chemicals in different microorganisms and animals and then generating computer models of risk to humans. The criticisms of such an approach is that it uses data from unusual biological sources and makes broad assumptions to create computer models of risk.

Emergency response agencies have been utilizing the GEDAPER process (Gather information, Estimate the potential course of action, Determine the appropriate strategic goals, Assess tactical options and resources, Plan of action, implementation, Evaluation of the effectiveness of the plan, Review the process) since the early 1990s and defines three processes: hazard assessment, which is to identify hazardous materials present, their location, quantity and what they do; vulnerability assessment which defines who and what will be affected if a release occurs; and risk assessment, the probability of various scenarios occurring (T-8).

## Chemicals

A chemical, biological, pollution, toxic spill or waste intrusion into a water system must be detected. Broad toxicity detection can act as an early warning system. Once incident recognition has occurred, agent identification must take place to determine response actions. This will require more powerful analytical technology. This aspect could be severely burdensome for a financially strapped utility. These utilities will need advanced support and assistance from regional or state environmental and public

health laboratories. CDC has initiated a Laboratory Resources Network for Chemical and Biological response funding (equipment and infrastructure), training, and technology transfer (methodology) (C-34, C-35, C38) for state, territory, and large cities/counties. Water systems should have access to this type of support.

**Chemical Contaminants:** Many of the chemical warfare agents have a short lifetime in water due to hydrolysis, thus reducing their toxicity via ingestion vs. inhalation or dermal exposure routes (C-4).

After a finding of toxicity or contamination has been made, more specific and definitive testing using established and advanced techniques may be conducted after appropriate emergency response steps have been taken to ensure no human exposure will occur. These would include isolation of the contaminated water slug. Instrumentation factors are listed in Table C-1.

**Detection Methodologies:** Routine and conventional water testing methods will be useful in scenarios where the threat is identified. Most analytical methods found in *Standard Methods for the Examination of Water and Wastewater* (G-1) or EPA documents that are devoted to analysis of known toxins, contaminants, or TIMs. These methods should be easily capable of detecting a known or suspected threat at acutely toxic levels.

Classical instrument analysis technology is generally focused on specific toxic elements or radioactive nuclides (mercury, cadmium, arsenic, beryllium, $^{239}Pu$, $^{237}Np$, $^{131}I$, $^{137}Cs$), classes of compounds (sarin, chlorinated pesticides, TIM), bacteria (salmonella), virus (West Nile, variola), or toxins. These techniques also can be slow, especially when a sample must be incubated as in classical microbiological analysis. No one technique or combinations of common water analysis techniques are capable of detecting all possible threats, and in many cases are incapable of producing timely data. Given the possible broad and unknown nature of possible toxic agents, a water treatment facility may fail threat recognition, with disastrous consequences, if either the wrong techniques are applied, if the necessary technologies are not available, or if data generation is not sufficiently timely to initiate proper emergency response.

Ideally, a general "toxicity" test could be used as a "trip wire" to indicate if a toxic agent was present in the source waters, incoming stream, inside the plant, in storage reservoir tanks, or in the distribution system. Once a threat is recognized, powerful analytical/ microbiological technologies can be brought to bear on identifying the threat to definitively identify the agent and execute the proper consequence management plans.

There are several broad brush "toxicity" detectors currently available and in use. One such technology (C-5, C-6) will detect the presence of a broad range of chemical pollutants, toxic industrial materials or agents present in the water sample by monitoring changes in bioluminescence of an indicator organism (*Vibrio fischeri*). This device is currently an at-line device requiring an analyst. Similar technology has

been developed in Europe and Israel that features automated at-line analysis (C-7, C-8). Both on-line and at-line devices, however, will not detect the presence of biological organisms.

**Table C-1:**

## Instrumentation for Chemical and Microbiological Analysis of Water

| Technique | Typical Analytes | Principle | Selectivity | Sensitivity | General Toxicity Detection | Biological Detection | Radioisotope, Isotope Ratio Detection | Response Time | Technical Support Requirement | Maintenance & Consumables Costs | Initial Investment | On-line Capability | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Commercially Available** | | | | | | | | | | | | | |
| Bioluminecence | Toxic chemicals | Bioluminescence inhibition by toxic material | L | M | H | N | N | H | L | L | L | H | 5,6,7 |
| ATP | Biological Agent | ATP detection | L | M | L | H | N | H | L | L | L | L | 8 |
| PH | Acid/base | Gross increase/decrease in H+ | L | M | L | L | N | H | L | L | L | H | 16 |
| Turbidity | Suspended Material | Gross change in light scattering | L | H | L | L | N | H | L | L | L | H | 17 |
| Tot. Org. Carbon | Organics | Catalytic oxidation to CO2 | L | M | L | L | N | L-M | L | M | M | H | 14 |
| Chlorine | Available chlorine | Electrochemical | H | H | L | L | N | H | L | M | M | H | 15 |
| Particle Size/Flow cytometry | Suspended Material | Laser light scattering for number/size distribution | L | M | N | L-M | N | H | M | L-M | M | H | 16 |
| BOD | BOD, oxygen | Electrochemical | H | H | L | L | N | L-M | L | M | M | L | 13 |
| PCR/Fluorescence | Bacteria, viruses | PCR amplification w/ coupled fluorescence | H | H | L | M-H | N | H | M-H | M-H | M | N | 21-24 |
| AAS | Toxic elements | Atomic absorbance of light | H | M | N | N | N | L-M | M | M | M | L | 25 |

| Technique | Typical Analytes | Principle | Selectivity | Sensitivity | General Toxicity Detection | Biological Detection | Radioisotope, Isotope Ratio Detection | Response Time | Technical Support Requirement | Maintenance & Consumables Costs | Initial Investment | On-line Capability | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ICP-OES | Toxic elements | Plasma generated optical emission | H | M | N | N | N | H | H | M-H | H | M | 25 |
| ICP-MS | Toxic elements | Plasma ionized elements analyzed by MS | H | H | N | N | H | H | H | M-H | H | L | 25 |
| GC/MS | Pollutants, Pesticides | Chromatographic separation, MS detection | H | H | N | M | N | M | M-H | M-H | M-H | L | 16,25 |
| LC/MS | Pollutants, Pesticides | Chromatographic separation, MS detection | H | H | N | L | N | M | M-H | M-H | M-H | L | 16, 5 |
| GC/MS-FAME | Bacterial Fatty Acids | FAME profile, pattern recognition | H | L-M | N | H | N | L | M-H | M-H | M-H | L | 26 |
| FTIR | Organic chemicals | Molecular absorbance of IR light | H | L-M | N | L | N | H | M-H | M | M-H | H | 27 |
| Radiological | Radionuclides | Beta, Gamma detection | H | M-H | N | N | H | H | L-M | L | L-M | H | 19,20,21 |
| | | | | | | | | | | | | | |
| **Under Development** | | | | | | | | | | | | | |
| MALDI TOFMS | Chem & Biologic agents | laser ionization, MS detection, pattern recognition. Bioorg. and chemical | H | H | L | H | M | H | H | H | H | H | 31-33 |
| Microarrays | DNA, imumoassy | Change in reflectivity or electrical property | H | M-H | M | H | N | H | L | L | L-M | L-M | 34 |

L = Low, slow; M = Moderate; H = High, Fast; N = No capability

Reference: Hickman DC. 1999. "A Chemical and Biological Warfare Threat: USAF Water Systems At Risk", USAF Counterproliferation Center, Air University, Maxwell AFB, AL

Microorganism detection is accomplished using a portable at-line device requiring an analyst's detection of ATP (adenosine triphosphate) bioluminescence (C-9). As this instrument uses a similar technology base, to the bioluminescence devices described above, an on-line instrument could be developed rapidly. The bioluminescence technology has been employed for over 25 years and has been used to screen water supplies in Operation Desert Storm, 1984 Los Angeles Olympics, 1996 Atlanta Olympics, and various water systems (C-5). However, this success must be tempered by the fact that any techniques that rely heavily on sole-source specialized reagents or cartridges, are vulnerable to manufacturing failures and other supply chain interruptions (C-10).

There are a number of pitfalls that must be recognized for broad spectrum toxicity techniques. Some of these technologies do not appear to detect lethal doses of certain biotoxins or organophosphate nerve agents, and can be interfered with by some elements and chemical processes (chlorination, chloramination), and do not indicate any capabilities for water-borne viral pathogen detection (C-11).

Classical water examination techniques such as biological oxygen demand (BOD) (C-12), has been adapted as a surrogate for rapid toxicity determination. Other standard test methods have been adapted with variable degrees of success of detection. Chlorine sensors have been adapted as a surrogate indicator for contamination (C-13). Total Organic Carbon (TOC) analysis also has been adapted as an indicator of a potential chemical threat from organic chemicals (C-14). Others such as pH, turbidity, particle size, electrochemical sensors have been employed as on-line analyzers (C-15, C-16). The premise for the use of these non-specific analyzers for pollution, CT, BT, and TIM detection, is that an incursion event might be sufficiently severe as to perturb one of these parameters, and this premise requires validation.

Most water systems have some rudimentary capabilities to perform some level of Standard Methods chemical testing. These methods are capable of detecting a relatively limited list of specific analytes that are commonly applied to water quality. Some examples of relatively cost effective testing that can be performed at a small facility are cyanide, nitrates, nitrites, fecal coliform, pH, TOC, BOD, TS, TDS, turbidity, phosphate, metals, sulfate, etc. If the contaminant is not identified by one of these routine tests, more sophisticated techniques must be employed.

Toxic metal analysis may be accomplished by using atomic absorption spectrophotometry (AAS – inexpensive, ppm-level sensitivity, slow/single element), graphite furnace AAS (GFAAS – moderately expensive, ppb-level sensitivity, very slow/single element), inductively coupled atomic emission spectroscopy (ICP-AES – expensive, ppm/ppb sensitivity, fast/multi-element) (C-24), ICP mass spectrometry (ICP-MS – very expensive, ppb/ppt sensitivity, fast/ multielement). ICP-AES and ICP-MS are capable of scanning their entire spectral and mass ranges and identifying metals on the basis of their exhibited wavelength emission or mass. This is a very useful tool for "scouting" for an unknown toxic element. Most of these techniques

require personnel with formal chemistry training. These techniques are not well suited for on-line use.

Organic chemical contaminant analysis will require the use of Fourier transform infrared spectroscopy (FTIR – moderately expensive, ppm-level, fast), gas chromatography/mass spectrometry (GC/MS – expensive, ppt/ppb sensitivity, moderately fast), and liquid chromatography/mass spectrometry (LC/MS – expensive, ppt/ppb sensitivity, moderately fast). FTIR is useful for identifying organic compounds by their infrared absorption signature. GC/MS (C-26, C-39) will separate and identify volatile organic compound by their mass spectral pattern. LC/MS functions similarly as GC/MS for less volatile species. These techniques are capable of scanning their entire wavelength and mass ranges and identifying compounds on the basis of their exhibited wavelength absorption or mass spectrum. This is a very useful tool for "scouting" for unknown toxic compounds. Many of the chemical warfare agents are not stable in water and these techniques would be required to determine the presence of corresponding hydrolysis products. Most of these techniques require personnel with advanced chemistry training (MS/PhD). FTIR is well suited for on-line use. There are several areas that need to be addressed. The compounds analyzed by GC must be either volatile or be chemically derivatized to a volatile compound. The compounds analyzed by LC must be sufficiently soluble in the eluent to allow analysis. In both cases, analyte properties and chemistry and chromatography must be compatible. One difficulty analysts will encounter with powerful analytical instrumentation dedicated to chemical and biological agent detection will be access to standard materials (C-34). Most live agents, cyanide being an exception, are tightly controlled and inaccessible to laboratory personnel on a daily basis.

Biological organisms can be detected by polymerase chain reaction amplification coupled with tagged complimentary base pair fluorescence (C-20, C-21, C-22). This technique will "grow" the analyte. A wide range of bacteria and viruses are currently detectable by this technique. There are several weaknesses associated with this technique – reagents available for a limited number of species, high selectivity can require some preliminary organism identification, reagent manufacturing defects/ shortages (C-10). GC/MS also has been used to identify bacteria by generating fatty acid methyl esters (FAME), chromatography, and analysis of fatty acid profiles using factor analysis and pattern recognition (C-25). Similarly, pyrolysis GC/MS has been used to identify microorganisms, but would require adaptation to aqueous systems and commercial development of military technology (C-27, C-28).

Radiological contamination, while not strictly a chemical issue in the classical sense, can exert adverse biological consequences if the radio nuclides are metabolized and incorporated into human or farm animal tissues and bones. These effects may be exhibited at levels below standard chemical toxicity levels, as some radio nuclides will accumulate in certain areas and thereby be concentrated. Some examples are $^{131}I$, $^{90}Sr$, and $^{137}Cs$. A variety of at-line and on-line instruments are available for particle and ray detection (C-17, C-18, C-19). Particle emitters will probably require some

sort of sample preparation such as isolation from water due to the low penetration of particles.

The systems described so far have been a mix of at-line and on-line systems. In general, on-line instrumentation will cost three to five times more than the at-line counterpart. Hardening the instrument to withstand environmental or plant conditions requires special enclosures, more rigorous specifications for tubing and pumps, sampling and analysis control electronics (usually a PLC), I/O busses, communications capability, annunciators, temperature and humidity conditioning, and trained maintenance staff to name but a few additional requirements. Also, development of an on-line instrument requires more than putting a laboratory instrument in an enclosure and then placing the ensemble out in the water system treatment plant. The cost factor will adversely affect small water systems, in both substantial initial investment difficulties and on-going cost of ownership and support.

The military has and continues to invest substantial resources for chemical, biological, and radiological agent detection for force protection. The National Institute of Justice (formerly part of Department of Justice, now Department of Homeland Security) has evaluated the military technologies, along with commercially available equipment, for civilian first responder use (C-27, C-28, C-29). The one shortcoming of field deployable equipment development has been in the area of sampling. The majority of development efforts have been for airborne agent detection. Waterborne agent detection technology is available for a limited number of chemical warfare agents using largely colorimetry.

Two promising methodologies for contaminant detection in water are being developed. An existing mass spectroscopic method, matrix assisted laser desorption and ionization mass spectrometry (MALDI-TOF-MS), is being developed as a definitive chemical and biological agent detection system (C-30, C-31, C-32). While detecting chemical compounds has always been a strong point of mass spectrometry, detection and identification of biological entities by mass spectrometry of whole organisms or their component proteins is a new and important application. Eventually water systems may be monitored by such a system for chemical and biological agents. The other technology is the use of a DNA chip to detect biological organisms (C-33). By using micro fabrication techniques, a large number of DNA probes can be incorporated on to a microchip. This then could be coupled with bioluminescence, coupled fluorescence, or immunoassay techniques to function as a very selective, sensitive biodetector, with very wide detection capability.

**In summary**, sampling regiment, frequency of collection and site points for a water system are dictated by the requirements of a threat/risk matrix. Each system must develop a threat/risk matrix that is unique to their particular situation. It is unlikely that New York will have the same threat/risk possibilities as North Dakota. Threat/risk is a function of the product of probability and severity. The military risk assessment/management protocol (C-36). could serve as a development model. The system plans also should incorporate data from Homeland Security and state/local

threat intelligence. Examples of this type of intelligence may be seen on the various state HLS websites (C-37).

Ideally, sampling and analysis would occur at exposed points such as water sources, pipes, storage tanks or ponds; plant interior, distribution lines (C-16, C-38). However, many of these centers of gravity could be protected by enhanced physical security. During high treat levels or pollution event, sampling locations and frequencies can be increased for the duration of the incident. Sampling at the source, just prior to plant entrance and selected points in the distribution system, should be implemented, especially under high threat levels.

It would be remiss if another potential terrorist threat were not discussed. Although somewhat outside the scope of this paper, water treatment plants, usually housing large (typically one ton) liquid chlorine tanks for purification purposes, can be viewed as a "soft" target by a dedicated terrorist. An explosive device (C4 or IED) may not compromise the actual tanks, but probably will destroy the valves and pipes as well as any containment structures. A tank system breach of this nature will release large quantities of liquid chlorine into the environment, thereby triggering a CT attack on the surrounding community.

For any water system, large or small, the evaluation of risk and the management of risk are critical to appropriately prepare for an adverse event, respond to the adverse event and organize a rapid recovery from the adverse event. Preparing for an adverse event requires that the water system management be part of the local, state and/or regional emergency preparedness and response system – usually referred to as the "emergency management agency."

Preparing for an adverse event also demands use of the best surveillance system possible. This will include appropriate agent/chemical testing at water sources, at the plant and near the end user. Surveillance also includes information on emergency room activity and hospital admissions for the catchment area, obtained in a timely manner. In addition, preparing for an adverse event also includes creating algorithms for shutting down the system or parts of the system, if attacked, and algorithms for handling an increased water use burden if a neighboring system is adversely impacted.

Multiple alternate sources of water for the system's users should be determined, prepared for dissemination and written agreements created. If an adverse event were to occur, the water system should have personnel who inform and are informed by the emergency management agency in a timely manner and be part of the response system. If the water system, or parts of the system are to be closed, the timing and consequences of the shutdown should be laid out. As many realistic scenarios as possible should be created and referred to during the response.

Water testing and emergency room/hospital surveillance should be increased, looking for water ingestion-related adverse effects – morbidity and mortality. A plan for recovery should be prepared as the third arm of the risk evaluation and risk

management. Risk evaluation as compared to risk assessment provides valuable insight to public health risks.

The water system should be prepared to inform the using community as to the status of the water, the sources of clean water and the time frames for disruption. For all three aspects of preparation, response and recovery, the water system should have, or be part of a systematic and timely public information system. Information should include the level of risk, means of protection, time course of the event, and adverse health effect signs and symptoms and where to seek assistance.

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# Methodology and Characteristics of Water System Infrastructure Security: Section 5.2 – Candidate Instruments and Observables

**Submitted to**

**American Civil Engineers Society**

**Prepared by**

Kenneth Carlson
David Byer
John Frazey

Department of Civil Engineering
Colorado State University
Fort Collins, Co

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## Section I. Introduction and Background

The goal of the drinking water industry has always been to provide safe and aesthetically pleasing water to its customers. From every indication, it has been successful thus far, with drinking water systems being named one of the greatest engineering and public health accomplishments of the 20th century (National Academy of Engineering 2000, Centers for Disease Control and Prevention 1999). This does not mean that the challenges to the industry are over. The tragic events of September 11, 2001 have heightened concerns that drinking water systems, particularly distribution systems are potential targets for saboteurs. With the distribution system covering a large geographic area, and being readily accessible, it is imperative that contamination in the distribution system be detected in a timely manner to ensure adequate time to respond and protect public health. Continuous monitoring of the distribution system offers the potential to address this challenge.

This white paper will provide information to assist in instrument, sensor, and other device selection, and the tradeoffs involved in making those choices. Instruments that are commercially available and those that are being developed will be considered. Attention will be focused on the classification of the contaminants that the instruments may be used for, utility of the instruments for detecting contaminants per class, contaminant-instrument response, maintenance requirements, and cost. In addition, this white paper will provide a description of how these instruments can be used for a security monitoring application and a case study describing the determination of detection limits will be provided.

**Desired properties of an early warning system:** Unfortunately, a continuous monitoring "silver bullet" does not exist. It will likely take a suite of instruments and monitors to provide early warning in the instance of a contamination event. Whatever the platform(s), one goal would be to detect as many contaminants as possible at a concentration that will allow response before consumers become ill, paying particular attention to ensure that all contaminant classes are covered (chemical, microbiological, toxin, and radiological). Figure 1 depicts an iron triangle for detection, emphasizing the importance of knowing which threat contaminants should be monitored for, selection and

placement of the appropriate monitoring equipment to detect those contaminants, and an appreciation of baseline water quality conditions specific to the distribution system that is being monitored.

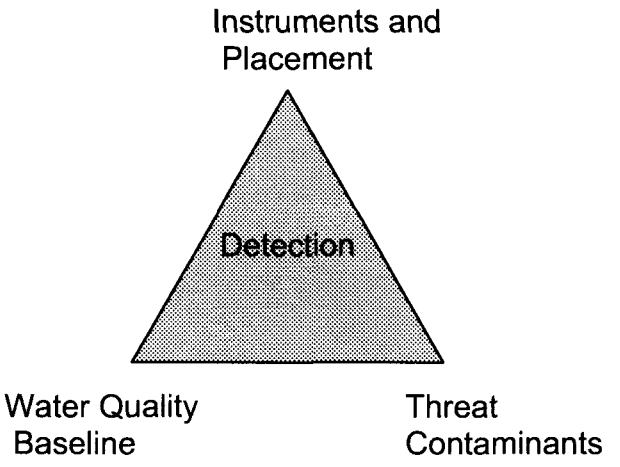



**Figure 1** Iron triangle for contaminant detect in distribution systems.

While trying to detect threat contaminants, false positives and negatives need to be minimized. False negatives would let contaminants through the system undetected, while false positives would soon discredit the monitor, and would likely result in it being removed from service. One approach for reducing false positive and negative readings would be to use instruments at multiple locations, anticipating a response downstream supportive of an upstream response. When results are obtained, they would need to be quantifiable and reproducible. The results need to be obtained fast enough, and at concentrations low enough, to allow an appropriate response. Where required, infrastructure would have to be in place to ensure that monitoring could be achieved during all seasons, and that monitoring results could be transmitted from remote locations. Finally, the technology used should require minimal skill, and training to perform the tests, and of course, be affordable.

Summarizing, the desired properties of a distribution early warning system include

- Ability to detect as many contaminants as possible per contaminant class

    - Chemical
    - Microbiological
    - Toxin
    - Radiological
- Capability to detect these contaminants below health threat levels (e.g. $LD_{50}$)
- Minimal false positives and negatives
- Ability to produce quantifiable and reproducible results
- Compatibility with infrastructure that is in place (e.g. SCADA, sanitary, power)
- Availability of remote monitoring
- Ability to withstand all seasons/climates/conditions
- Alarm triggered auto-sampling for further analysis and evidence

**Contaminant specific versus water quality surrogate monitors:** Once it has been determined that on-line monitoring is a feasible approach to continuously monitor the distribution system, one consideration is whether to monitor for specific contaminants (e.g. cyanide, Cryptosporidium oocysts) or to monitor for changes in water quality parameters (e.g. pH, conductivity, chlorine residual, turbidity) that indicate that a contamination event has taken place. At this point, both approaches need to be considered.

Monitoring water quality parameters in the distribution system continuously is considered to be an effective approach for detecting chemical contamination events. During a chemical contamination event, the chemical will influence changes in water quality parameters, relative to the concentration of the contaminant in the system, and induce a water quality instrument response. This is demonstrated in a case study that is presented later in this paper. One advantage to using water quality surrogates is the ability to cast a wider net -- to be able to detect a potentially unlimited number of contaminants with the right suite of instruments.

This same point highlights a major disadvantage of using contaminant specific monitors. Several government agencies have increased the funding of research and development efforts aimed at new technology for contaminant specific detection. Even though considerable additional research in this area is needed, there are concerns about

the ability to implement this technology due to the potential costs. Another issue associated with the contaminant-specific monitoring approach would be the choice of target chemical and biological agents to measure. If a system was monitoring for five chemical agents that did not include cyanide for example, it might be vulnerable if this information became available to potential terrorists. With the ability of a continuous water quality surrogate monitor to detect a chemical contamination event, an auto-sampler to capture a sample of the contaminated water, and a toxicity indicator kit to determine toxicity of the contaminant in less than an hour, the potential benefits of knowing exactly what the contaminant was can be postponed.

Radiological contamination is often discounted as a true threat. Since concern of contamination is also a matter of public perception, the resulting panic that may ensue if a drinking water system may have been contaminated with a radiological source would be considerable. Regardless, there is on-line instrumentation available to detect gross alpha, beta, and gamma radiation in water. An example of an on-line radiological monitor is provided in Table 2a. Again, these are surrogates for radiological contaminants. They do not specify the contaminant, but provide an instrument response that indicates that the water quality has been compromised with a radiological contaminant.

Water quality surrogates as described above will not work directly for toxins. One of the primary challenges with detecting toxins is that they are very toxic at very low concentrations, typically in the sub-microgram/liter range. The impacts to water quality at these concentrations would not likely generate an instrument response. Toxicity indicators have shown some success with detecting toxins at concentrations well below lethal doses. There is additional information in Table 2a and in the appendix on toxicity indicators.

Trying to detect microbiological contaminants presents a totally different challenge. Detecting these contaminants using surrogate water quality indicators does not appear to be feasible *at this time*, with only limited potential success. Some toxicity indicator kits use ATP to indirectly measure viable biomass. Methods that use ATP are limited when being used to try and detect spores or oocysts, because ATP that is generated is linked to a microbe's metabolism. When the organism is in a dormant state such as an oocyst or spore, the metabolism is essentially shut down, and ATP is not

generated in the quantities that a typical viable organism will generate. Another concern is the inability of ATP based tests to detect viruses because they do not exhibit the equivalent metabolic activity. Similarly, portable polymerase chain reaction (PCR) technology is available that will detect specified pathogen contaminants. These test kits are commonly referred to as Ruggedized Advanced Pathogen Identification Device (RAPID), and offer detection in as little as 30-minutes. The drawback of this technology is that it does not appear to be adaptable to on-line applications. Similarly, the toxicity indicators mentioned in the beginning of this paragraph are not presently available in a continuous, on-line mode. There is one model that is projected to be available in the Summer of 2004.

## Section II. Candidate Instruments and Observables

Table 1 provides a summary of potential surrogates per contaminant class that may be considered to detect contamination events indirectly.

**Table 1** Potential water quality surrogates per class of contaminant.

| Chemical Surrogates | Microbiological Surrogates | Toxin Surrogates | Radiological Surrogates |
|---|---|---|---|
| pH | Toxicity indicators | Total Organic Carbon | Alpha |
| Turbidity | Turbidity | Biomonitors | Beta |
| Total Organic Carbon | Phosphate | Toxicity indicators | Gamma |
| Chlorine Residual | High Temp TOC | | Toxicity indicators |
| Conductivity | Nitrate, Nitrite | | |
| Dissolved Oxygen | Chlorine Residual | | |
| Nitrate, Nitrite | Multi-angle light scattering | | |
| Phosphate | Fluorometry | | |
| Oxidation Reduction Potential | Biomonitors | | |
| $UV_{254}$ | | | |
| Biomonitors | | | |
| Toxicity indicators | | | |

Emphasis needs to be placed on the word "potential" that is included in the title for Table 1. The case study will validate pH, turbidity, total organic carbon, and conductivity for some chemical contaminants and discuss the use of these parameters for

one microbiological contaminant. The instrument database will provide information on continuous instruments that are used in the wastewater industry for nitrate, nitrite, and phosphorous, and may have potential in the drinking water industry.

Some toxicity indicators state that they will work for microbiological and radiological contaminants, but not all. The challenge with determining the appropriate toxicity indicator to use is understanding the method that the toxicity indicator uses, and choosing the right application to satisfy the monitoring need. Most toxicity screening kits presently use a reduction in luminescence to determine that a toxic contaminant is in the water sample. Examples of three different approaches include an enzyme based chemical reaction that reduces luminescence in the presence of a toxic contaminant, bacteria that will reduce their respiration and hence their luminescence in the presence of a toxic contaminant, and the use of daphnia that when stressed and after the addition of reagents will reduce their luminescence. These three approaches and other screening techniques were evaluated independently by States et al. (2004). A different approach uses a colorimeter or spectrophotometer to measure toxicity based on reduced respiration of bacteria that quantifies the change as a reduction of absorptivity at 603 nm. Each of these tests has their own advantages and disadvantages, and each needs to be considered so that the monitoring goal, or the gap that these kits will fill, is adequately addressed. A good place to look for further information on these toxicity kits and others is EPA's ETV web-page available at http://www.epa.gov/etv/verifications/vcenter1-27.html.

Using biomonitors in chlorinated water presents a challenge since the chlorine needs to be removed before the water enters the reactor. Some toxins have a large percentage of organic carbon in their molecules, and on the surface may appear to be detected by TOC, but again, at relatively low concentrations, they may not provide an instrument response significantly above baseline. The next section provides more information on selecting water quality surrogates per contaminant class.

**Selection of surrogates:** Of the drinking water quality parameters, chlorine is cited most frequently in the literature for providing both a barrier to contamination in the distribution system, and for use in detecting contamination events. The most prevalent disinfectant in the water industry is chlorine, being used by 80% of large and medium

sized utilities, with chloramines being a distant second (Macler et al., 2000). Real-time monitoring of the chlorine residual in the distribution system is not a common practice, but it is inexpensive (Clark and Deininger, 2000). In order to provide safe drinking water to the entire population, the chlorine residual should be monitored at strategic places in the distribution system (Deininger et al., 2000).

The National Research Council (2002) insists that in order to ensure the safety of the water supply, an adequate disinfectant residual must be maintained in the distribution system, and that the best line of defense against dangerous bacteria and toxins is maintenance of a high chlorine residual in the distribution system. They emphasize monitoring the chlorine residual real time at representative locations, and stress that the distribution system has the greatest vulnerability to contamination. The National Research Council also suggests a variance in turbidity from baseline properties as an approach to detect contamination. Khan et al., (2001) identify the need for research in areas that would use chlorine residual or turbidity in distribution systems with on-line, remote monitoring to detect changes in these parameters.

Deininger (2000) points out that one proactive utility has 14 continuous monitoring stations equipped to measure pH, temperature, conductivity, chlorine residual, and turbidity in its distribution system. Clark et. al (2002) highlights chlorine residual and pH as having been previously considered in research as surrogate candidates for on-line monitoring of distribution systems. Finally, Landers (2003) emphasizes the interest in monitoring pH, conductivity, chlorine residual, and turbidity while discussing an EPA award to USGS for real-time monitoring research.

Total organic carbon (TOC) is not noted in the literature, probably due to cost. Regardless, it is an obvious surrogate for the detection of organic contaminants. As the percentage of organic carbon in the contaminant molecule increases, so will a TOC instrument's response after introduction of the contaminant. High temperature TOC analysis (a UV/persulfate oxidation step will not oxidize microorganisms and therefore no $CO_2$ signal will be produced) may offer an increased chance of oxidizing microorganisms, offering the potential to indirectly quantify the introduction of microorganisms in a drinking water distribution system.

Chlorine residual, turbidity, pH, and conductivity, are all referenced in the literature as good choices of surrogates for detecting distribution system contamination. Total organic carbon is not cited, but is an obvious choice to detect organic contaminants. The drawback to on-line TOC analysis is its relatively high cost. Further work may be directed at how effective the other water quality surrogates (chlorine residual, turbidity, pH, conductivity) are at detecting organics without the use of TOC to eliminate this costly equipment from the suite of instruments required to provide robust early warning in the distribution system.

Possible scenarios where water quality surrogates may prove useful for detecting microbiological contamination may have more to do with what would be added to the water either with or before introduction of the contaminant, than the contaminant itself. Examples include a turbid microbiological preparatory solution that may provide nutrients for the microbes before injection, in which case turbidity may be successful at detecting the contaminant. Another scenario may involve the injection of a thiosulfate solution before the microbiological contaminant to significantly reduce the chlorine residual, thus providing the contaminant a better chance of surviving and causing disease. In this scenario, an on-line chlorine residual analyzer would provide a significant instrument response, and would provide indication of contamination.

Another potential area for continuous contaminant detection includes the use of biomonitors. As used in raw water supply, a side stream of the source water is directed into a fish tank, and native fish or other fresh water species are used to detect changes in water quality that would be detrimental to the species. Not only do toxic contaminants generate a response, but also contaminants that change water quality enough to irritate the species. The challenge with applying this technology directly to finished drinking water is the residual oxidant. Another challenge includes the maintenance and cost of the bio-sentinels. With continued effort, this may turn out to be an additional tool in continuously detecting contamination events, and may be effective across most contaminant classes.

Phosphate, nitrite, and nitrate continuous monitoring is also available and is currently used in the wastewater industry. Applying this technology to drinking water monitoring offers another option to indirectly determine microbiological contamination

in the distribution system. Nitrogen is a component of prokaryotic cells, composing 6-15% of the cell depending on cell type and nutrient conditions (Rittman & McCarty, 2001). Phosphorous is a required element for bacterial growth, is assimilated into cells, and found in nucleic acids, proteins, phospholipids, ATP, and coenzymes. When cells are lysed, phosphate is released. There is typically a stoichiometric relationship between nitrogen in a cell, and phosphate, with cells containing considerably more nitrogen. Utilizing nitrogen and phosphorous as water quality surrogates offer the potential to detect microbiological contaminants, and also to provide more specificity to detecting chemical contaminants. One key consideration for applying this technology to drinking water would be in lysing the cell before the solution was passed through monitors. Common ways to lyse cells include sonication and homogenization.

Multi-angle light scattering (MALS) technology is offering promise for detecting microbiological contaminants in water. This technology is based on laser scattering and motion analysis to determine the nature and amount of bacteria in a water sample. Adding pattern recognition techniques to the MALS technology has the potential to address the present shortfall in continuous monitoring for microbiological contaminants. The Computing Research Centre at Sheffield Hallam University, Sheffield, United Kingdom is using a MALS device patented by Rustek Ltd, to pursue this opportunity (http://www.shu.ac.uk/scis/artificial_intelligence/biospeckle.html).

Another option to detect microbiological contamination in water includes the use of fluorometry. This technology has been applied to the continuous analysis of source waters for chlorophyll-a and algal biomass. In addition, it has been demonstrated to work with E-coli (Samset et al., 2000) off-line. A continuous monitoring instrument has been developed and is highlighted in the instruments database (keyword Colifast). Fluorometry offers considerable flexibility in choosing microorganisms to monitor for. It is based on the excitation and emission wavelengths of fluorescent compounds that would become indicative of contamination as the number of bacteria increase in population, and enzymes in the bacteria react with the fluorescent dyes to luminesce.

Table 2a provides a summary of information on the instruments that are included in the Appendix. The table is arranged by manufacturer alphabetically and provides a brief summary of the instrument or test kit. The database that is included in the appendix

includes more information *as available*, such as a link to a manufacturer's web-page, cost, maintenance summary, and a photo. The summary table and database are separated into two distinct groups--those instruments that are presently available (Table 2a) and those that represent an emerging technology (Table 2b). For those instruments that are in the emerging technology category, references to title projects, authors, and brief descriptions of the technology are provided.

Table 2a **Summary of commercially available instruments and testing kits presented in Appendix A.1.**

| Instrument/Testing Kit | Manufacturer | Parameters Observed/Sampled |
|---|---|---|
| 4670 Series Turbidity System | ABB Instrumentation | turbidity |
| Series B20 Residual Chlorine Recorder | Analytical Technology, Inc. | free chlorine, chloramines |
| bbe Algae Online Analyser | bbe | direct chlorophyll fluorescence (this measurement corresponds to the wet-chemical chlorophyll analysis); active chlorophyll fluorescence (Genty Parameter -- this measurement shows the percentage of active chlorophyll under defined conditions); transmission (in order to compensate the influence of substances which cause turbidity, transmission measurement takes place automatically during each analysis); differentiation of fluorometrical algae classes (it is possible to determine at least the content of chlorophyll according to green algae, bacillariophycae (diatoms, dinoflagellates, ...), blue-green algae, cryptophyceae) |
| Tox Screen | CheckLight, Ltd. | colchicines, cyanide, dicrotophos, thallium sulfate |
| VVR Water Anlysis System | Chemetrics | ammonia, bromine, chlorine, chlorine dioxide, chromate, copper, cyanide, DEHA, formaldehyde, glycol, hydrazine, hydrogen peroxide, iron, molybdate, nitrate, nitrite, oxygen (dissolved), ozone, peracetic acid, phenols, phosphate, silica, sulfide, zinc |
| Colifast At-line Monitor (CALM) | Colifast | Provides water quality data for thermotolerant coliforms/*E.coli* and total coliforms. |
| Colifast Analyzer (CA) | Colifast | Tests for thermotolerant coliforms /*E.coli,* total coliforms, Total Viable Organisms and *P. aeruginosa*, are available. |
| Cyranose® 320 | Cyrano Sciences | The unique polymer composite sensors have been shown to respond to a wide range of organic compounds, bacteria and natural products. |
| Six-CENSE™ | Dascore | chlorine (no reagents required), monochloramine or dissolved oxygen, pH, temperature, conductivity, ORP/REDOX |
| RiboPrinter® Microbial | DuPont Qualicon | Up to eight bacterial isolates can be tested at one |

| Instrument/Testing Kit | Manufacturer | Parameters Observed/Sampled |
|---|---|---|
| Characterization System | | time, with results available eight hours from sample input. |
| MiniTROLL | Electronic Data Solutions | collect real-time information for analysis of both short- and long-term water level trends |
| MP-TROLL 9000 | Electronic Data Solutions | surface water quality monitoring, dissolved oxygen |
| Ocean Seven 316 Water Probe | General Oceanics, Inc. | The probe is equipped with the following standard sensors to measure: pressure, temperature, conductivity, salinity, oxygen, pH, oxidation-reduction potential. |
| WDM PipeSonde In-Pipe Probe | Hach | pH, ORP, conductivity, turbidity, dissolved oxygen, line pressure, temperature |
| Water Distribution Monitoring Panel (WDMP) | Hach | chlorine, conductivity, pH, turbidity, pressure, temperature |
| Color Disc-based Test Kit | Hach | |
| MEL P/A Safe Drinking Water Laboratory | Hach | total coliforms and *E.coli*, chlorine, nitrate, TDS, pH |
| ToxTrak Toxicity Test Kit | Hach | toxicity of wastes and chemicals in wastewater treatment processes |
| astroTOC HT (High Temperature) | Hach | TOC measurement |
| 1950plus On-line TOC Analyzer | Hach | TOC measurement |
| AccuChlor 2 Residual Chlorine Measurement System | Hach | chlorine |
| CL17 Free Residual Chlorine Analyzer | Hach | chlorine |
| Series 4 Multiparameter Water Quality Monitoring Sondes | Hydrolab | ammonium, chloride, conductivity, dissolved oxygen, nitrate, pH/reference, pH/ORP/reference, temperature, TGD, turbidity, chlorophyll, PAR |
| Quanta – Display Multiparameter Water Quality Instrument | Hydrolab | temperature dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity |
| Quanta-G – Transmitter Multiparameter Water Quality Instrument | Hydrolab | temperature dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity |
| Quanta – Transmitter Multiparameter Water Quality Instrument | Hydrolab | temperature dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity |
| Quick™ II Test Kit and four other kits | Industrial Test Systems, Inc. | arsenic |
| PolyTox™ Rapid Toxicity Test | InterLab Supply, Ltd. | pH, dissolved oxygen (ppm), temperature (°C), toxic metals (ppm) |
| BIOX 1010 BOD Analyzer | ISCO, Inc. | BOD measurement |
| EZ TOC Continuous Low-temperature On-line TOC/TC Analyzer | ISCO, Inc. | TOC measurement |
| STIP-toc Continuous | ISCO, Inc. | TOC measurement |

| Instrument/Testing Kit | Manufacturer | Parameters Observed/Sampled |
|---|---|---|
| High-temperature On-line TOC Analyzer | | |
| STIPTOX-adapt (W) On-line Toximeter | ISCO, Inc. | TOC measurement |
| Threat Detection Kit™ | Kingwood Diagnostics, LLC | The Threat Detection Kit not only can be used to assess water contamination after a security breach – but, also should be considered as at tool for daily monitoring – in effect an early warning system. |
| SMART 2 Colorimeter with the 3660-SC Reagent System Portable Cyanide Analyzer | LaMotte Company | Alkalinity UDV, Aluminum, Ammonia, Nitrogen-LR (Fresh Water), Ammonia, Nitrogen-LR (Salt Water), Ammonia Nitrogen, Boron, Bromine LR, Bromine UDV, Cadmium, Carbohydrazide, Chloride TesTab, Chlorine, Chlorine Free UDV, Chlorine Liquid DPD, Chlorine Total UDV, Chlorine Dioxide, Chromium, Hexavalent, Chromium TesTab, Chromium (Total, Hex & Trivalent), Cobalt, COD LR 0-150 with Mercury, COD LR 0-150 without Mercury, COD SR 0-1500 with Mercury, COD SR 0-1500 without Mercury, COD HR 0-15,000 with Mercury, COD HR 0-15,000 without Mercury, Color, Copper BCA – LR, Copper Cuprizone, Copper DDC, Copper UDV, Cyanide, Cyanuric Acid, Cyanuric Acid UDV, DEHA, Dissolved Oxygen (DO), Erythorbic Acid, Fluoride, Hydrazine, Hydrogen Peroxide, Hydroquinone, Iodine, Iron, Iron UDV, Iron Phenanthroline, Lead, Manganese LR, Manganese HR, Mercury, Methylethylketoxime, Molybdenum HR, Nickel, Nitrate Nitrogen LR, Nitrate TesTab, Nitrite Nitrogen LR, Nitrite TesTab, Ozone LR, Ozone HR, pH CPR (Chlorphenol Red), pH PR (Phenol Red), pH TB (Thymol Blue), Phenol, Phosphate LR, Phosphate HR, Potassium, Silica LR, Silica HR, Sulfate HR, Sulfide LR, Surfactants, Tannin, Turbidity, Zinc LR |
| PDV 6000 Heavy Metal Analyzer | Monitoring Technologies International, Pty. Ltd. | arsenic |
| AF46 Dual Channel UV Absorption Sensor | Optek | concentrations of acetone, aniline, benzene, halogens, HMF, hydrogen peroxide, ketones, trace mercury, nitric acid, ozone, phenols/phenates, sulfur dioxide, toluene, tracers, xylene |
| Mini-Analyst Model 942-032 Portable Cyanide Analyzer | Orbeco-Hellige | cyanide |
| Analyte 2000 Fiber Optic Fluorometer | Research International | performs evanescent-wave fluoroimmunoassays |
| Eclox™ | Severn Trent Services | chemiluminescence testing, also includes equipment and specific tests to measure arsenic, pesticides /nerve agents, pH, total dissolved solids (TDS), color, chlorine |

| Instrument/Testing Kit | Manufacturer | Parameters Observed/Sampled |
|---|---|---|
| TOC-4110 On-line Water Quality Analyzer | Shimadzu North America | NPOC(acidify/sparge removal of IC) and TC (standard). NPOC, TOC (TC-IC) (option). NPOC,TOC (TC-IC and POC + NPOC) (option) |
| TOCN-4110 On-line Water Quality Analyzer | Shimadzu North America | NPOC (acidify/sparge removal of IC) and TC (standard). NPOC, TOC(TC-IC) (option). NPOC,TOC(TC-IC and POC+NPOC) (option) |
| TOCvsh On-line TOC analyzers | Shimadzu North America | Wide variety of measurement methods -- NPOC (TOC measurement by IC removal using acid sparging), TC (total carbon), and IC (inorganic carbon) measurements are all possible. Adding the optional TNM-1 allows continuous monitoring of TN (total nitrogen) in samples. |
| WTM500 On-line Turbidimeter | Sigrist | turbidity |
| Deltatox® | Strategic Diagnostics Inc. / Azur Environmental | partial list: phenol, lead, arsenic, mercury, sodium cyanide, selenium, potassium cyanide, chromium, PR-toxin, copper, aflatoxin, ochratoxin, rubratoxin, chloroform, ammonia, sodium lauryl sulfate, benzoyl cyanide, lindane, DDT, cresol, formaldehyde, malathion, carbaryl, flouroacetate, trinitrotoluene (TNT), parathion, 4-phehnyl toluene, carbofuran, pentachlorophenol, patulin, paraquat, diazinon, cyclohexamide, cadmium, quinine, dieldrin, microbiologicals |
| Model 500 Microtox® | Strategic Diagnostics Inc. / Azur Environmental | Microtox Acute Toxicity, Microtox Chronic Toxicity, Mutatox, ATP |
| SSS-33-5FT Drinking Water Rad-safety Monitor | Technical Associates | This detector measures alpha, beta, and gamma from any non-ionized radioactive liquids. |
| Apollo 9000 HS Combustion TOC Analyzer | Teledyne Tekmar | TOC measurement |
| Phoenix 8000 UV-Persulfate TOC Analyzer | Teledyne Tekmar | TOC measurement |
| F-NTK NECi Environmental Field Nitrate Test Kit | The Nitrate Elimination Co., Inc. | nitrate |
| AQUAfast® IV AQ4000 with AQ4006 Cyanide Reagents Portable Cyanide Analyzer | Thermo Orion (Thermo Electron Corporation) | cyanide |
| Model 96-06 Cyanide Electrode with Model 290 A+ Ion Selective Electrode Meter Portable Cyanide Analyzer | Thermo Orion (Thermo Electron Corporation) | cyanide |
| Nano-Band™ Explorer Arsenic Test Kit | TraceDetect | arsenic |
| Aquafluor Fluorometer/ Turbidimeter | Turner Designs | chlorophyll a, histamine, DO matter, ammonimum, cyanobacteria, DNA, RNA, LIVE/ DEAD® BacLight™ Bacterial Viability Assay, alkaline phosphatase fluorescence |
| Self-contained | Turner Designs | chlorophyll a and rhodamine WT versions |

| Instrument/Testing Kit | Manufacturer | Parameters Observed/Sampled |
|---|---|---|
| Underwater Fluorescence Apparatus (SCUFA) | | |
| TD-700 Laboratory Fluorometer | Turner Designs | fluorescence, turbidity in one sample; available in three models: in vivo chlorophyll a/turbidity, rhodamine WT/turbidity, ammonium/extracted chlorophyll a |
| NAS-2E In-situ Nutrient Analyzer | WS EnviroTech | Four versions are available for the measurement of nitrate (and/or nitrite) phosphate, silicate, and now ammonia. |
| Cyanide Electrode CN501 with Reference Electrode %503D, and Multi-parameter handheld 340i | WTW Measurement Systems | pH, DO, temperature or pH, cond., cyanide |
| YSI 600 OMS Multi-parameter Probe | YSI Environmental | chlorophyll, rhodamine, or turbidity in combination with temperature, conductivity, and depth in fresh, sea or polluted water |
| YSI 600 QS (Quick Sample™) Multi-parameter Display-datalogger System | YSI Environmental | dissolved oxygen in mg/L, dissolved oxygen % saturation, temperature, conductivity, pH, ORP and depth are measured simultaneously |
| YSI 600 R Multi-parameter Probe | YSI Environmental | dissolved oxygen, temperature, conductivity, salinity, pH |
| YSI 600 XL Multi-parameter Probe | YSI Environmental | dissolved oxygen, temperature, conductivity, ORP, salinity, vented level, depth, pH, TDS, specific conductance |
| YSI 600 XLM Multi-parameter Probe | YSI Environmental | dissolved oxygen, open-channel flow, temperature, conductivity, vented level, salinity depth, ORP, pH |
| YSI 650 MDS Multi-parameter Display-datalogger System | YSI Environmental | handheld, rugged, waterproof display for all 6-series sondes |
| YSI ADV6600 Sonde Multi-parameter Probe | YSI Environmental | dissolved oxygen, conductivity, temperature, pH, ORP, pressure, velocity, direction, turbidity, chlorophyll, rhodamine, chloride, ammonia, and nitrate along with calculated parameters such as specific conductance and salinity |
| YSI 6600 Sonde Multi-parameter Probe | YSI Environmental | dissolved oxygen, open-channel flow, temperature, TDS, rhodamine, chlorophyll conductivity, vented level, specific conductance, nitrate-nitrogen, ammonium-nitrogen, ammonia, turbidity, chloride, salinity, depth, ORP, pH |
| YSI 6600 EDS (Extended Deployment System) Multi-parameter Probe | YSI Environmental | temperature/conductivity, turbidity, Rapid Pulse™ dissolved oxygen sensor, chlorophyll, and pH/ORP |
| YSI 6820 Multi-parameter Probe | YSI Environmental | dissolved oxygen, temperature, conductivity, TDS, vented level, nitrate-nitrogen, chlorophyll, rhodamine, ammonium-nitrogen, specific conductance, ammonia, turbidity, chloride, salinity, depth, ORP, pH |
| YSI 6920 Multi- | YSI Environmental | dissolved oxygen, open-channel flow, |

| Instrument/Testing Kit | Manufacturer | Parameters Observed/Sampled |
|---|---|---|
| parameter Probe | | temperature, conductivity, vented level, nitrate-nitrogen, rhodamine, TDS, specific conductance, chlorophyll, ammonium-nitrogen, ammonia, turbidity chloride, salinity, depth, ORP, pH |

Table 2b provides information on emerging technology that may prove useful for distribution system monitoring at a later time. Because this is emerging technology, the information presented in Table 2b varies significantly from that provided in Table 2a. Namely, the intent was to provide references to where more information could be acquired by the reader. Again, the appendix provides even more information as available.

Table 2b: **Summary of experimental-stage instruments presented in Appendix A**

| Title/Project | Authors/Organization | Parameters Observed/Sampled |
|---|---|---|
| Heterogeneous Integration of CdS filters with GaN LEDS for Fluorescence Detection Microsystems | Chediak, J.A., L.Zhongsheng, S Jeonggi, N. Cheung, L.P. Lee, T. D. Sands | fluorescence |
| MEMS Bio-Chemical Transducer – Calorimetric MEMS Sensor Array Platform | Britton, C. L. | (1) sensing and control of chemical and biological reactions such as those produced by glucose and cholesterol; and (2) real-time analyses of non-linear oscillating chemical reactions |
| Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting | Wagner, R. J., H. C. Mattraw, G. F. Ritz, and B. A. Smith | temperature, specific conductance, dissolved oxygen, and pH data, although systems can be configured to measure other properties such as turbidity or chlorophyll |
| Real-Time Remote Monitoring of a Distribution System – A Case Study in Washington D.C. | Panguluri, S., R. M. Clark, and R. C. Haught | This paper outlines: the steps involved in selecting an appropriate online real-time sampling system, the data acquisition system selection/setup criteria, security and dissemination of monitoring data and costs associated with the project. |
| Continuous Monitoring of Nitrate and Chlorophyll a in North Carolina Estuaries | Bales, J.D. | Sensors to measure near-surface and near-bottom nitrate concentration, fluorescence (chlorophyll *a* concentration), salinity, temperature, dissolved-oxygen, and pH. Nitrate and chlorophyll *a* were measured hourly and other parameters were |

| Title/Project | Authors/Organization | Parameters Observed/Sampled |
|---|---|---|
| | | measured at 15-minute intervals. |
| Sequential Injection Analysis-Based System for On-line Monitoring of Nitrite and Nitrate in Wastewater | Lapa, R. A. S., J. L. F. C. Lima, and I. V. O. S. Pinto | Nitrite and nitrate, simultaneously |
| Continuous Water Quality Monitoring in Southern Kaneohe Bay: Linking Fluvial Nutrient and Sediment Inputs with Bay Water Quality and Reef Degradation | HCRI-RP (Hawaii Coral Reef Initiative Research Program) | Nutrients and chlorophyll-a |
| Use of Biosensors for Bacterial Water Quality Monitoring | McLaughlin, J. | Enzymes, antibodies, DNA or RNA, microorganisms |
| Pattern Recognition – Laser Scattering for Low Cost Bacteria Identification and Counting in Water Treatment | Rodrigues, M.A., D. Cooper, L. Alboul, J. Penders, A. Chamski, and G. Chliveros | Laser scattering can be used to determine the nature and the amount of bacteria in water samples through motion analysis. We are investigating pattern recognition techniques for identification and counting of bacteria in water treatment using the Rustek equipment pursuing the ultimate aim of the water industry, which is to detect one bacteria per 100ml of solution! |
| The "Dreissena-Monitor" – First Results on the Application of this Biological Early Warning System in the Continuous Monitoring of Water Quality | Borcherding, J. and M. Volpers | Biological early warning system in the continuous monitoring of water quality |
| Drinking Water Early Warning Detection and Monitoring Technology Evaluation and Demonstration | VonderHaar, S. S., D. Macke, R. Sinha, E.R. Krishnan, and R. C. Haught | The instrument can be set to provide "alert" and "alarm" status at predetermined toxicity index values or limits. Test pollutants that are being evaluated include cadmium, atrazine, and dieldrin. |

**Sample collection for further analysis and evidence:** Whether the detection method includes the use of water quality surrogates, contaminant specific technology, toxicity indicators, or the use of biomonitors, once a contamination event becomes evident, several processes need to take place. This topic is covered extensively in another white paper titled Response to Contamination Events, but one important part of a response effort will be highlighted in a general form here. The first step needs to be human verification. Did the instruments respond to a planned change in water quality such as a change in source water, flushing, change in treatment plant operation, or a series of other potential water quality changing events, or was there really a significant deviation from

baseline for an event that needs to be investigated. Regardless, it is likely that the slug of water as it passed by the detector would be key to determining what exactly triggered the indication of a contamination event.

Consideration should be given to the use of auto-samplers in conjunction with the installation of continuous monitors. Ideally, if a monitor triggers an alarm for an anomalous event, it would initiate the start of an auto-sampler to capture a sample of the slug for further analysis and evidence of the event. Again, a disadvantage of using an auto-sampler includes cost, but "catching up" to the slug of contaminated water after an alarm was triggered to collect a grab sample manually would be challenging. Another key piece of information significant to sample collection or maintenance of evidence is the data log of the anomalous event, providing a location of the instrument that spiked and the time. This will likely be provided via SCADA software, and will be key to determining the potential source of contamination and the required time to respond. Finally, chain of custody must be established for all samples that are collected and taken from a particular location.

**Public health indicators, epidemiology:** The options provided above do not satisfactorily address the threat. Even in the best scenario, there will still be vulnerabilities in the distribution system that will not be addressed with continuous monitoring. Continuous monitoring in the distribution system adds another barrier to contamination, but like a residual chemical oxidant, does not provide a 100% guarantee that the drinking water is contaminant free. This emphasizes the significance of the public health system to note anomalous behavior. When private physicians or emergency rooms note an unusual frequency of gastrointestinal disruptions in the population, or pharmacies cannot maintain standard stock levels of anti-diarrhea over-the-counter medications, public health agencies need to be notified. Another consideration may be noting unusual behavior or illness in household pets. Due to their body weight, and the fact that some animals are more sensitive to certain contaminants, pets may provide an early indication that something is wrong. Adding veterinarians to the public health mix could only help. Additionally, if relationships exist between public health agencies, local physicians, veterinarians, and water supply personnel, informal notifications are usually

quicker in initiating investigations and can be very productive. This is one of the valuable lessons learned in Milwaukee that all organizations can always strive to be better at inter-organizational communication.

**Maintenance considerations:** This section will highlight general maintenance issues to aid in deciding which types of instruments to select. It is not meant to be an exhaustive guide to maintenance since another white paper titled Operational and Upgrading Considerations will provide more detailed and specific information. One of the first questions that needs to be answered includes the monitoring objective. If it is anticipated that numerous monitors will be purchased to place in a distribution system, emphasis should be placed on identifying the appropriate sensor(s) with plans to purchase the same sensor to place in numerous locations. This type of standardization will allow a reduced spare parts inventory, and minimized training requirements. Another consideration includes the use of life-cycle cost analysis to determine the impact of platform, communications, support equipment, waste stream handling/drainage, maintenance, reagents, and replacement costs.

This becomes particularly significant when comparing wet chemistry analyzers to multi-sensor probes that are becoming more abundant on the market. Wet chemistry analyzers require reagents, and significant supporting infrastructure, while multi-sensor probes may have expensive microchip replacements that occur annually or semi-annually. Other issues that should be considered when comparing monitors includes the frequency of required cleaning to prevent fouling, calibration frequency and requirements, self diagnostics to ensure valid results, requirements necessary to keep the system operational, and the potential to incorporate new technologies as they become available.

## Section III. Concentration –Instrument Response Relationships

When considering using water quality surrogates to detect when a contamination event has occurred, a relationship between the concentration of selected contaminants and the water quality instrument's response must be determined to ensure that the probability of detection at a concentration low enough to protect public health can be guaranteed.

Ideally, the relationships between all credible threat contaminants, and the respective water quality instrument response would be established. As it presently stands, this information is not readily available. Effort would have to be put into conducting many more additional tests to ensure that the water quality surrogates that were selected are robust enough to detect most, if not all, contaminants from all classes. The following is a case study describing how the contaminant-instrument response relationship was determined for four credible chemical, and one microbiological contaminant.

Five credible threat drinking water contaminants (sodium arsenate, sodium cyanide, sodium fluoroacetate, and Cryptosporidium oocysts) were added to tap water and analyzed at different concentrations to determine their detectability in a drinking water distribution system. Bench top analysis and on-line monitoring equipment was used to measure pH, chlorine residual, turbidity, conductivity, and total organic carbon values before and after introduction of these contaminants. Results indicate that the four chemical contaminants can be detected at relatively low concentrations. The Cryptosporidium oocysts were detected, but at a high concentration. Three of the four chemical contaminants were detected below a concentration that will cause significant health impact.

## METHODS & MATERIALS

**Baseline water quality data.** Running tap water, via a one-inch PVC pipe loop, was connected to two on-line water quality panels: a multi-instrument panel that measured pH, turbidity, conductivity, and chlorine residual[1]; and one that measured TOC[2]. Data was collected once per minute using datalogger software[3], collecting over 16,000 data points. This data was used to determine what represents "normal" water quality in the distribution system, and to estimate the population standard deviation. In addition, some general information about the distribution of the data was provided, as well as summary statistics.

Distribution system water quality fluctuates with temperature, seasonal source water quality, flow, demand, and water treatment plant operations. Taking this into consideration, additional 100-minute baselines were collected just prior to the introduction of contaminants into the bench scale distribution system. This allowed for

the comparison of the contaminated water with a baseline established immediately before the contaminants were added.

The on-line instruments required up to two hours to warm up before readings were considered valid. For this study, the water quality panel and the TOC panel were both started at least 12 hours before any data was obtained. In addition, on-line instruments that measure pH[4] and chlorine residual[5] were calibrated against bench top analytical equipment on a daily basis. The TOC panel, turbidimeters[6,7], and conductivity probe[8] were all calibrated before they were placed in to service.

Miller and Miller (2000) define the limit of detection as being equal to the blank signal, $y_B$, plus three standard deviations of the blank, or

$$\text{Limit of detection} = y_B + 3s_B \qquad (1)$$

In this case, the "blank" signal is zero, as the *difference* between baseline conditions and the addition of a contaminant is what's being measured, leaving three standard deviations as the limit of detection.

The baseline is key to determining the normal signal variation defined as three standard deviations from the mean and this should account for 99.96% of the random variability. Anything outside of three standard deviations represents an anomaly, and should be addressed accordingly (there is a 4 in 10,000 chance that the anomaly is a false positive). The standard deviation in the baseline data will be used to compare beaker test data to the 3-sigma values to determine a limit of detection. This will provide the first indication on the potential of using water quality parameters as surrogates to detect a contamination event. Similarly, the baseline data will also be collected for 100 minutes immediately before the introduction of contaminants into the distribution system. This will ensure that the baseline data is representative of system conditions when the experiments were conducted.

**Beaker tests.** The chemical contaminants are all commercially available, and in powder form. They were measured using an analytical scale[9], and mixed with tap water to obtain the desired stock concentration. The beaker tests were conducted using bench

top analytical equipment[10-13]. The distribution system experiments used on-line instruments.

After the 16,000 data point baseline was established using on-line equipment, tap water was added to a beaker, and the parameters were measured using bench top analytical equipment. The four contaminants were then added to the beakers in specified concentrations, and the water quality parameters were measured again, using the same analytical equipment. Finally, the difference was taken between the tap water only measurements and the tap water plus contaminant measurement, and a change in the water quality parameters were determined.

**Bench scale distribution system tests.** The bench scale distribution system provides the flexibility to conduct controlled experiments to determine on-line contaminant-instrument response in a drinking water distribution system. This is accomplished without compromising simulation of real-world distribution system parameters, including water quality, dilution, flow, and pipe materials.

The first data collection effort using the bench scale distribution system established the baseline. In this mode, the contaminant feed system was not used. The only influent to the system was tap water from the local distribution system. The only effluent was from the bench scale distribution system to the two panels, and then the non-hazardous waste effluent from the panels themselves.

The second data collection effort using the bench scale distribution system measured direct contaminant-instrument response. Before contaminants were added, a 100-minute baseline was established to ensure that contaminant-instrument response was compared to water quality just prior to introduction of the contaminants. After the short baseline was established, the system was ready for introduction of contaminants. The influents to the system included the tap water from the local distribution system, and the contaminants that were pumped in using a peristaltic pump[14]. The effluents were from the bench scale distribution system to the two panels, and then the hazardous waste effluent from the multi-instrument panel. The hazardous waste was redirected with the use of valves and collected under the ventilation hood for proper disposal.

The on-line equipment was started up the night before any distribution system experiments were conducted. In addition, once the peristaltic pump[15] that re-circulates

the system water was turned on, it took 1-2 hours for the on-line equipment to stabilize. This is due to the increased flow and turbulence in the system, stirring up particulate matter that may have settled onto the PVC piping. After the monitoring equipment had returned to steady state, and had shown consistent readings, the 100-minute baseline data collection began.

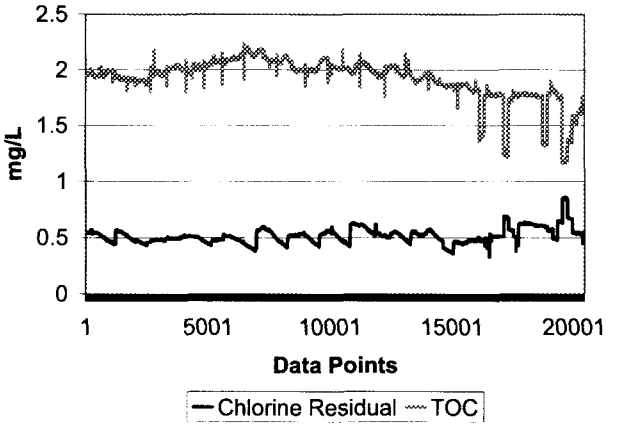
**Baseline.** The water quality in the distribution system is quantified in terms of the baseline conditions, utilizing on-line analytical equipment to capture multiple parameters every minute. Over 20,000 data points were collected between June-October 2003. Over 16,000 of the data points were collected during a two-week period in June 2003, with the remaining 4,000 being collected 100-minutes immediately before the introduction of contaminants into the distribution system during July-October 2003.

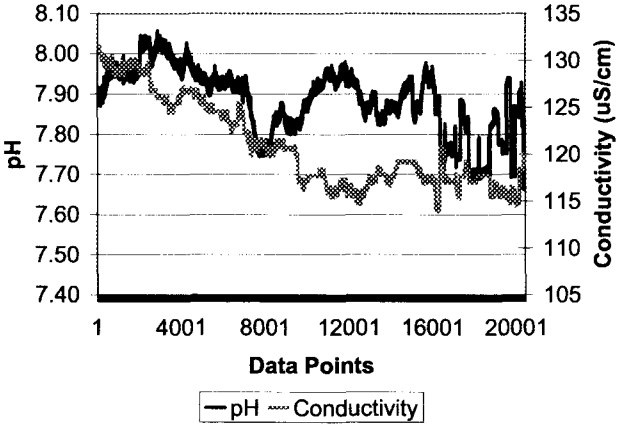
The baseline provided valuable information to determine what is "normal" in the distribution system relative to the time that the data was collected. The standard deviation in the on-line baseline data is used in conjunction with the beaker test data to determine a limit of detection. This will provide the first indication on the potential of using water quality parameters as surrogates to detect a contamination event. The data provided in Table 3 defines baseline drinking water quality conditions relative to the *timeframe* that the data was collected.

**Table 3** On-line monitoring baseline water quality results.

| | Chl Res (mg/L) | Conduct (uS/cm) | pH | TOC (mg/L) | Turbidity (NTU) | Laser Turbidity (NTU) |
|---|---|---|---|---|---|---|
| **Min** | 0.33 | 113.91 | 7.66 | 1.17 | 0.08 | 0.06 |
| **Avg** | 0.52 | 120.96 | 7.88 | 1.92 | 0.11 | 0.10 |
| **Max** | 0.86 | 131.50 | 8.06 | 2.24 | 0.75 | 1.00 |
| **3σ** | **0.20** | **14.08** | **0.25** | **0.56** | **0.07** | **0.12** |

Figure 2 displays time series plots of the large baseline data set. The time series plots indicate that every parameter behaves differently with respect to time, and that the values of the parameters are in a constant state of flux.



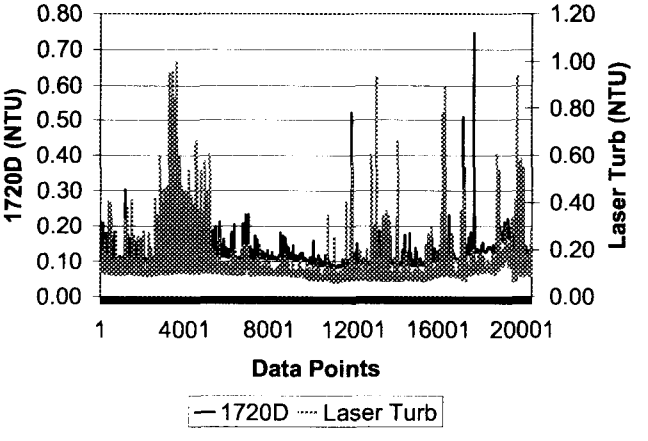




**Figure 2** Baseline water quality time series plots.

Another consideration is the distribution of the data. Histograms were plotted for the data, and all were quite different per parameter, and in most cases it was very easy to see that the data was not normally distributed.

In the case of a suspected normal distribution, for example pH, a look at kurtosis, skewness, and the Anderson-Darling normality test was used in a statistical software package[16] to quantitatively determine if the distribution was normal. Kurtosis measures the peakedness of a distribution, and like skewness, ranges from negative to positive infinity. A kurtosis of zero indicates a Gaussian curve. Positive kurtosis values indicate narrower and more sharply peaked distributions. Negative values indicate flatter distributions. The kurtosis for the pH data was -0.34. Skewness measures the asymmetry of the data. A skewness of zero indicates a Gaussian curve. A positive skewness indicates more values to the left of the mean, a negative skewness indicates more values to the right of the mean. The skewness for the pH data was -0.57.

The Anderson-Darling normality test uses a p-value to test the null hypothesis that the data fits a normal distribution. The criteria for normality is a p-value greater than 0.05. The p-value for the pH data was 0.00 indicating that the data does not fit a normal distribution. Environmental data can typically be fit to a log normal distribution (Gilbert, 1987). Similarly, the Anderson-Darling normality test was used to determine if the data distributions fit a lognormal distribution. All p-values for the different parameters were 0.00, indicating that the distributions are not lognormal.

Since the baseline data does not fit well to a normal distribution, a fair question would be "what exactly is the significance of three-sigma?" Is the assumption that 99.96% of the baseline data under normal conditions will fall within x-bar plus or minus three-sigma valid? To better understand that, the baseline data was analyzed to specifically answer those questions. Table 4 provides the percentage of baseline data points per parameter that fall inside of x-bar plus or minus three-sigma. As Table 4 demonstrates, even for data that is not normally distributed, it is fair to state that any data point outside of x-bar plus or minus three-sigma represents an anomaly.

**Table 4** Percentage of baseline data points falling within x-bar +/- 3σ.

| Conductivity (uS/cm) | pH | Turbidity (1720D) (NTU) | Turbidity (Laser) (NTU) | Chlorine Residual (mg/L) | TOC (mg/L) |
|---|---|---|---|---|---|
| 100.00% | 100.00% | 98.34% | 98.65% | 99.02% | 96.58% |

Figure 1 emphasizes the importance of knowing the baseline water quality real-time in the distribution system, as the water quality is always changing. This is significant, as on-line analysis to detect a contamination event must have an established baseline to compare the suspect data to, at the time that the comparison is taking place. In the absence of timely baseline data, the potential exists to inaccurately determine that an anomalous event has or hasn't taken place. In addition, the ideal of assuming that water quality data in the distribution system can be characterized as fitting a classical normal or log-normal distribution may prove to be erroneous, nullifying any data analysis carried out using such assumptions. However, descriptive statistics and the determination of anomalous events could prove very useful.

**Beaker tests.** Beaker tests were conducted before the contaminants were introduced into the bench scale distribution system. There were three primary objectives behind conducting the beaker tests: to determine which parameters would be directly influenced by specific contaminants, to determine the approximate minimal concentration that contaminants in a controlled environment would impact water quality, and to anticipate concentrations that would be pumped into the bench scale distribution system.

In addition, the beaker tests served as indicators of the actual concentration that the on-line instruments saw. The contaminants were pumped into the bench scale distribution system at known concentrations, and then diluted due to mixing within the system before flowing through the instrument panels. At this point, the contaminant concentration flowing through the panels was an unknown. The beaker tests provide an indication of the concentration flowing through the on-line panels, similar to a calibration curve.

Figures 3-5 provide changes from baseline water quality parameters after a contaminant was added to tap water at the specified concentration. In addition, toxic

contaminant concentrations are provided to allow comparison of the limit of detection and the concentration that would cause potential serious illness. All of the toxic concentrations cited in Figures 3-5 are much lower than their respective human oral $LD_{50}$ values.

The $3\sigma$ line represents an estimate for the limit of detection for a contamination event using the water quality surrogate specified. Theoretically, 99.96% of the data points under "normal" conditions will fall within three standard deviations and anything outside of the three sigma line will represent a non-random deviation in the signal. More importantly, as seen in Figures 3 and 4, the limit of detection is much lower than the corresponding dangerous contaminant concentrations.

As noted in Figure 3, the limit of detection of sodium fluoroacetate using a change in chlorine residual is approximately 16 mg/L. This is good news, in that the "highly dangerous concentration" of sodium fluoroacetate is 60 mg/L. Ideally, the goal is always to detect these contaminants at the lowest possible concentration. To be able to directly detect a contaminant at a concentration below that which would result in considerable health impacts is the goal of monitoring.

The TOC curve levels out at the instrument's maximum published TOC range of 10 mg/L. Again, the limit of detection is much lower than the specified concentration that would cause significant health impact. A comparison between the two charts in Figure 3 may provide justification for the cost of a TOC analyzer. As can be seen, the TOC analyzer's limit of detection for sodium fluoroacetate was 1.5 mg/L, significantly lower than using chlorine residual (16 mg/L). This result should be expected for organic contaminants, with molecules having more organic carbon being detected at lower concentrations than those having less.

Figure 4 provides a similar result. Sodium cyanide was detected well below the "life threatening toxicity" using pH as a surrogate. Of the four contaminants, cyanide was the easiest to detect, changing all of the water quality parameters significantly at relatively low concentrations.

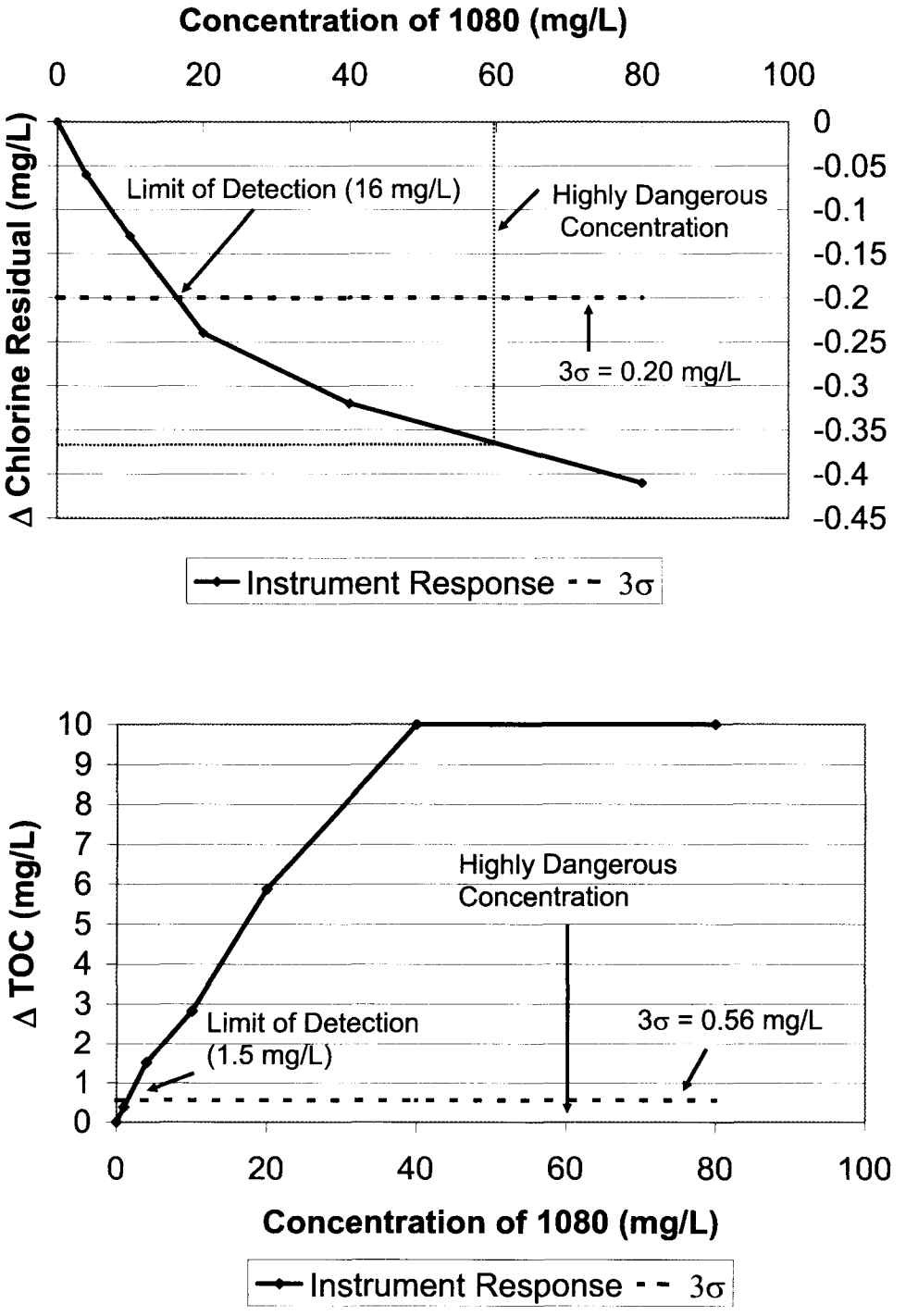
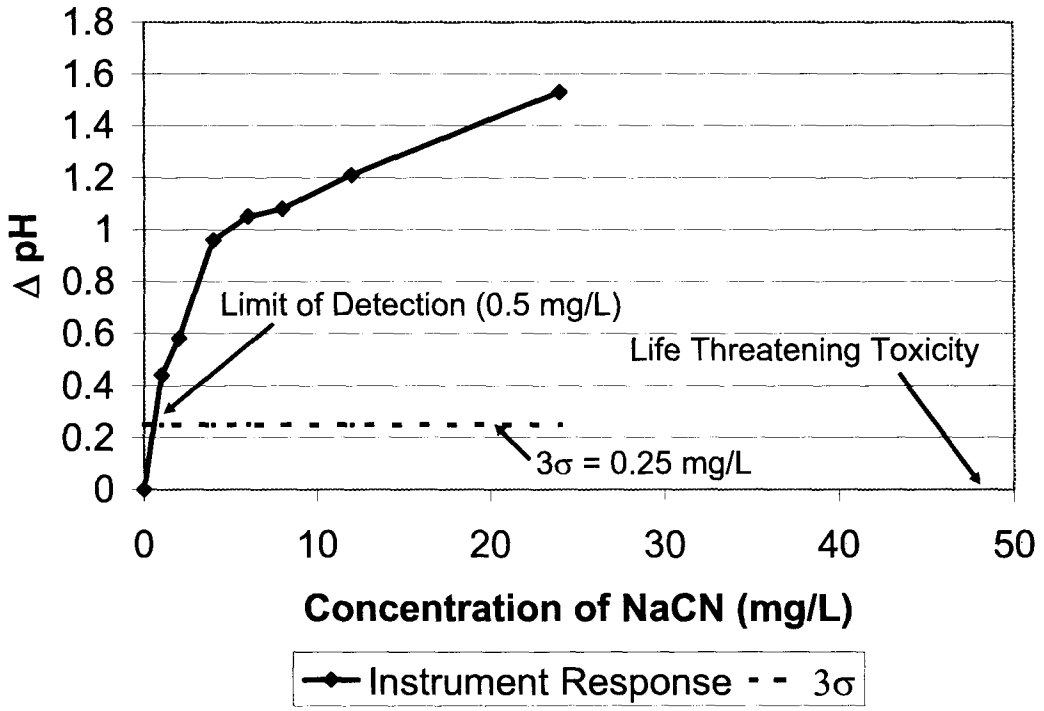



**Figure 3** Concentration-instrument response for sodium fluoroacetate (1080), chlorine residual, and TOC.



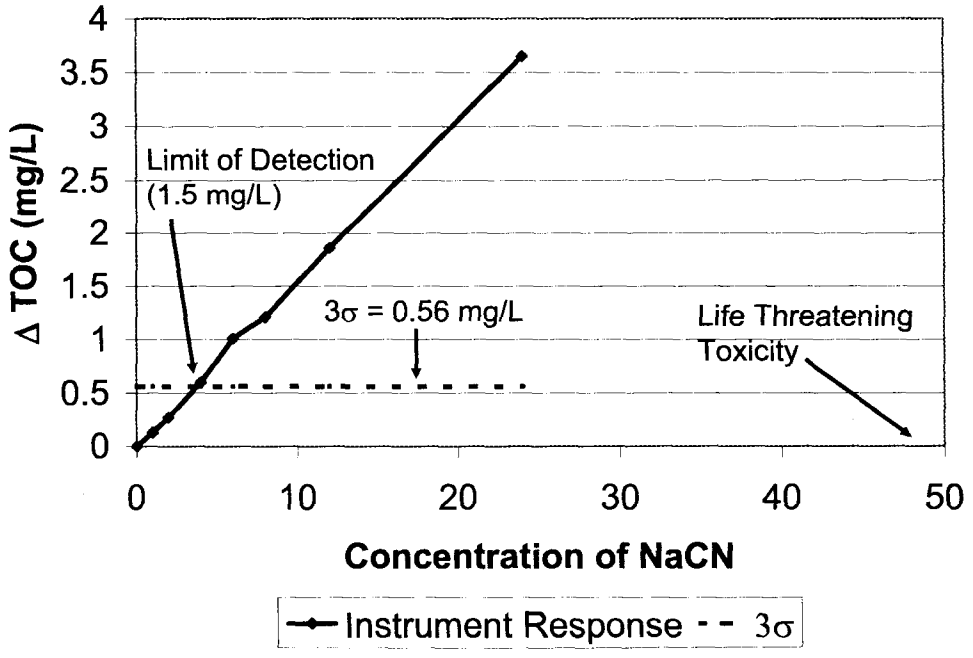




**Figure 4** Concentration-instrument response for sodium cyanide, pH, and TOC.

Even though cyanide is an inorganic compound, sodium cyanide elicited a significant instrument response from the TOC analyzer at a concentration well below the point of significant health impact. It is thought that the low-temperature UV-persulfate oxidation analysis method used in the TOC analyzer was not effective at purging the triple-bonded carbon-nitrogen molecule, so the carbon remained and was oxidized to carbon dioxide, and therefore detection as TOC was complete.

Figure 4 displays changes in conductivity after varying concentrations of sodium arsenate were added to tap water in a beaker. This figure demonstrates a requirement to reduce the limit of detection for certain contaminants, as direct detection using water quality surrogates will not suffice to protect public health. As can be seen, sodium arsenate is detected *above* the concentration of concern. The published value for sodium arsenate toxicity was the U.S. Army's "life threatening toxicity" for inorganic arsenic of 14 mg/L (USACHPPM TG 230, 2002).

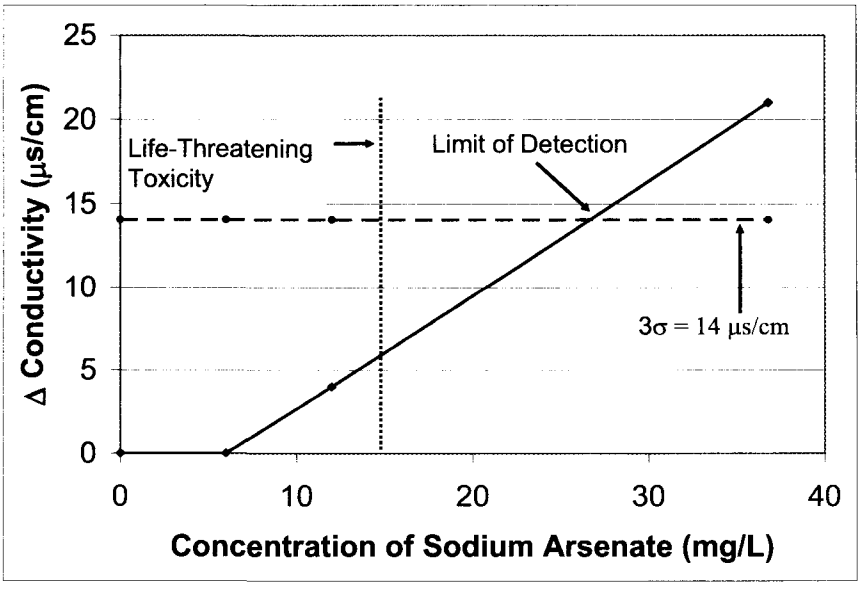



**Figure 5** Concentration-instrument response for sodium arsenate and conductivity.

Figures 3 and 4 demonstrate the potential of using on-line water quality monitoring to detect contamination events at concentrations below those that would cause significant health effects. Figure 5 demonstrates the need for more sophisticated data analysis techniques to reduce the limit of detection. Consideration may be given to data mining techniques that would take the large quantity of on-line generated data, and use pattern recognition techniques or artificial neural networks to further reduce the limit of detection obtained by direct on-line analysis. In addition, perhaps using biofilm that is ever-present in distribution systems to provide a secondary response due to cell death and the resultant sloughing-off of biomass due to acute chemical toxicity may provide a reduced limit of detection as well.

**Bench scale distribution system tests.** Before introducing the contaminants into the bench scale distribution system, data was collected for 100 minutes to determine baseline conditions. The values in Table 5 indicate the lowest concentration that the contaminant was detected at using the water quality parameter in the column heading. These values are the result of comparing the change in the water quality parameter to both the three-sigma value from the 100-minute baseline, and the published instrument error. Highlighted values indicate the lowest limit of detection, or a recommended water quality surrogate for detecting that contaminant.

**Table 5** Limits of detection for contaminants per water quality surrogate.

| Contaminant | Chlorine Residual | Conductivity | pH | TOC | Turbidity | Laser Turb |
|---|---|---|---|---|---|---|
| Sodium Arsenate (mg/L) | >100 | 25 | >100 | >100 | <15 | <15 |
| Sodium Cyanide (mg/L) | <0.5 | 5 | 1 | >10 | <0.5 | 1 |
| Sodium Fluoroacetate (mg/L) | 10 | 10 | 3 | 10 | 3 | 3 |
| Crypto Oocysts (Cysts/L) | | | | | 200k | |

Table 5 provides encouraging results. All four chemical contaminants were detected at relatively low concentrations using the routine on-line equipment whereas only three of the four chemical contaminants were detected at low enough concentrations using the beaker tests and bench top analytical equipment. The key difference is using

the on-lines turbidimeters to detect sodium arsenate. The "life threatening toxicity" for inorganic arsenic of 14 mg/L was discussed previously for evaluation of the beaker test data. The on-line data suggests that sodium arsenate may be detected at concentrations below 15 mg/L, or a lot closer to the concentration of concern than conductivity was able to detect (~27 mg/L). Unfortunately, the Cryptosporidium oocysts were detected at a very high concentration of 200,000 oocysts/L, indicating that routine water quality instruments will not be effective at detecting this contaminant before consumers would become ill.

The anticipated result of including biofilm results in the *chemical* contaminant analysis would be to reduce the limit of detection using turbidity specifically, as the sloughed-off biofilm may result in an increased turbidity instrument response. This combined with data mining techniques may very well reduce the limit of detection to a more acceptable concentration.

Figures 6 through 9 are time series plots showing the on-line instrument response after the contaminants are pumped into the bench scale distribution system at varying concentrations. The first 100-minutes are baseline conditions. With the contaminant pump turned on at t=100 minutes, it took four minutes to feed the one-liter of contaminant into the system. Conductivity showed the most significant instrument response for sodium arsenate. Sodium cyanide and sodium fluoroacetate also had measurable instrument responses for conductivity.

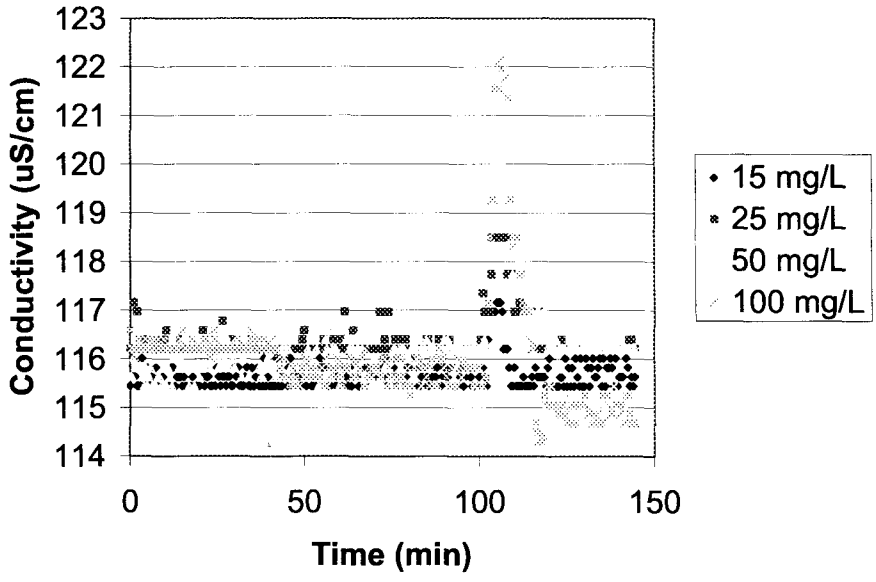



**Figure 6** Time series plot of on-line instrument response for sodium arsenate and conductivity.

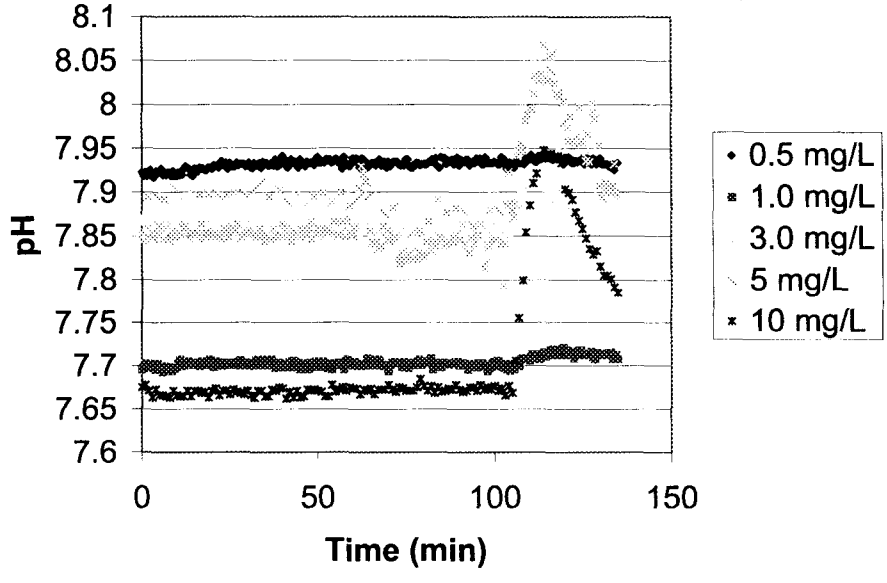



**Figure 7** Time series plot of on-line instrument response for sodium cyanide and pH.

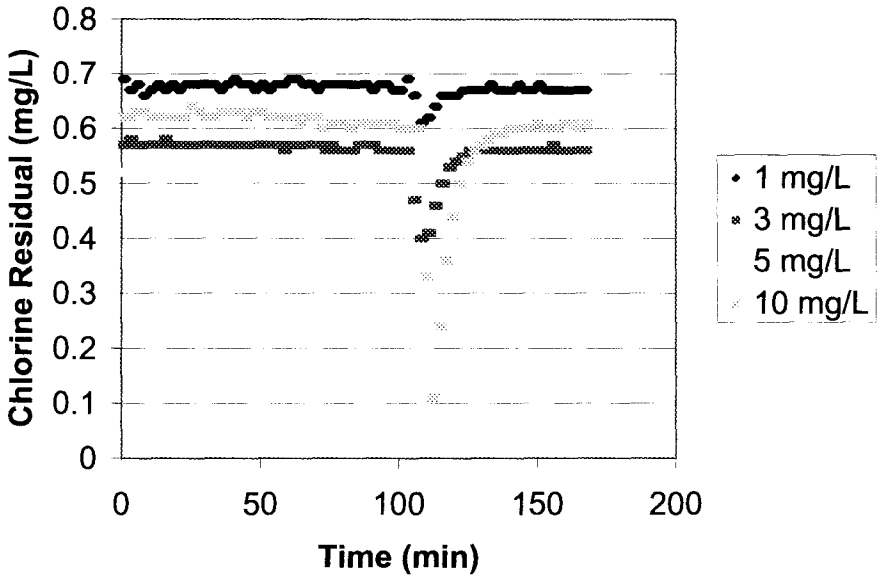



**Figure 8** Time series plot of on-line instrument response for chlorine residual.

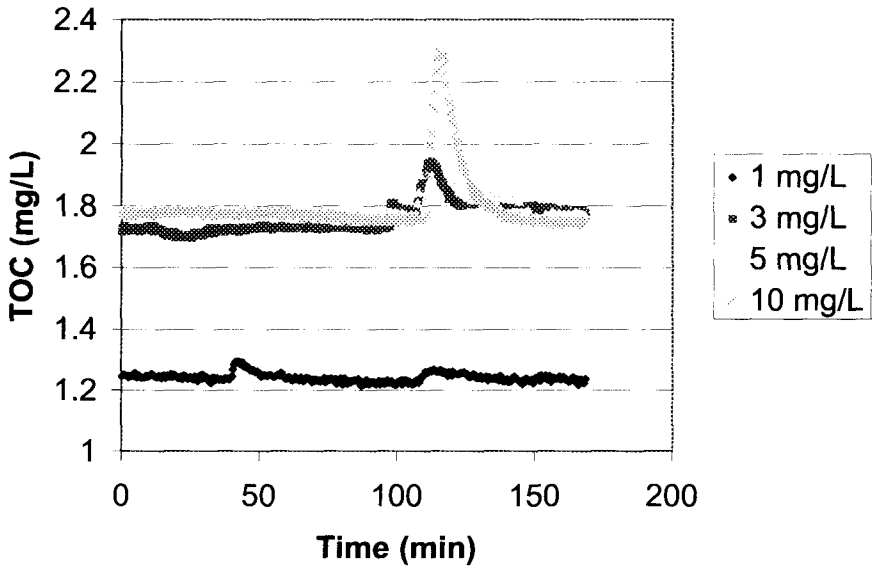



**Figure 9** Time series plot of on-line instrument response for TOC.

Sodium cyanide significantly changed all of the water quality parameters at relatively low concentrations. It was the only contaminant that significantly changed pH.

Sodium cyanide affected the chlorine residual quickly. Sodium fluoroacetate increased the TOC as would be expected.

## Section IV. Summary

The threat of chemical or microbiological contamination to drinking water is well established and requires an urgent effort to protect our drinking water systems from malevolent acts of sabotage. As it presently stands, the technology to detect these contaminants is lacking. Early detection of these contaminants via on-line or real-time monitoring has been identified as a feasible way to provide early warning to protect public health in some cases.

Chemical contaminants seem to lend themselves to detection by a variety of means, including on-line water quality surrogate analysis, biomonitors, and toxicity indicators. Detection of microbiological contaminants is more elusive, with minimal available technology on-line at the present time, and with many gaps across the contaminant class. Detecting toxins is also difficult, with some promise shown using toxicity indicators. Finally, radiologicals can be detected using on-line water quality surrogates specifically for radioactive contaminants, with some promise shown using toxicity indicators -- more an indication of exposure to heavy metals than the radionuclides themselves.

Results from the case study indicate that routine water quality instruments can detect chemical disturbances in drinking water distribution systems at relatively low concentrations. Three of the four contaminants were detected well below concentrations of concern. The fourth, sodium arsenate, was detected near the "life threatening toxicity" concentration using on-line monitoring of turbidity. On-line TOC analysis has proven very helpful in reducing the limit of detection for organic contaminants. If the cost of on-line TOC analyzers proves prohibitive for some utilities, an effort to quantify changes in other water quality parameters when organic contaminants are added to drinking water may offer a viable option.

In addition to detecting intentional threat contaminants in a distribution system, real-time monitoring offers the secondary benefit of providing valuable water quality data

that may be key to detecting routine water quality compromises associated with line breaks, backflow events, treatment plant failures, or seasonal biofilm sloughing.

The case study in this white paper considered univariate analysis. It looked at one parameter at a time to determine when an anomalous event (or contamination event) occurred. The goal of any detection program is to detect contaminants at the lowest possible level. The potential exists to further reduce the limit of detection using data mining that will incorporate multivariate analysis. Data mining will be discussed in another white paper titled Data Analysis.

Finally, understanding and knowing the distribution system water quality baseline conditions must be emphasized (every system will have different baseline conditions). Many of the kits and instruments require knowledge of the baseline water quality conditions before the equipment can be applied appropriately. What is typically being looked for is a significant variation in the baseline to provide an alarm condition.

## ACKNOWLEDGEMENTS

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|---|---|
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| John Cook | Charleston Public Works |
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| Karl King | Hach Company |
| Ed Roehl | Advanced Data Mining, Inc. |


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**FOOTNOTES**

[1]Distribution monitoring panel, Hach Co., Loveland, Colo.
[2]Astro autoTOC 1950plus process TOC analyzer, Hach Co., Loveland, Colo.
[3]OPC datalogger, Hach Co., Loveland, Colo.
[4]GLI P53 pH/ORP analyzer, Hach Co., Loveland, Colo.
[5]CL17 chlorine analyzer, Hach Co., Loveland, Colo.
[6]1720D/L low range process turbidimeter, Hach Co., Loveland, Colo.
[7]FT660 laser light nephelometer, Hach Co., Loveland, Colo.
[8]GLI C53 conductivity analyzer, Hach Co., Loveland, Colo.
[9]AE100 Analytical Balance, Mettler-Toledo, Inc., Toledo, OH
[10]AR25 pH meter, Fischer Scientific, Pittsburgh, PA
[11]Hach 2100 AN turbidimeter, Hach Co., Loveland, Colo.
[12]DR/3000 spectrophotometer (for chlorine residual), Hach Co., Loveland, Colo.
[13]ECTestr Low conductivity meter, Oakton Instruments, Vernon Hills, IL
[14]MasterFlex 7016-20/7521-40 peristaltic pump, Cole-Parmer Instrument Co., Vernon Hills, IL
[15]MasterFlex 77601-10/7591-50 peristaltic pump, Cole-Parmer Instrument Co., Vernon Hills, IL
[16]MINITAB Statistical Software v13, Minitab Inc., State College, PA

# APPENDIX A.1

## Database of Commercially Available and Emerging Technology Water Monitoring Equipment

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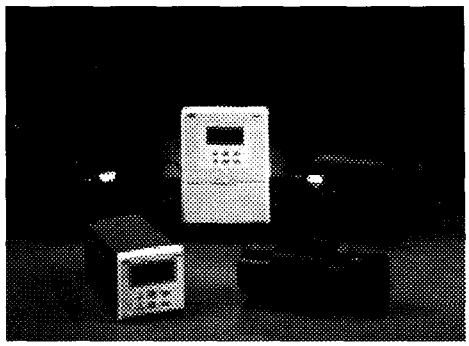
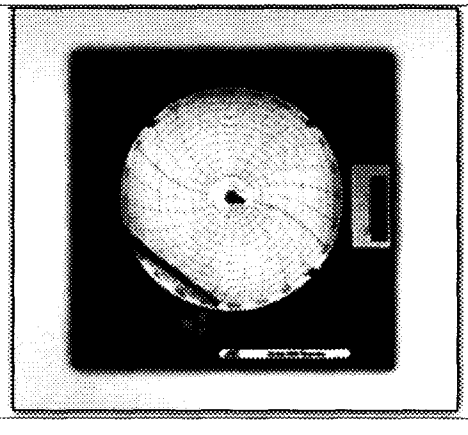
## Table A.1: **Database of commercially available instruments and testing kits**

| | |
|---|---|
| **Instrument/Testing Kit:** | Turbidity System |
| **Model/Product No.:** | 4670 Series |
| **Manufacturer:** | ABB Instrumentation |
| **Description:** | An ABB Instrumentation turbidity system comprises a 4670 wall-mounting or 4675 panel-mounting, analyzer, together with one of four sensors designed to meet specific<br>applications. The sensors are available in flow and dip versions and, where appropriate, are supplied with auto-cleaning to minimize maintenance where optical fouling occurs. |
| **Features:** | • **Dry Secondary Calibration Standard** – A key feature of the systems are the dry secondary calibration standards, which simplify routine calibration and virtually eliminate the need for chemical standards to be produced, a major safety factor. This is available for all models including the dip system and provides a very convenient, repeatable calibration technique.<br>• **Ease of Maintenance** -- As with all analyzers, the key to success is the reliability of the sensing device coupled with simple maintenance procedures. The sensing systems are very easy to maintain and can be site-serviced without the need of a skilled technician.<br>• **Automatic Cleaning** -- The automatic cleaning system is an essential feature which overcomes the problem of optical fouling and ensures that performance is maintained for long periods (up to 6 months) without the need for manual intervention. This feature has proven invaluable even on apparently 'clean' water samples where small amounts of iron/manganese can cause fouling problems.<br>• **Confidence in Service** -- To complement the system's well proven design, unrivalled accuracy and reliability in service, the entire sensing loop is regularly self-monitored to ensure the light source is operating within specification, thereby eliminating the risk of electrical drift. In addition, the function of the wiper module is continuously validated by the processor thereby assuring the correct performance of the cleaning function.<br>• **Ease of Calibration** -- Calibration can be carried out using Formazine standard or by using the optional secondary calibration device which can be ordered separately. This enables both zero and span checks to be carried out. |
| **Cost:** | |
| **Maintenance Requirements:** | As with all analyzers, the key to success is the reliability of the sensing device coupled with simple maintenance procedures. The sensing systems are very easy to maintain and can be site-serviced without the need of a skilled technician. |
| **Parameters Observed/ Sampled:** | Turbidity |
| **Source/URL:** | www.epa.gov/etv/pdfs/vrvs/01_vr_abb.pdf |
| **Other:** | |

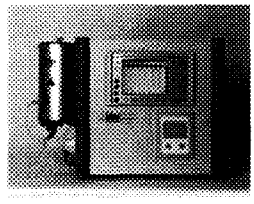


| | |
|---|---|
| **Instrument/Testing Kit:** | Residual Chlorine Recorder |
| **Model/Product No.:** | Series B20 |
| **Manufacturer:** | Analytical Technology, Inc. |
| **Description:** | Chlorine monitoring assures proper residual at all points in the system, helps pace re-chlorination when needed, and quickly and reliably signals any unexpected increase in disinfectant demand. Monitoring chlorine levels in the system also can serve as a "surrogate" for detecting potentially threatening contamination, because many chemical and biological contaminants are known to combine with chlorine. Therefore, a significant decline or loss of residual chlorine could be an indication of potential threats to the system.<br>For residual chlorine monitoring where both measurement and circular chart recording are required, the B20 recording analyzer is an excellent choice. The system combines both a free or chloramine analyzer inside a circular chart recorder to provide either 24 hour or 7 day recording of chlorine residuals<br>Providing permanent chlorine residual records normally means purchasing a residual chlorine monitor and connecting the output of the monitor to a separate recorder. ATI's B20 provides an integrated solution to this problem, combining both the analyzer and recorder functions in a single package. This means simpler installation, easier operation, and lower cost. And best of all, the system uses our direct measuring membraned sensor for reliable measurement with minimal maintenance. |
| **Features:** | • Free or combined chlorine recording<br>• Selectable 24-hour or 7-day chart<br>• Modular sensor for easy service<br>• Digital concentration display<br>• NEMA 3 wall or panel mount enclosure<br>• Replaceable felt tip chart pens<br>• Direct measuring chlorine sensor<br>• No chemical reagents required<br>• Simple constant-head flowcell<br>• Two alarm standard |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | free chlorine, chloramines |
| **Source/URL:** | http://www.analyticaltechnology.com/frames.htm |
| **Other:** | |

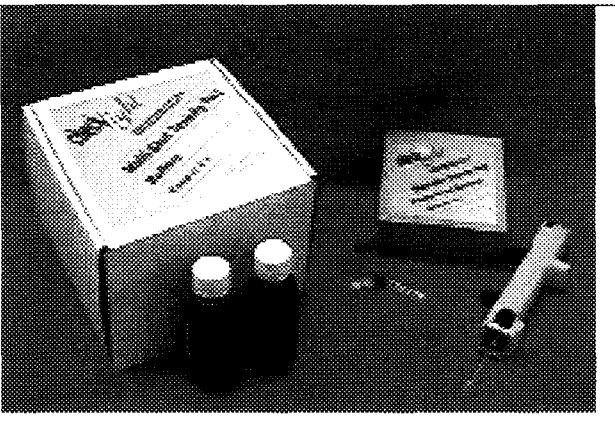


| | |
|---|---|
| **Instrument/Testing Kit:** | bbe Algae Online Analyser |
| **Model/Product No.:** | |
| **Manufacturer:** | Bbe |
| **Description:** | An instrument for continuous chlorophyll and photosynthetic activity determination.<br>The measurement: A sample is pumped into the measuring chamber by external pump. Concentration and activity of the algae are determined exactly. The concentration of each algae group is calculated. After draining of the sample chamber the automatic cleaning device cleans the chamber thoroughly and removes any particles or biofilms with a mechanical piston.<br>The apparatus can be used in the following fields: water control, limnological work, environmental control, research and education, and river dam control |
| **Features:** | • an online chlorophyll analysis for measuring stations as well as for laboratory use<br>• simultaneous determination of chlorophyll concentration, activity of chlorophyll and transmission.<br>• the sample determination of different algae classes by excitation with coloured LEDs (fluorescence spectroscopy).<br>Calculation of the content of green algae, green-blue algae diatoms and dinoflagellates, cryptophyceae.<br>• direct measurement without sample preparation<br>• due to different patterns of excitation information from fluorescence allow determination of photosynthetic chlorophyll activity. This activity is related to oxygen evolution. The common used fluorescence signals $f_0$, f, $f_m$ referring to the Genty-Parameter-method are used for calculation.<br>Online in a water control station or single measurement in a laboratory.<br>• RS232 for the connection to an external PC<br>• 2 analogue outputs<br>• automatic cleaning of the chamber and tubes<br>• reutilization of the cleaning solution<br>• auto-start after current failure<br>• battery-buffered for data saving<br>• CE-sign<br>• splash-proof housing and industrial PC with coloured LCD-display (optional) |
| **Cost:** | |
| **Maintenance Requirements:** | |

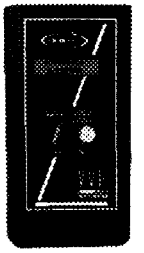
| | |
|---|---|
| **Parameters Observed/ Sampled:** | direct chlorophyll fluorescence (this measurement corresponds to the wet-chemical chlorophyll analysis); active chlorophyll fluorescence (Genty Parameter -- this measurement shows the percentage of active chlorophyll under defined conditions); transmission (in order to compensate the influence of substances which cause turbidity, transmission measurement takes place automatically during each analysis); differentiation of fluorometrical algae classes (it is possible to determine at least the content of chlorophyll according to green algae, bacillariophycae (diatoms, dinoflagellates, ...), blue-green algae, cryptophyceae) |
| **Source/URL:** | http://www.bbe-moldaenke.com/english/fluoro_online.html |
| **Other:** | |



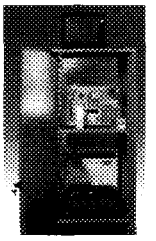
| | |
|---|---|
| **Instrument/Testing Kit:** | Tox Screen |
| **Model/Product No.:** | |
| **Manufacturer:** | CheckLight, Ltd. |
| **Description:** | The modified ToxScreen-II test (ETV verified) is now available, offering higher sensitivity and longer (up to one week) stability of suspended reagent. The toxicity test kit can be used on-site or in the laboratory. |
| **Features:** | • Principle - changes in the level of luminescence indicate potential toxicity.<br>• Bioassay - freeze-dried luminous bacteria<br>• Detection spectrum - a wide range of acute and chronic toxic agents (respiratory inhibitors, phosphorganic agents, chlorinated hydrocarbons, heavy metals, and protein synthesis inhibitors).<br>• Discriminatory - a unique buffer set (Pro-Metal & Pro-Organic) enables the discrimination between organic toxicants and cationic heavy metals.<br>• Fast - results obtained in 30 minutes.<br>• Sensitive - sub-ppm detection levels; for most of the tested chemical agents the ToxScreen-Test was many folds more sensitive than other available bioluminescence-based tests.<br>• Reliable - highly accurate with only around 10% deviation in precision.<br>• Equipment - CheckLight luminometer, pipettor, tips.<br>• User-friendly - minimal lab experience necessary. A simple three-step procedure that can be performed under field conditions in ambient temperature (18°-35°C). Only 1mL of sample is necessary to run the assay, making collection, storage, and disposal of sample material easy and cheap.<br>• Cost effective - up to one week usage of suspended reagent together with low price encourages more frequent testing for rapid response to changing conditions in water quality. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | colchicines, cyanide, dicrotophos, thallium sulfate |
| **Source/URL:** | http://www.checklight.co.il/ |
| **Other:** | |
| | |



| | |
|---|---|
| **Instrument/Testing Kit:** | Water Analysis System |
| **Model/Product No.:** | VVR |
| **Manufacturer:** | Chemetrics |
| **Description:** | Chlorine monitoring assures proper residual at all points in the system, helps pace re-chlorination when needed, and quickly and reliably signals any unexpected increase in disinfectant demand. Monitoring chlorine levels in the system also can serve as a "surrogate" for detecting potentially threatening contamination, because many chemical and biological contaminants are known to combine with chlorine. Therefore, a significant decline or loss of residual chlorine could be an indication of potential threats to the system.<br>CHEMetrics' VVR direct-reading multi-analyte photometer and Vacu-vials® self-filling reagent ampoules bring a high level of simplicity and affordability to precision water analysis. Ideal for the lab and field. The VVR System delivers accurate, reliable results in just 4 seconds–with no buttons to push, no calibrations to perform, and no complicated scrolling! Priced at only $632.50, the VVR photometer is considerably more affordable than other multifilter photometers. A storage module, zeroing blank, and coded blank are included with the instrument. (A dedicated filter is included with each individual analyte module which the user purchases.) The VVR system also features the convenience of CHEMetrics' "snap-and-read" Vacu-vials® self-filling reagent ampoules.<br>Vacu-vials® ampoules are packaged in individual analyte modules, which contain everything needed for fast, easy analysis–including 30 ampoules, a dedicated filter, accessories, instructions, and MSDS. Refill packs of 30 Vacu-vials® ampoules may be ordered separately. VVR modules are available for all the most popular analytes (see list below), with more under development. Absorbance filters are available for 425, 445, 485, 510, 555, 609, and 670 nm. The VVR system accepts samples in 1/2-inch test tubes as well as in self-filling Vacu-vials® ampoules. This allows the analyst to use custom chemistries with readout in absorbance units. |
| **Features:** | • Photometric Accuracy: Better than 1%.<br>• Response Time: 4 seconds.<br>• Light Source: Stabilized tungsten lamp.<br>• Cell Size: 13 mm (1/2 inch).<br>• Power Source: 4 AA alkaline batteries - 4000 readings. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | ammonia, bromine, chlorine, chlorine dioxide, chromate, copper, cyanide, DEHA, formaldehyde, glycol, hydrazine, hydrogen peroxide, iron, molybdate, nitrate, nitrite, oxygen (dissolved), ozone, peracetic acid, phenols, phosphate, silica, sulfide, zinc |
| **Source/URL:** | http://www.chemetrics.com/vvr.html |
| **Other:** | |

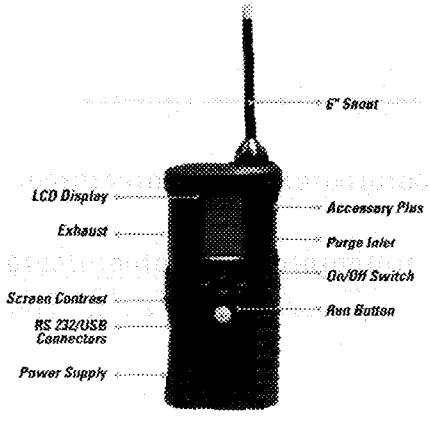


| | |
|---|---|
| **Instrument/Testing Kit:** | At-line Microbial Monitor |
| **Model/Product No.:** | Colifast At-line Monitor (CALM) |
| **Manufacturer:** | Colifast |
| **Description:** | Assessing microbial water quality is a central function in total water management. The traditional methods for detecting coliforms in water need 18-24 hours, which mostly gives historical information. The Colifast At-Line Microbial monitor, CALM, is an automated early warning system for rapid and systematic quality monitoring.<br>Combining an analyzer and advanced custom software, the CALM provides water quality data for thermotolerant coliforms/*E.coli* and total coliforms. This early warning system offers rapid results for earlier hazard assessment as part of an integrated emergency response program, or for routine microbial monitoring. With increasing regulatory requirements, and customer demand for quality service while minimizing cost, the CALM creates value through earlier results for faster operational decisions. Whether evaluating source water quality in supply networks or monitoring waters for environmental management, this system provides results earlier to enhance performance, reduce response times and improve services. Applications are:<br>• Source water / raw water quality<br>• Environmental / recreational water<br>• Industrial process water<br>• Effluents<br>• Water plant (Operations, QC)<br>• Distribution system (finished water) |
| **Features:** | • Rapid results. Results obtained within 2-12 hours.<br>• Automated analyses -- easy-to-use.<br>• Early Warning and Quantitation. Depending on level of bacteria in the water there are two main methods to use:<br>o Rate of MU-production as an indicator of fecal contamination<br>o MPN (most probable number) for coliform/microbial growth:<br>• Remote Warning System for earlier operational decision.<br>• User defined alarm level. The user can set an alarm level according to the limit for taking action.<br>• More frequent sampling and better safety. Automatic sampling allows more frequent analyses without increasing labor. More frequent analysis ensure a better control with the water, and safety for the public.<br>• Time saving = cost saving. Rapid results for rapid decisions reduces release time of product. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Provides water quality data for thermotolerant coliforms/*E.coli* and total coliforms. |
| **Source/URL:** | |
| **Other:** | |

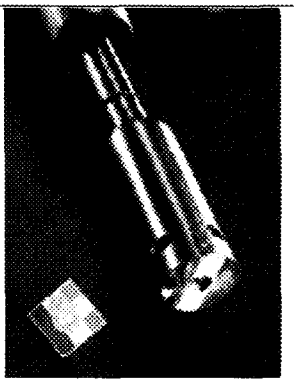


| | |
|---|---|
| **Instrument/Testing Kit:** | Colifast Analyzer |
| **Model/Product No.:** | Colifast Analyzer (CA) |
| **Manufacturer:** | Colifast |
| **Description:** | Assessing microbial water quality is a central function in total water quality management. The Colifast Analyser is a semi-automated early warning system for rapid and systematic water quality monitoring. Tests for thermotolerant coliforms /*E.coli,* total coliforms, Total Viable Organisms and *P. aeruginosa,* are available. Applications for water monitoring are:<br>• Source water quality<br>• Surface and groundwater<br>• Non-disinfected waters<br>• Marine and recreational waters |
| **Features:** | • Rapid results, e.g., Coliform results are obtained within 2-12 hours (18-24 h for traditional methods).<br>• Automated analysis – easy-to-use. After addition of the test sample to the Colifast medium and registration, only hit "Start," and the Colfast Analyser performs the analysis automatically.<br>• Remote warning system. The Colifast Analyser's remote warning system gives automatic and early warning of positive sample status allowing earlier operational decisions by e-mail.<br>• More frequent sub-sampling = faster results. Automatic sub-sampling allows more frequent analyses without increasing labour. Faster results ensure better control of water and safety for the public.<br>• Time saving = cost saving. Rapid results for rapid decisions reduces release time of product.<br>• Multiple sample loading for all day testing. Multiple sample batches can be loaded and tested simultaneously throughout a work-shift according to the day's testing requirements.<br>• Customized test runs for specific testing regimes. Test run parameters can be customized for specific testing matrices/requirements. Test confidence levels can be adjusted for earlier reporting of positive results, according to experience with local water sources and test regimes. |
| **Cost:** | |
| **Maintenance Requirements:** | Operational testing – systems maintenance testing |
| **Parameters Observed/ Sampled:** | Tests for thermotolerant coliforms /*E.coli,* total coliforms, Total Viable Organisms and *P. aeruginosa,* are available. |
| **Source/URL:** | http://www.colifast.no |
| **Other:** | |

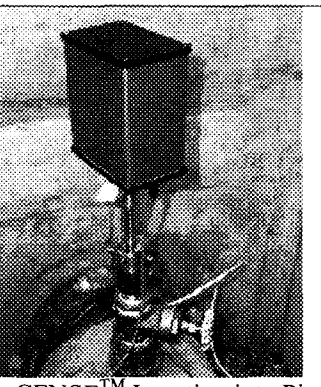
| | |
|---|---|
| **Instrument/Testing Kit:** | Hand-held Chemical and Biological Detection Device |
| **Model/Product No.:** | Cyranose® 320 |
| **Manufacturer:** | Cyrano Sciences |
| **Description:** | Whether you're inspecting raw materials or testing for freshness, contamination, batch-to-batch consistency or off-odors, missing a problem can be costly. While the sense of smell can detect many of these problems, widespread implementation is often impractical. That's why we've created the Cyranose® 320 electronic nose, the efficient and affordable way to accurately perform on-site analysis. With a touch of a button, smells are digitized to provide immediate answers you can depend on. It's a valuable tool for any quality control professional. In fact, the Cyranose® 320 has applications in such markets as chemical, petrochemical, food, packaging, plastics and the flavor industry to name a few.<br>The Cyranose® 320 can be customized for your specific application. The unit is trained by measuring vapors representative of your process. These measurements create a database of digitized patterns. All future measurements are compared to these patterns to identify the vapor |
| **Features:** | |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | The unique polymer composite sensors have been shown to respond to a wide range of organic compounds, bacteria and natural products. |
| **Source/URL:** | http://cyranosciences.com/products/cyranose.html |
| **Other:** | |



| | |
|---|---|
| **Instrument/Testing Kit:** | Six-CENSE™ |
| **Model/Product No.:** | |
| **Manufacturer:** | Dascore |
| **Description:** | The Six-CENSE™ is a 6-in-1 multiparameter in-line sensor that can measure Chlorine (free chlorine), Monochloramine, or Dissolved Oxygen, pH, Conductivity, Oxidation-Reduction Potential, and Temperature. This electrochemical technology sits on a robust ceramic chip. Six-CENSE™ is the only multi-parameter sensor designed for direct insertion into pressurized water mains from 2 inches to 72 inches in diameter. This capability makes the Six-CENSE™ ideally suited to fulfill the requirements of water utilities to monitor the water quality throughout their distribution systems. The unit is easy to install, simple to calibrate, and is designed for durability and minimum operator maintenance.<br>6-in-1 Water Quality Sensor -- According to the AWWA, during the past five years, distribution systems have been responsible for 45% of outbreaks of waterborne disease. (AWWA Journal, Sept 2001) Now, you have an option! You can continuously monitor the water quality throughout your entire distribution system while assisting your water security program.<br>The Dascore Six-CENSE™ is CENSAR® technology and uses thin and thick film plating/printing techniques to produce a sensing array on a single ceramic chip. |
| **Features:** | • Data available in 4-20 mA, Modbus, Ethernet and others.<br>• Single point calibration makes installation and set-up easy, with low maintenance.<br>• Direct and reagent-free measurement of Chlorine<br>• Capability for measuring Monochloramine for plants using chloramination.<br>• Membrane-Free measurement of Dissolved Oxygen<br>• Sensor chip field replaceable with typical six-month service life under normal potable water parameters.<br>• Units available in NEMA 4X/IP66 and IP68/submersible enclosures.<br>• Installs in 1.5" or 2" corporation stop. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | chlorine (no reagents required), monochloramine or dissolved oxygen, pH, temperature, conductivity, ORP/REDOX |
| **Source/URL:** | http://www.dascore.com/sixcense.htm |
| **Other:** | |

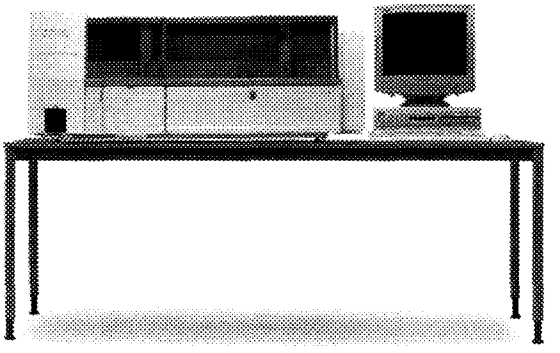


Probe Head and Chip

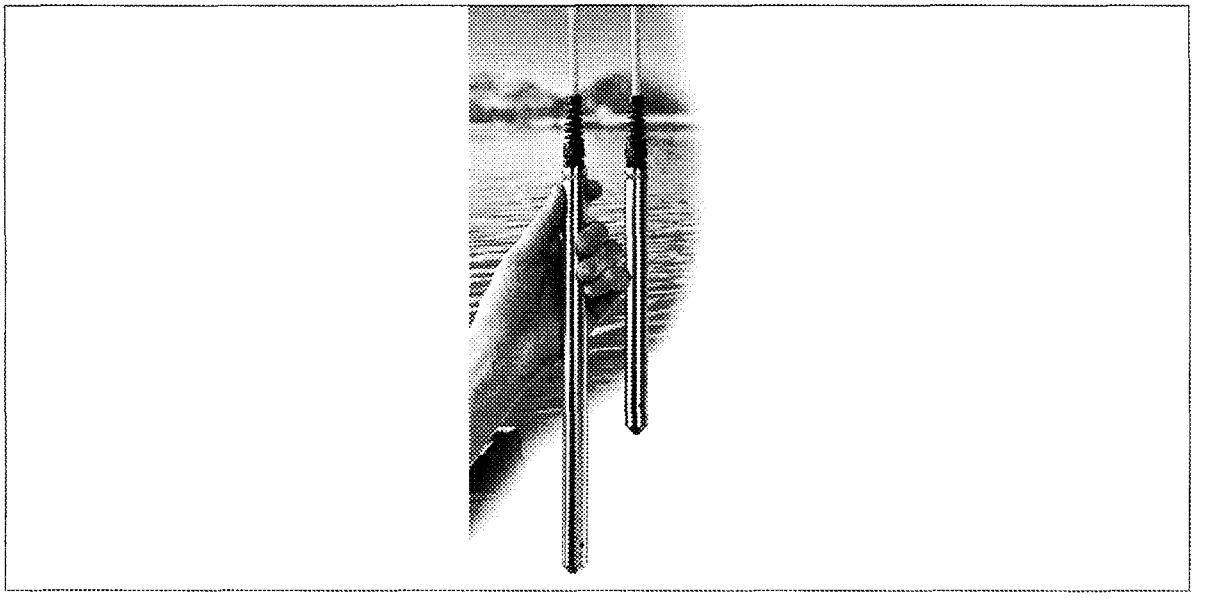


Six-CENSE™ Insertion into Pipe

| | |
|---|---|
| **Instrument/Testing Kit:** | RiboPrinter® Microbial Characterization System |
| **Model/Product No.:** | RiboPrinter® |
| **Manufacturer:** | DuPont Qualicon |
| **Description:** | The RiboPrinter® microbial characterization system provides the speed, accuracy and resolution needed to identify microorganisms and characterize them efficiently and consistently. These determinations can be applied to virtually all bacteria.<br>Using powerful genetic information, the RiboPrinter® system provides an automated genetic snapshot, or RiboPrint® pattern, of any bacterium in less than eight hours.<br>RiboPrint® patterns characterize environmental isolates, pathogens, spoilage organisms, control strains, beneficial organisms or any bacterium that is important to the pharmaceutical, personal care and food safety industries.<br>Until now, the methods for genetic characterization of bacteria required highly skilled technicians and lacked standardization and consistency. The RiboPrinter® system provides the speed, accuracy, reproducibility and confidence never before possible.<br>From start to finish, the RiboPrinter® system process is automated, simplifying operator training and minimizing errors due to technique. Loading and operating the characterization unit are easy and intuitive. The workstation software is user-friendly, providing sophisticated data analysis that eliminates the need for subjective interpretation of results.<br>Only the RiboPrinter® system combines automation and the power of DNA to go beyond identifying and documenting a problem. The RiboPrinter® system produces an exact genetic snapshot of organisms, delivering the unparalleled power to track sources of contamination and gain control of any microbial environment. |
| **Features:** | • The flexibility to match any situation<br>• Greater speed and confidence throughout the day<br>• Control any microbial environment<br>• Data security and audit trails<br>• Validation packages<br>• Remote client software |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Up to eight bacterial isolates can be tested at one time, with results available eight hours from sample input. |
| **Source/URL:** | |
| **Other:** | |



| | |
|---|---|
| **Instrument/Testing Kit:** | MiniTROLL |
| **Model/Product No.:** | |
| **Manufacturer:** | Electronic Data Solutions |
| **Description:** | The miniTROLL is self-contained and completely submersible and it features the smallest diameter at only 0.72 inches (18.3mm)! The miniTROLL is used by water professionals around the world to collect real-time information for analysis of both short- and long-term water level trends. |
| **Features:** | • Smallest diameter at only 0.72 inches (18.3mm)<br>• Powerful onboard data logger<br>• Internal memory - up to 1MB (440,000 data points)<br>• Linear, linear average, logarithmic, and event logging modes<br>• User-replaceable AA batteries - no need to return to the factory!<br>• High quality vented Quick-Connect cable (FEP or Polyurethane) - Fully detachable!<br>• Ultimate 4-way pressure compensation including automatic barometric compensation<br>• Optional stainless steel backshell for cableless applications or suspension by low-cost wire<br>• Real-time crystal clock<br>• Networking and telemetry capable<br>• Accuracy certified to NIST-traceable standards<br>• Multiple product versions - select only the features you need to match your budget<br>• Always upgradeable! |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | collect real-time information for analysis of both short- and long-term water level trends |
| **Source/URL:** | http://www.elecdata.com/groundwater/insitu/insitu.html |
| **Other:** | |
| | |



| | |
|---|---|
| **Instrument/Testing Kit:** | MP-TROLL 9000 |
| **Model/Product No.:** | |
| **Manufacturer:** | Electronic Data Solutions |
| **Description:** | In-Situ multiparameter water quality probe. Elecdata will now be the exclusive representative for In-Situ's multi-parameter water quality instrument, the MP-TROLL 9000 for concentrating on surface water monitoring. Smaller, more powerful and easier to use than other multi-probes on the market, the MP-TROLL 9000 uses the most current sensor and electronics technology available.<br>Designed with the highest quality 316L stainless steel, the TROLL 9000 is very rugged yet lightweight. Capable of monitoring up to 9 sensors simultaneously, the TROLL 9000 is the ultimate tool for water quality profiling applications and unattended, long-term deployments. The TROLL 9000 features many new technological innovations such as "Smart Sensors", "Sure-Tension D.O. Membranes", "Optional Pre-Calibrated Sensors", "Single Quick-Calibration Solutions", and more. Get a fresh perspective on water quality with the TROLL 9000. |
| **Features:** | • Smart Sensors that are 'Plug and Play' remember calibration<br>• Dissolved Oxygen -- Constant Power for Maximum Accuracy<br>• Single "Quick-Cal" solution -- calibrate most sensors at the same time!<br>• The most sensors in a 45mm (1.75") diameter-- up to 9 sensors<br>• Pre-Calibrated and ready to use -- Ready to use right out of the box!<br>• Flexible sensor ports -- add sensors of your choice to any port<br>• Small, lightweight design using high quality 316L stainless steel<br>• Internal datalogger with up to 4MB (1,760,000 data points!)<br>• User-replaceable, powerful D batteries provide maximum power -- up to 6 months.<br>• Vented Quick-Connect cable (FEP or Polyurethane) -- Fully detachable!<br>• Internal barometric sensor -- record real-time barometric changes<br>• Networking and telemetry capable<br>• Multiple product versions -- select features to match your budget. Always upgradeable! |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | surface water quality monitoring, dissolved oxygen |
| **Source/URL:** | http://www.elecdata.com/waterqual/insitu/insitu9000.html |
| **Other:** | |
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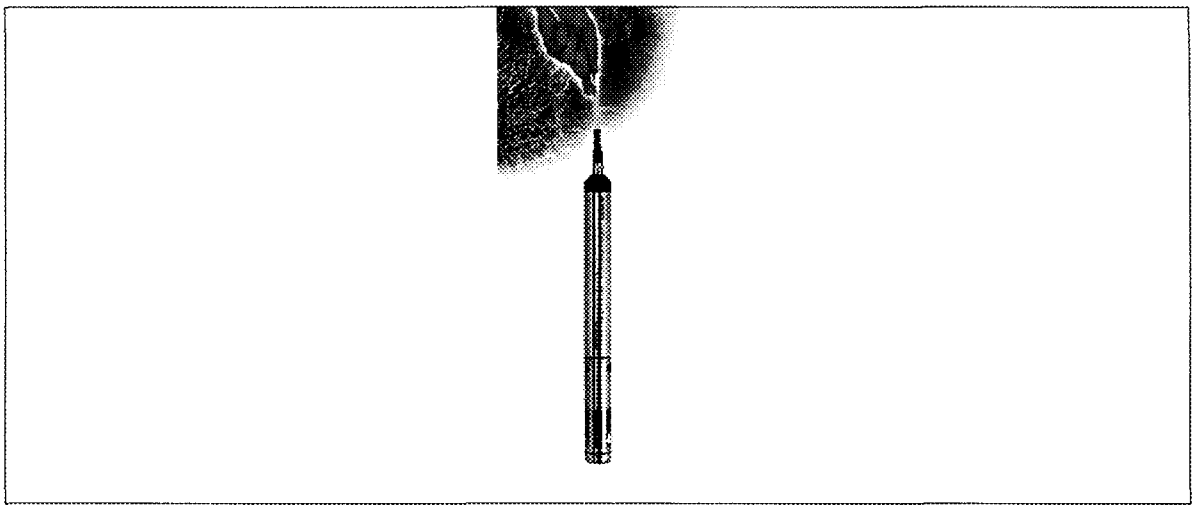

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| **Instrument/Testing Kit:** | Water Probe |
| **Model/Product No.:** | Ocean Seven 316 |
| **Manufacturer:** | General Oceanics, Inc. |
| **Description:** | The 16-bit multiparameter OCEAN SEVEN 316 PROBE is the result of fifteen years of experience in designing high-technology probes for scientific, research and monitoring applications. The long-term stability, combined with the high resolution and accuracy, makes this probe the ideal instrument for oceanographers and limnologists. The 316 Probe is available in two versions: 100 mm diameter and 75 mm diameter; the latter is particularly indicated for bore hole application.<br>The measurement sensors installed in the OCEAN SEVEN 316 Probe are exported all over the world. They are used by several other multiparameter probe manufacturers. All sensors have extremely low time constants: 50 milliseconds for physical parameters (CTD) and 3 seconds for chemical parameters (DO, pH). A high-precision resistor acts as a reference for the accuracy of the sensor electronic amplifiers. This resistor presents a thermal drift of only 1 pmm/deg. C and is temperature-compensated. There is no trim pot adjustment inside the probe.<br>The OCEAN SEVEN 316 is microprocessor-controlled and can measure, store and transmit sensor data according to various methods. The most significant ones are: real time data acquisition which implies acquisition and transmission of data to a personal computer; timed data acquisition which enables the user to automatically acquire and store sensor data at a configurable time interval (from 1 tenth of second to 24 hours). A wide spectrum of data processing functions is provided by the internal firmware: sliding average, polynomial and polynomial rational interpolation over the real time data. |
| **Features:** | • The OCEAN SEVEN 316 Probe can be equipped with an external battery package which greatly extends the probe operation (150 bar).<br>• The OCEAN SEVEN 316 Probe can be configured to be directly connected to a personal computer by means of: the RS232C serial interface or the telemetry interface |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | The probe is equipped with the following standard sensors to measure: pressure, temperature, conductivity, salinity, oxygen, pH, oxidation-reduction potential. |
| **Source/URL:** | |
| **Other:** | |

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| **Instrument/Testing Kit:** | WDM PipeSonde In-pipe Probe |
| **Model/Product No.:** | PS4ABASE |
| **Manufacturer:** | Hach |
| **Description:** | The Water Distribution Monitoring Panel (WDMP) is part of the Hach solution for real-time water distribution quality surveillance provides and optimum accuracy, sensitivity, and EPA reportable data. Panels are ideally located in plants, pump houses, system stations, and more vulnerable sites such as hospitals and schools. PipeSondes may be located to provide insight into the heart of the distribution system, such as major interconnections, trunk mains, air vaults, remote storage tanks and reservoirs, river intakes and other areas of concern. Both systems provide multiple-parameter measurement and continuous monitoring. This supplemental/complementary monitoring strategy helps a system realize a comprehensive baseline, maximized continuous surveillance, and optimized real-time "fate and transport" profiling in the event of contamination. Utilizing both systems, operators have more information to identify the source and extent of contamination and to implement prompt and effective isolation. |
| **Features:** | • Continuous monitoring of seven different water quality parameters - eliminates the manual sampling needed to establish an operating baseline, monitor for contamination, and comply with regulatory mandates under the Lead and Copper Rule, the Ground Water Rule, and Phase II D/DBP Rule<br>• Advanced yet established technology - familiar to operators and easy on cost of ownership.<br>• Sampling port for auto sampler, grab sampling and side stream analyzer - ideal for supplemental monitoring of key parameters such as TOC that are not suited for in-pipe measurement, or connecting to an auto sampler.<br>• Sensor housing, sensor guard, and adapter assembly constructed exclusively of 316-stainless steel (316-SS) - provides superior durability and corrosion resistance.<br>• 12 VDC power that can be provided by external battery, AC line converter, or solar panel - allows installation in a variety of conditions. (Includes plug-in for AC.)<br>• Data communication to SCADA or other data management systems - real-time surveillance, alarm, and response. (DB9 connector for RS232 or SDI-12 connection; converter allows RS485 or RS422 communication.) |
| **Cost:** | $8,000.00 |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | pH, ORP, conductivity, turbidity, dissolved oxygen, line pressure, temperature |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |
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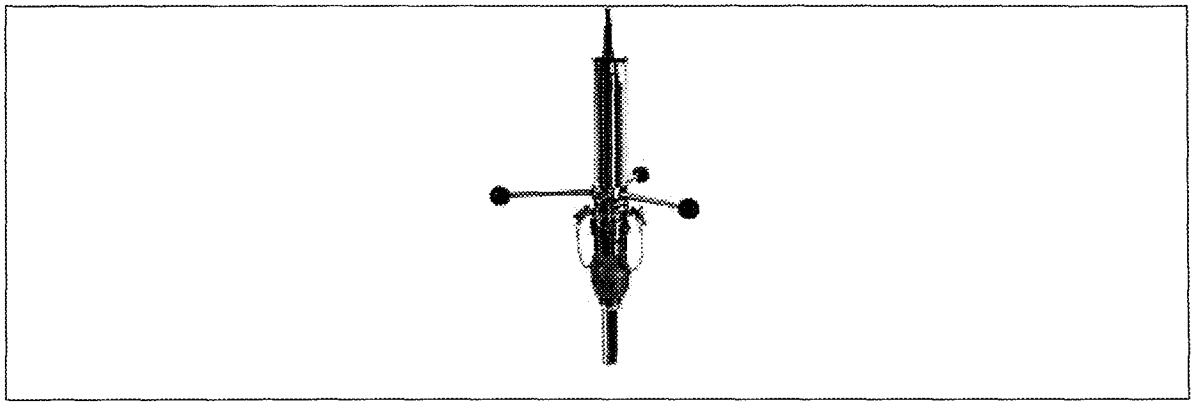

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| **Instrument/Testing Kit:** | Water Distribution Monitoring Panel (WDMP) |
| **Model/Product No.:** | 5980000 |
| **Manufacturer:** | Hach |
| **Description:** | The WDMP provides 24/7 surveillance of drinking water distribution systems. The WDMP is designed to monitor multiple indicator parameters that can signal changes in water quality profile. Includes: Hach CL17 Chlorine Analyzer, Free or Total (specify when ordering), Hach 1720D Turbidimeter, Hach/GLI Online pH Monitor, Hach/GLI Online Conductivity Monitor |
| **Features:** | • The right tool to establish your distribution system's baseline<br>• Instruments you can count on, each ranked top in category<br>• A sole-source supplier with breadth of product and depth of service<br>• Flexible system can be enhanced with on-line TOC analyzer and auto-sampler<br>• A partner you can depend on |
| **Cost:** | $12,800.00 |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | chlorine, conductivity, pH, turbidity, pressure, temperature |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |
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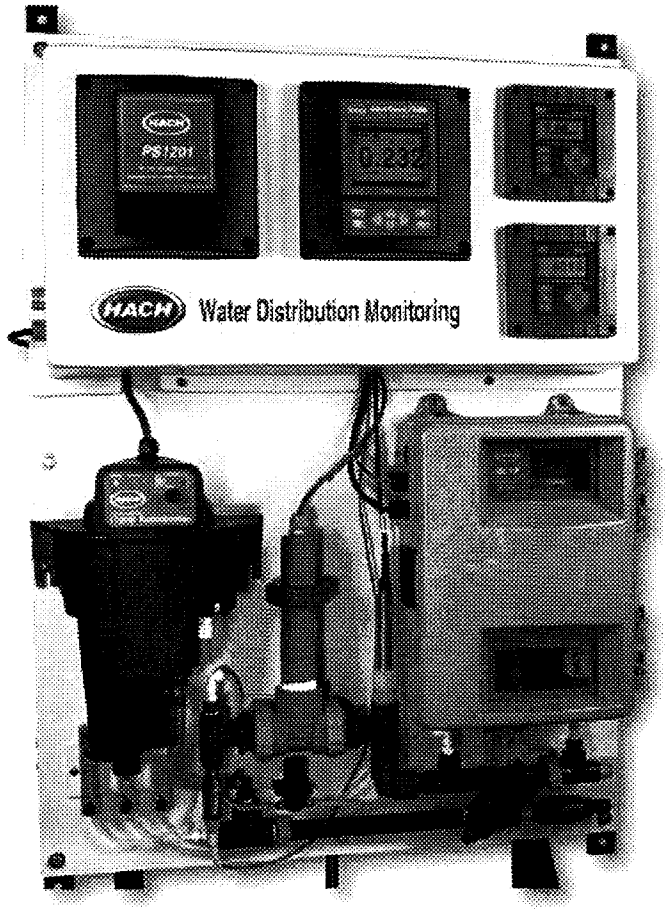
HACH
Water Distribution Monitoring

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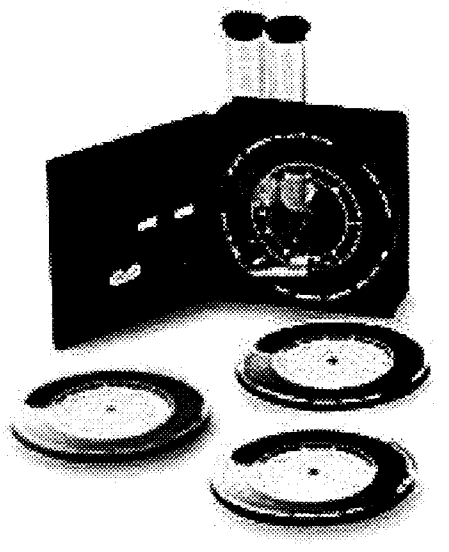
| **Instrument/Testing Kit:** | Hach Color Disc-based Test Kits |
| **Model/Product No.:** | |
| **Manufacturer:** | Hach |
| **Description:** | Our unique color disc kits feature a continuous-gradient color wheel for fast, accurate comparisons. The continuous color provides higher levels of accuracy. Kits also use a blank as a reference in color comparison, compensating for color in the sample.<br>Simply react the sample, then insert the blank and the sample into the holder. Rotate the color wheel to obtain a color match between the blank and the reacted sample. Accuracy for color disc kits is typically ± 10% or ± the smallest increment, subject to individual color perception. |
| **Features:** | |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |



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| **Instrument/Testing Kit:** | MEL P/A Safe Drinking Water Laboratory |
| **Model/Product No.:** | MEL P/A/2569600 |
| **Manufacturer:** | Hach |
| **Description:** | Monitor the following parameters with the MEL P/A Lab:<br>**Total Coliforms and *E. coli***: The Mel P/A includes Bromcresol Purple P/A Broth with MUG. The World Health Organization (WHO) recommends using the P/A method for drinking water to ensure zero total coliforms and zero fecal coliforms or E.coli. The P/A Broth with MUG allows simultaneous detection of total coliforms and E. coli. In 24 to 48 hours, you can determine whether a potable water source is contaminated.<br>The P/A method is a qualitative test that indicates only the presence or absence of coliforms, not the number of coliforms. If total coliforms are present, the medium changes from red-purple to yellow. If E. coli are present, the liquid medium fluoresces under long-wave ultraviolet (UV) light.<br>**Chlorine**: With an easy-to-use color disc comparator, you can quickly measure total and free chlorine concentration from 0-3.5 mg/L. You will know whether effective levels of residual chlorine are available to maintain proper disinfection.<br>**Nitrate**: With a color disc comparator, you can measure nitrate concentration from 0-50 mg/L. Excessive amounts of nitrate in potable water can cause infant death and adult illness. High nitrate levels can indicate non-point source pollution.<br>**TDS**: A Pocket Pal TDS Tester quickly measures TDS, which helps you check overall water quality and can indicate high levels of salinity, metals and inorganic compounds.<br>**pH**: A Pocket Pal pH Tester quickly measures pH, a commonly measured water quality parameter that influences the effectiveness of chlorine disinfection. |
| **Features:** | The MEL P/A Lab includes:<br>• Step-by-step, illustrated procedures manual<br>• 50 P/A Broth with MUG tests, disposable bottles<br>• Portable Incubator (can be plugged into 12 V automotive lighter, battery not included)<br>• PA Bottle Rack, holds 6 bottles<br>• 50 Whirl-Pak Bags with dechlorinating agent for sampling<br>• Pocket thermometer, -10 to 110 °C<br>• Five germicidal cloths for disinfecting test surfaces.<br>• Portable long-wave UV lamp for E. coli detection. |
| **Cost:** | $1,584.70 |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | total coliforms and *E.coli*, chlorine, nitrate, TDS, pH |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |
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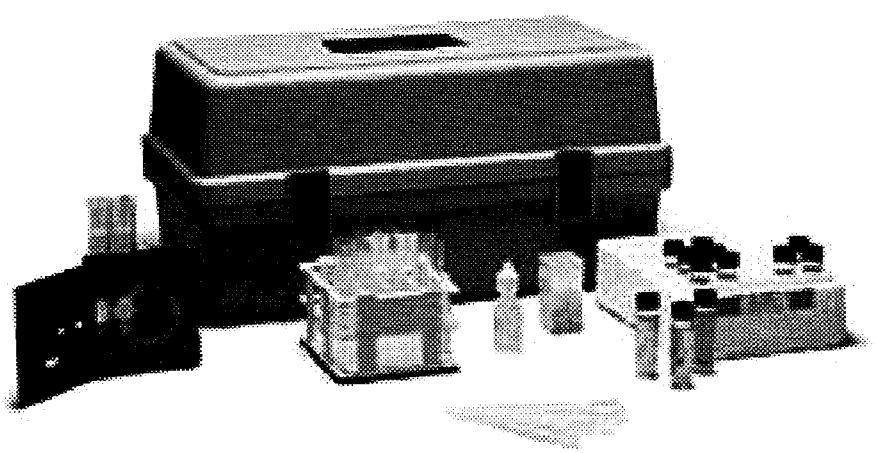
| **Instrument/Testing Kit:** | ToxTrak Toxicity Test Kit |
| **Model/Product No.:** | 2597700 |
| **Manufacturer:** | Hach |
| **Description:** | The ToxTrak™ Toxicity Test allows you to evaluate the toxicity of wastes and chemicals in wastewater treatment processes. The test provides results within 45 minutes.<br>Toxicity-the inhibitory effects of a waste stream on bacterial growth-can be monitored using methods such as direct growth, specific enzyme activity, bioluminescence, and respiration. These methods usually require lengthy incubation times, centrifugation, solvent extraction, laborious colony counting procedures, and expensive equipment. The ToxTrak(TM) Toxicity Test uses a colorimetric method to determine toxicity with a spectrophotometer or color disc comparator. The colorimetric method is quick and inexpensive, making it practical to monitor more frequently and with larger numbers of samples.<br>Use either treatment plant biomass or freeze-dried bacteria (order separately) to monitor percent inhibition. Using your plant's biomass, the ToxTrak Toxicity Test closely approximates the actual inhibitory effects of toxicity in your process. Using freeze-dried bacteria, you can screen for toxicity at any point in the waste stream. |
| **Features:** | • Protect wastewater treatment plant biomass<br>• Protect receiving waters from toxic substances<br>• Evaluate toxicity of chemicals used in the lab or the plant<br>• Obtain real-time data on toxic or inhibitory wastes<br>• Implement corrective action immediately |
| **Cost:** | $210.00 (25 tests) |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | toxicity of wastes and chemicals in wastewater treatment processes |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |



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| **Instrument/Testing Kit:** | Total Organic Carbon Analyzer for Industrial Applications |
| **Model/Product No.:** | astroTOC HT (High Temperature) |
| **Manufacturer:** | Hach |
| **Description:** | The astroTOC HT performs on-line Total Organic Carbon (TOC) analysis for industrial process control and industrial/municipal wastewater treatment, utilizing a high-temperature reactor that provides more uptime and lower maintenance and ownership costs than comparable instruments.<br>The analyzer combines the established platform of the Astro analyzer with a proven high temperature reactor system. The large volume furnace prevents severe-duty samples from plugging or causing premature failure, consequently extending intervals between routine maintenance.<br>Continuous sample feed by a peristaltic pump provides a robust, easy to maintain sample injection into the furnace. Advanced diagnostic features integrated into the instrument detect loss of sample or loss of UV reactor flow. Intuitive menu-driven software provides one-step initiation of single sample analysis, analyzer calibration and validation. |
| **Features:** | • Large volume furnace prevents plugging and failing<br>• Drift and interference free NDIR detector with PVDF (KYNAR®) flow-through is impervious to corrosion<br>• Options include: self-cleaning blowback filter, dual stream valve assembly, and an air purifier<br>• Simplified sample delivery system<br>• Alarms for loss-of sample & loss-of flow preserve the integrity of the system<br>• Industrial design withstands the most severe conditions<br>• Grab sample analysis capability<br>• Passive sample cooling device<br>• Combines proven astro process TOC analyzer platform with a patented high temperature reactor system<br>• Complies with Standard Methods 5310 B and EPA Method 415.1 |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |
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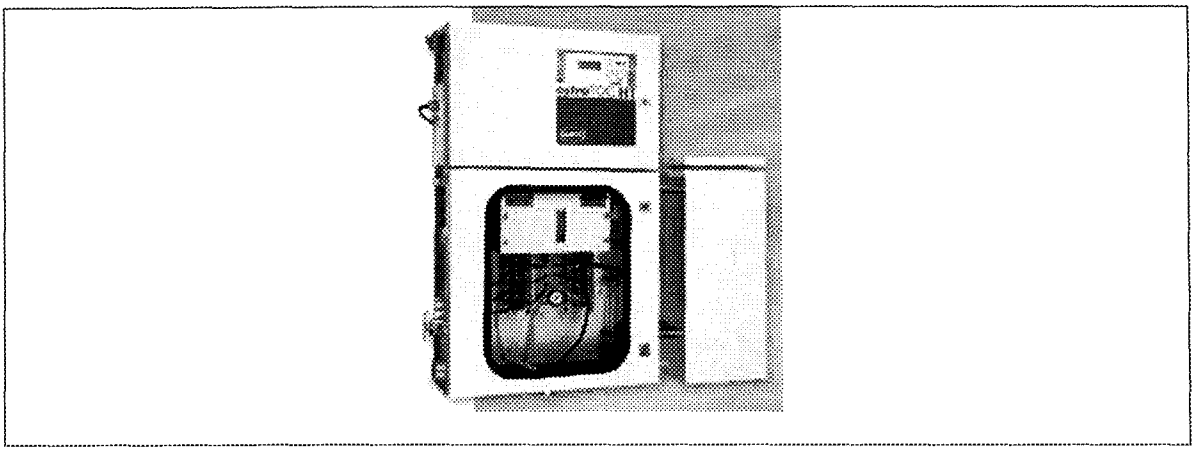

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| **Instrument/Testing Kit:** | 1950plus On-line TOC Analyzer |
| **Model/Product No.:** | 1950plus |
| **Manufacturer:** | Hach |
| **Description:** | With the introduction of the Disinfectants and Disinfection By-Product Rule (D/DBPR) by the United States Environmental Protection Agency, the measuring of Total Organic Carbon concentrations throughout a drinking water plant has become profoundly important. The D/DBP rule requires reporting of the TOC removal percentage based on the TOC and Alkalinity concentration of the source water compared to the TOC concentration of the distribution water.<br>Continuous on-line measurement of TOC removal percentage provides two key benefits. The first benefit is an immediate knowledge of your compliance status. The second benefit is continuous knowledge of removal percentage information, which allows you to actively control the employed removal technology (e.g. enhanced coagulation) |
| **Features:** | • Intelligent software reports pass/fail status for TOC removal percentage<br>• Complies with Standard Methods 5310 C and EPA Method 415.1<br>• Dual stream sample system for source and distribution water<br>• Grab sample analysis capability for immediate manual TOC measurements<br>• Flexible analysis system with CO2 NDIR detection and onboard sample dilution allows high salts and hard-to-oxidize sample analysis<br>• Loss of sample and loss of UV reactor flow are standard integrated analyzer diagnostics features<br>• Tolerant to changes in sample composition, pH, and temperature<br>• Drift and interference free NDIR detector with PVDF (KYNAR) flow-through cell<br>• Modular construction simplifies maintenance & service<br>• Optional self-cleaning blowback filter removes particles from sample lines<br>• Optional air purifier upgrades compressed air supply and improves analyzer efficiency |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |
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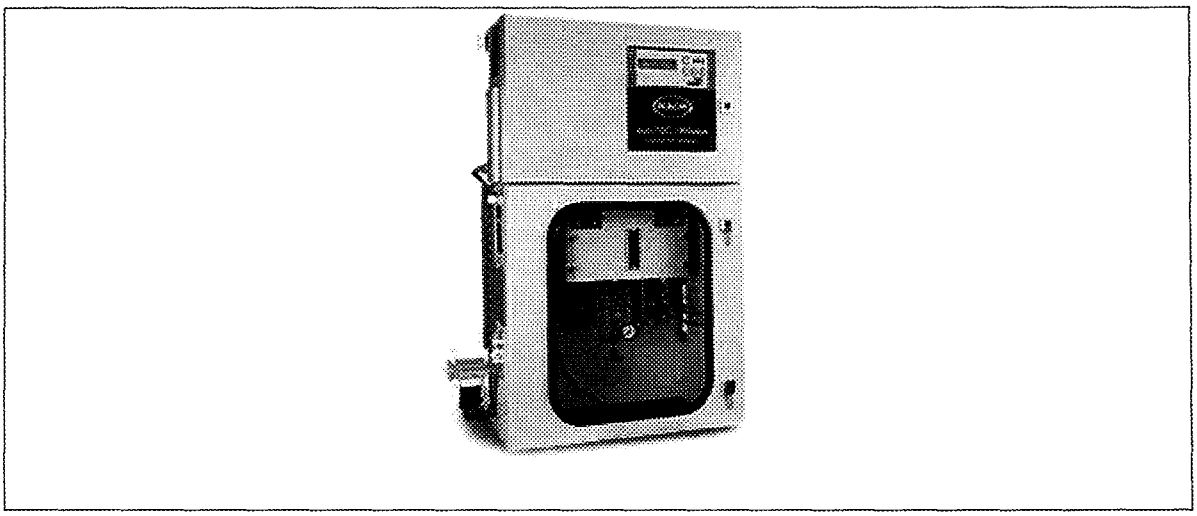

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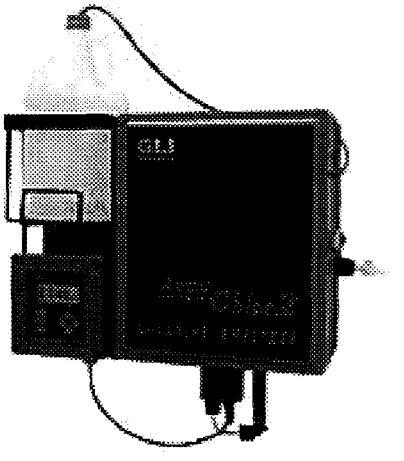
| **Instrument/Testing Kit:** | Residual Chlorine Measurement System |
| **Model/Product No.:** | AccuChlor 2/ AC2000P1A1N |
| **Manufacturer:** | Hach |
| **Description:** | Chlorine monitoring assures proper residual at all points in the system, helps pace re-chlorination when needed, and quickly and reliably signals any unexpected increase in disinfectant demand. Monitoring chlorine levels in the system also can serve as a "surrogate" for detecting potentially threatening contamination, because many chemical and biological contaminants are known to combine with chlorine. Therefore, a significant decline or loss of residual chlorine could be an indication of potential threats to the system.<br>The AccuChlor2 Residual Chlorine Measurement System is an amperometric measurement system. Two dissimilar metals are immersed in a liquid, and electrical potential develops, and a current may pass between them until the electrodes become polarized. The current generated is proportional to the concentration of the oxidizing agent-in this case, residual chlorine.<br>The AccuChlor2 measuring cell consists of a gold cathode and a copper anode. The water sample flow rate to the measuring cell is kept constant by using an integral overflow weir. Distilled white vinegar is pumped to the measuring cell and mixed into the water sample. The vinegar serves two purposes: it buffers the water sample to provide pH control and it keeps the electrodes free of dirt to reduce calibration frequency. |
| **Features:** | • EPA-approved amperometric measurement of residual chlorine, both free and total<br>Complete integrated system<br>• Inexpensive buffering agent<br>• Continuous and unique sample/hold monitoring<br>• Low maintenance, self cleaning cell design |
| **Cost:** | $3,228.75 |
| **Maintenance Requirements:** | low maintenance, self cleaning cell design |
| **Parameters Observed/ Sampled:** | chlorine |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |



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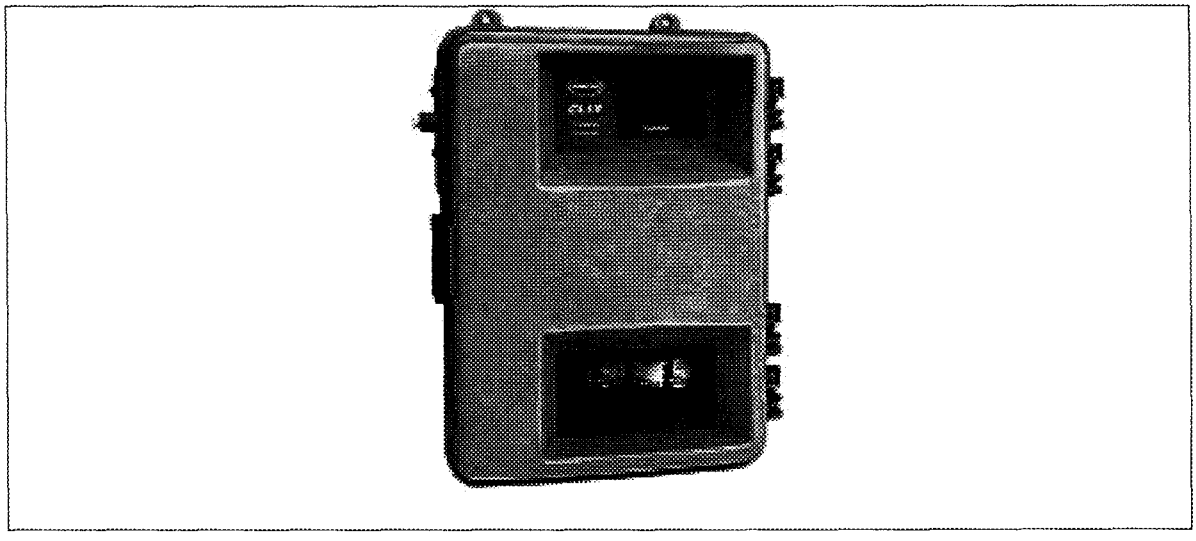
| **Instrument/Testing Kit:** | Free Residual Chlorine Analyzer |
| **Model/Product No.:** | CL17/5440001 |
| **Manufacturer:** | Hach |
| **Description:** | Chlorine monitoring assures proper residual at all points in the system, helps pace re-chlorination when needed, and quickly and reliably signals any unexpected increase in disinfectant demand. Monitoring chlorine levels in the system also can serve as a "surrogate" for detecting potentially threatening contamination, because many chemical and biological contaminants are known to combine with chlorine. Therefore, a significant decline or loss of residual chlorine could be an indication of potential threats to the system.<br>With Hach's advanced colorimetric chemistry, the CL17 Chlorine Analyzer provides a fast, reliable method of determining free or total residual chlorine. It performs around the clock, assuring proper disinfection and regulatory compliance. The CL17 also offers unbeatable cost-efficiency with minimal reagent consumption and ultra-low maintenance.<br>• Dependable chlorine analysis at an affordable price<br>• Superior accuracy and reliability in the most demanding process environments: Drinking Water, Chemical/Industrial Feed or Process Water, Food and Beverage Industry, Wastewater, Reverse Osmosis Filtration Systems – Heating and Cooling Systems |
| **Features:** | • Fast, automatic operation<br>• Colorimetric analysis<br>• Alarms and outputs -<br>• Genuine Hach reagents<br>• Big LCD display, intelligent menus, and flexible programming<br>• Rugged, lightweight enclosure<br>• Maintenance-free mixing and condensation control |
| **Cost:** | $2,725.00 |
| **Maintenance Requirements:** | Ultra-low maintenance |
| **Parameters Observed/ Sampled:** | chlorine |
| **Source/URL:** | http://www.hach.com/ |
| **Other:** | |



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| **Instrument/Testing Kit:** | Multiparameter Water Quality Monitoring Sondes |
| **Model/Product No.:** | Series 4 Multiparameter Water Quality Monitoring Sondes |
| **Manufacturer:** | Hydrolab |
| **Description:** | Tough and durable multiparameter water quality monitoring sondes. |
| **Features:** | • Ammonium-- Disallows zero activity standard for NH4+ and NO3-. Corrects current setup values for NH4+ and NO3-.<br>• Ammonium -- Series 4a Sondes. Alters chloride and total ammonium computation formula.<br>• Chloride -- Series 4 Sondes. Adds language switches and changes "CL-" to "Cl-." Corrects default number of calibration points.<br>• Chloride -- Series 4a Sondes. Alters chloride and total ammonium computation formula.<br>• Conductivity -- Series 4 Sondes. Supports graphite conductivity sensor.<br>• Dissolved Oxygen -- Series 4 Sondes. To be used only with graphite conductivity sensor.<br>• Nitrate -- Series 4 Sondes. Disallows zero activity standard for NH4+ and NO3-. Corrects current setup values for NH4+ and NO3-.<br>• Nitrate -- Series 4a Sondes. Alters chloride and total ammonium computation formula.<br>• pH/Reference -- Series 4 Sondes. Disallows zero activity standard for NH4+ and NO3-. Corrects current setup values for NH4+ and NO3-.<br>• pH/ORP/Reference -- Series 4 Sondes. Disallows zero activity standard for NH4+ and NO3-. Corrects current setup values for NH4+ and NO3-.<br>• Temperature -- Series 4 Sondes. Corrects TempC conversion to TempK (273=273.13).<br>• TDG -- Series 4 and 4a Sondes (mini TDG). Reports no setup for TDG:mV parameter.<br>• Turbidity (non-shuttered) -- Series 4 and 4a Sondes with non-Shuttered Turbidity. Note: Update Main MPL code to latest revision before loading driver.<br>• Chlorophyll -- Series 4 and 4a Sondes. Changes calibration acceptance window.<br>• Chlorophyll -- Resolution Driver. Increases SCUFA resolution to x.xx<br>• PAR -- Series 4 and 4a Sondes. Provides minor format changes. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | ammonium, chloride, conductivity, dissolved oxygen, nitrate, pH/reference, pH/ORP/reference, temperature, TGD, turbidity, chlorophyll, PAR |
| **Source/URL:** | http://www.hydrolab.com |
| **Other:** | |

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| **Instrument/Testing Kit:** | Multiparameter Water Quality Instrument |
| **Model/Product No.:** | Quanta -- Display |
| **Manufacturer:** | Hydrolab |
| **Description:** | The Quanta system is a compact and complete system capable of monitoring temperature, dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity, and can log 100 frames of data. All Quanta components, including sensors, are covered by an industry best three-year warranty.<br>The Quanta display is also made of the super durable Ryton®, allowing it to be submerged. The Quanta display stores three "C" size batteries, which powers the display and the transmitter. The display itself shows five parameters at once. There are two screens of data, which can be toggled with the push of a button. The user interface is easy and intuitive. New users can get up and running almost immediately. Calibration is simple with the Quanta display.<br>The display can also store 200 frames of data in the non-volatile flash memory. This means you won't lose your data if you change your batteries. Each data frame can be reviewed by scrolling through, and you can quickly access a specific frame. The battery compartment is easy opening with a coin, allowing the batteries to be changed in 30 seconds. |
| **Features:** | • Reliable<br>• Easy to use<br>• Affordable<br>• Robust<br>• 3 Year Warranty<br>• PC Data Dump Function and Real Time Clock -- The optional PC data dump function allows you to download data to your PC eliminating the time-consuming task of manual data entry. The Real Time Clock (RTC) displays on a third screen and is always accurate to within 2 minutes per month. The small clock board runs on a separate, 10-year battery, so the RTC continues to function while you change the main operating batteries.<br>• With these enhancements, you can download all 200 frames of data into your PC in about 3 minutes and each stored frame displays an accurate date and time stamp! |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | temperature, dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity |
| **Source/URL:** | http://www.hydrolab.com/Qcomponents.html |
| **Other:** | |

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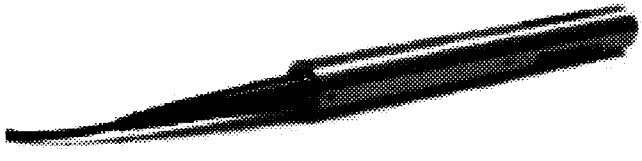
| **Instrument/Testing Kit:** | Multiparameter Water Quality Instrument |
| **Model/Product No.:** | Quanta-G – Transmitter |
| **Manufacturer:** | Hydrolab |
| **Description:** | The Quanta system is a compact and complete system capable of monitoring temperature, dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity, and can log 100 frames of data. All Quanta components, including sensors, are covered by an industry best three-year warranty.<br>The Quanta transmitters hold the sensors. Every transmitter is automatically equipped with temperature, but you can choose which additional sensors you wish to add. The Quanta and Quanta-G are multi-parameter, they can monitor up to eight different parameters simultaneously.<br>Designed specifically for ground water applications, Hydrolab's Quanta-G monitors up to eight different water quality parameters simultaneously. The Quanta-G is equipped with a heavy duty 1.75" diameter 316 stainless steel housing for easy cleaning, minimizing the potential for cross contamination. SDI-12 output allows the Quanta-G to connect directly to 3rd party data loggers without custom software. |
| **Features:** | • Reliable<br>• Easy to use<br>• Affordable<br>• Robust<br>• 3-Year Warranty |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | temperature, dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity |
| **Source/URL:** | http://www.hydrolab.com/Qcomponents.html |
| **Other:** | |



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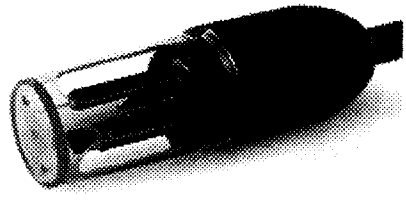
| **Instrument/Testing Kit:** | Multiparameter Water Quality Instrument |
| **Model/Product No.:** | Quanta – Transmitter |
| **Manufacturer:** | Hydrolab |
| **Description:** | The Quanta system is a compact and complete system capable of monitoring temperature, dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity, and can log 100 frames of data. All Quanta components, including sensors, are covered by an industry best three-year warranty.<br>The Quanta transmitters hold the sensors. Every transmitter is automatically equipped with temperature, but you can choose which additional sensors you wish to add. The Quanta and Quanta-G are multi-parameter, they can monitor up to eight different parameters simultaneously.<br>The Quanta housing is made of super durable Ryton®, and it is submersible to 100 meters. The compact design, barely 9" long (23 cm), is also extremely light, weighing in at about three pounds (1.3 kg).<br>Output from the Quanta transmitter is SDI-12 format, allowing it to be connected to numerous third-party dataloggers. For ground water monitoring, a flow cell can be attached to the Quanta transmitter. |
| **Features:** | • Reliable<br>• Easy to use<br>• Affordable<br>• Robust<br>• 3-Year Warranty |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | temperature, dissolved oxygen, conductivity, pH, ORP (redox), depth, turbidity |
| **Source/URL:** | http://www.hydrolab.com/Qcomponents.html |
| **Other:** | |



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|---|---|
| **Instrument/Testing Kit:** | Test Kit |
| **Model/Product No.:** | Quick™ II / 481303 (only kit presented here)<br>Quick™ Ultra Low II<br>Quick™ Low Range<br>Quick™ Low Range II<br>Quick™ ARSENIC |
| **Manufacturer:** | Industrial Test Systems, Inc. |
| **Description:** | Arsenic Quick II was designed to give the user accurate results without sacrificing cost and time. Designed using cutting-edge chemistry, Arsenic Quick II reports results in only 14 minutes. Additionally, there are no dangerous chemicals needed to run this kit. With only 3 simple test procedures, Arsenic Quick II is a must for any lab, water testing professional, or service technician who values accurate, rapid results without sacrificing cost. |
| **Features:** | |
| **Cost:** | $219.99 (50 tests) |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | arsenic |
| **Source/URL:** | http://www.sensafe.com/481303.php |
| **Other:** | |

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|---|---|
| **Instrument/Testing Kit:** | PolyTox™ Rapid Toxicity Test |
| **Model/Product No.:** | |
| **Manufacturer:** | InterLab Supply, Ltd. |
| **Description:** | For use in determining the biological decomposibility or toxicity of wastewater to a sewage treatment facility. Polytox™ is a blend of specialized microbial cultures in an easy-to-use kit, designed to provide a simple, rapid test for measuring the toxicity of wastewater to biological systems within 30 minutes, without the use of expensive instrumentation. Polytox™ is EPA recommended |
| **Features:** | By utilization of a specially prepared bacterial culture and through the measurement of dissolved oxygen content, one can achieve several advantages which have not been available with prior processes. Some of these advantages include:<br>• A rapid biological test for determining the toxicity of a wastewater sample<br>• A rapid, reproducible, biological test for determining the toxicity of a specific chemical as a function of its concentration in water<br>• A rapid method of assessing the toxicity of acidic or basic solutions of various specific chemicals, and organic and inorganic compounds to bacteria<br>• A rapid method of determining the effects of determining the effects of pH, temperature or a dissolved gas such as H2S, NH3, and CO2 on bacteria |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | pH, dissolved oxygen (ppm), temperature (°C), toxic metals (ppm) |
| **Source/URL:** | http://www.polyseed.com/documents/pdf/tech/polytoxtds.pdf |
| **Other:** | |

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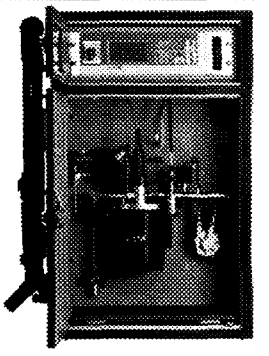
| **Instrument/Testing Kit:** | BOD Analyzer |
| **Model/Product No.:** | BIOX 1010 |
| **Manufacturer:** | ISCO, Inc. |
| **Description:** | BIOX-1010 is an on-line analyzer for continuous BOD measurement in industrial and municipal wastewater treatment plants. BOD data are generated with a lag time of only 3 to 15 minutes, with a standard measurement range of 20 to 1500 mg/liter BOD and available ranges covering 5 to 100,000 mg/liter. The real-time BOD data correlate well with five-day BOD5 laboratory results.<br>Wastewater is continuously pumped through a sample bypass. The peristaltic pump built into BIOX continuously feeds a small stream of wastewater from the sample bypass to the bioreactor. Before it reaches the bioreactor, this wastewater stream is diluted with oxygen-saturated dilution water supplied by a gear pump.<br>Inside the bioreactor, microorganisms grow inside small plastic cylinders where they are protected against mechanical abrasion caused by turbulent mixing. The respiration rate of the microbial population is automatically maintained at a constant level by a feedback loop that varies the dilution ratio. Increasing contamination of the wastewater increases the respiration rate, which in turn increases the dilution rate. Similarly, if the contamination level of the wastewater decreases, so does the dilution rate. The wastewater concentration in the reaction chamber is thus kept at a constant, low level, and the mixing ratio of wastewater and dilution water is used to calculate the BOD parameter.<br>• Increase the efficiency of water/wastewater treatment to reduce process costs in both industrial and municipal applications.<br>• Provide warning of organic spills, to protect expensive processes and equipment in addition to monitoring for regulatory compliance. |
| **Features:** | • True continuous measurement<br>• Response time: 3 to 15 minutes<br>• Measurement ranges of 20 - 1500 mg/liter BOD; 20 - 100,000 mg/liter BOD; 5 - 1500 mg/liter BOD<br>• Sample preparation with self-cleaning coarse filter<br>• Programmable concentration alarms<br>• Up to 14 days historical data can be recalled and displayed graphically |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | BOD measurement |
| **Source/URL:** | http://www.isco.com |
| **Other:** | |



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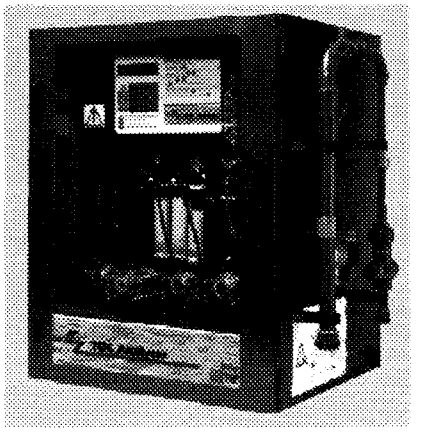
|---|---|
| **Instrument/Testing Kit:** | Continuous Low-temperature On-line TOC/TC Analyzer |
| **Model/Product No.:** | EZ TOC |
| **Manufacturer:** | ISCO, Inc. |
| **Description:** | Continuous on-line TOC/TC measurement using ultraviolet (UV)-promoted, low-temperature oxidation. Total Organic Carbon (TOC) measurement is increasingly accepted as an excellent overall indicator of water quality. TOC measurement is becoming the method of choice for continuous screening for organic compounds, without having to test for each substance individually. Used to increase the efficiency of water/wastewater treatment, TOC analysis can reduce process costs in both industrial and municipal applications.<br>Used as a warning of organic spills, TOC analysis can protect expensive processes and equipment in addition to monitoring for regulatory compliance.<br>The Isco EZ TOC analyzer is your solution for on-line, continuous TOC monitoring. It is easy to use, accurate, reliable, and suitable for a variety of applications.<br>Analysis methodology complies with EPA and ASTM standard methods for TOC determination, as well as ISO and CEN international standards. The EZ TOC analyzer can be configured to measure TOC in these ranges: 0-10 mg/L; 0-100 mg/L; 0-500 mg/L; 0-1000 mg/L; 0-5000 mg/L; 0-10,000 mg/L. |
| **Features:** | • Easy Programming<br>• High Efficiency Reactor<br>• Enhanced Detector<br>• Flexible Four-Motor Pump System<br>• Advanced Dual Calibration |
| **Cost:** | |
| **Maintenance Requirements:** | Auto-calibration and cleaning cycles provide hands-off low maintenance operation. Easily accessible components make routine maintenance a snap. Up to eight programmable relays can provide a remote indication of system operation and report trouble conditions. A fail-safe shutdown feature prevents damage, should a malfunction occur. |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.isco.com |
| **Other:** | |



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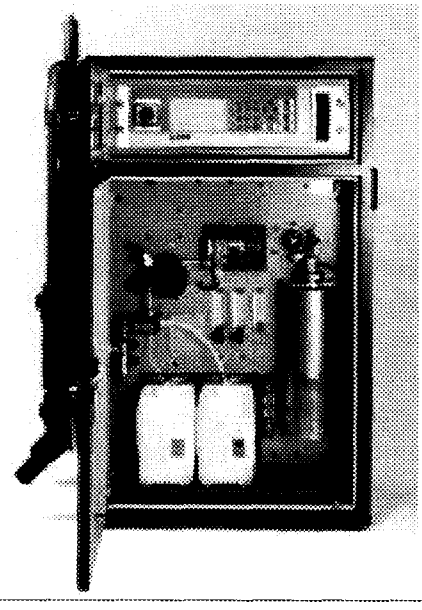
| **Instrument/Testing Kit:** | Continuous High-temperature On-line TOC Analyzer |
| **Model/Product No.:** | STIP-toc |
| **Manufacturer:** | ISCO, Inc. |
| **Description:** | A large sample stream is taken in via an automatically self-cleaning coarse filter in the sample bypass. In the stripping cell, inorganic carbon is removed through acidification and sparging.<br>In the rotating slit filter, a sub-stream for analysis is split off directly before the furnace. In the furnace the analysis stream is thermally and catalytically oxidized. After the evolved gas mixture is dried and neutralized, it is measured as CO2 in the IR detector, and reported as TOC. The system automatically calibrates itself daily with two TOC standards (two point calibration).<br>STIP-toc functions as a high temperature TOC analyzer without ultra- or fine filtration. Applications range from solids-containing municipal wastewater to industrial wastewater with dissolved salts to river water and cooling water. |
| **Features:** | • Temperature selectable from 600° C to 900° C (1100° F to 1650° F)<br>• True continuous operation<br>• Response time: 3 to 15 minutes<br>• Measuring range: 2 - 10,000 mg TOC/liter (detector dependent)<br>• Salt trap<br>• Catalyst outside furnace<br>• Rotating slit filter<br>• Digital and analog output signals for external alarms and controls<br>• Sample preparation with self-cleaning coarse filter |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.isco.com |
| **Other:** | |



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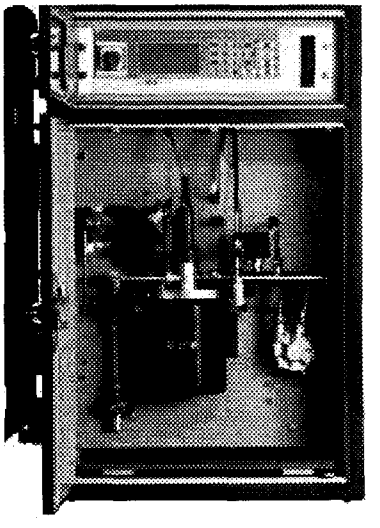
|---|---|
| **Instrument/Testing Kit:** | On-line Toximeter |
| **Model/Product No.:** | STIPTOX-adapt (W) |
| **Manufacturer:** | ISCO, Inc. |
| **Description:** | STIPTOX-adapt (W) is a toxicity analyzer with immobilized turbulent-bed biology. As in the BIOX-1010, the microbes grow on the inner surface of small hollow cylinders. Like the activated sludge of a treatment plant, the microbial population in the bioreactor is adapted to the conditions of the wastewater. So long as the wastewater is not toxic to the adapted biology, the organisms in the bioreactor take up dissolved oxygen. A toxic impact inhibits the respiration of the organisms, causing an increase in the dissolved oxygen level.<br>If the respiration rate decreases by more than about 20%, an additional dilution of the wastewater is triggered, and is regulated such that the overall depression of microbial activity does not exceed 20%. This protects the microbes and provides the mechanism for toxicity measurement.<br>The mixing ratio of wastewater and dilution water, together with the oxygen difference, are used to calculate the toxicity reading. |
| **Features:** | • True continuous measurement<br>• Response time: 3 to 15 minutes<br>• Measurement range: 0 - 100% toxicity<br>• Turbulent-bed bioreactor<br>• Sample preparation with self-cleaning coarse filter<br>• Automatic calibration<br>• Programmable concentration alarms<br>• Charts and instantaneous toxicity level displayed on LCD graphic display<br>• Up to 14 days historical data can be recalled and displayed graphically |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.isco.com |
| **Other:** | |



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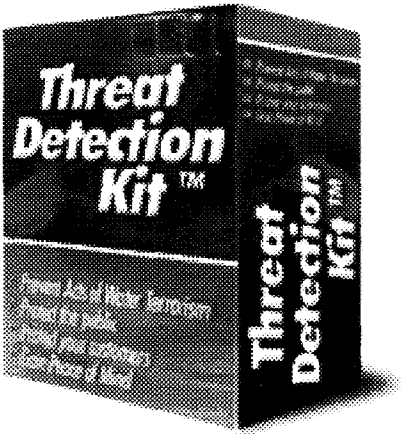
|---|---|
| **Instrument/Testing Kit:** | Detection Kit |
| **Model/Product No.:** | Threat Detection Kit™ (starter and maintenance kits) |
| **Manufacturer:** | Kingwood Diagnostics, LLC |
| **Description:** | The Threat Detection Kit not only can be used to assess water contamination after a security breach – but, also should be considered as at tool for daily monitoring – in effect an early warning system. If you are responsible for providing potable water to residents in your town or city or responsible for providing potable water to a food or beverage manufacturing facility, you should consider the use of the Threat Detection Kit at your water processing facility as a screening tool or early warning system.<br>The Threat Detection Kit is supplied in two forms: a Starter kit and a Maintenance kit. The kits contain the necessary supplies to conduct a month of testing (30 days) assuming 1 /test per day is performed. The Starter Kit is purchased once and contains supplies that are needed to get the test system and organism culture up and running in your facility. The Maintenance Kit provides the expendable supplies needed to maintain your organism culture for 30 days and the necessary materials to perform an additional 30 tests. |
| **Features:** | • Sensitivity – Detected most threat contaminants at 1/20 of the dose that would affect humans<br>• Simplicity – Scored with the unaided eye<br>• Quick – Provide results in 1 hour and 15 minutes<br>• Inexpensive – Less than 2 cents/person/month (including labor) for a town of 100,000<br>• Reliability – No complex machine required, inherently reliable<br>• Benefits – Safeguards the public against potential terrorist acts to our water supply. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | The Threat Detection Kit not only can be used to assess water contamination after a security breach – but, also should be considered as at tool for daily monitoring – in effect an early warning system. |
| **Source/URL:** | http://www.detect-water-terrorism.com/ |
| **Other:** | |



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| **Instrument/Testing Kit:** | Portable Cyanide Analyzer |
| **Model/Product No.:** | SMART 2 Colorimeter with the 3660-SC Reagent System |
| **Manufacturer:** | LaMotte Company |
| **Description:** | |
| **Features:** | • Menu-driven display<br>• Over 50 pre-programmed tests with 10 user tests<br>• Automatic wavelength selection<br>• The SMART 2 Colorimeter is supplied with 4 sample tubes, AC adapter, and instruction manual including test procedures. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Alkalinity UDV, Aluminum, Ammonia, Nitrogen-LR (Fresh Water), Ammonia, Nitrogen-LR (Salt Water), Ammonia Nitrogen, Boron, Bromine LR, Bromine UDV, Cadmium, Carbohydrazide, Chloride TesTab, Chlorine, Chlorine Free UDV, Chlorine Liquid DPD, Chlorine Total UDV, Chlorine Dioxide, Chromium, Hexavalent, Chromium TesTab, Chromium (Total, Hex & Trivalent), Cobalt, COD LR 0-150 with Mercury, COD LR 0-150 without Mercury, COD SR 0-1500 with Mercury, COD SR 0-1500 without Mercury, COD HR 0-15,000 with Mercury, COD HR 0-15,000 without Mercury, Color, Copper BCA – LR, Copper Cuprizone, Copper DDC, Copper UDV, Cyanide, Cyanuric Acid, Cyanuric Acid UDV, DEHA, Dissolved Oxygen (DO), Erythorbic Acid, Fluoride, Hydrazine, Hydrogen Peroxide, Hydroquinone, Iodine, Iron, Iron UDV, Iron Phenanthroline, Lead, Manganese LR, Manganese HR, Mercury, Methylethylketoxime, Molybdenum HR, Nickel, Nitrate Nitrogen LR, Nitrate TesTab, Nitrite Nitrogen LR, Nitrite TesTab, Ozone LR, Ozone HR, pH CPR (Chlorphenol Red), pH PR (Phenol Red), pH TB (Thymol Blue), Phenol, Phosphate LR, Phosphate HR, Potassium, Silica LR, Silica HR, Sulfate HR, Sulfide LR, Surfactants, Tannin, Turbidity, Zinc LR |
| **Source/URL:** | http://www.lamotte.com/pages/wawa/smart2.html |
| **Other:** | |

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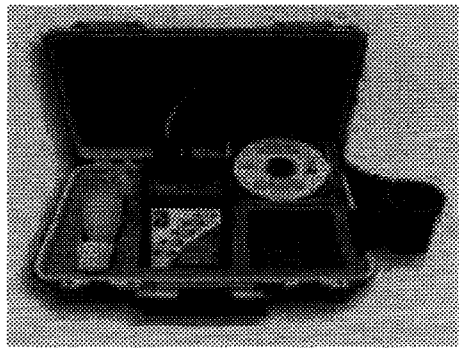
| **Instrument/Testing Kit:** | Heavy Metal Analyser |
| **Model/Product No.:** | PDV 6000 |
| **Manufacturer:** | Monitoring Technologies International, Pty. Ltd. |
| **Description:** | The PDV 6000 is a portable analyser designed to identify and measure the concentrations of heavy metal ions in a wide range of matrixes. It can be used either as a standalone unit or connected to a laptop or desktop computer running the supplied VAS software.<br>The principle of analysis used by the PDV 6000 is Anodic Stripping Voltammetry (ASV), a well established electrochemical technique. |
| **Features:** | The PDV 6000 offers:<br>• Low running costs.<br>• Easy to use<br>• Set up in very short time (less than 10 minutes)<br>• Part per billion (ppb) detection levels<br>• Results obtained in as little as 30 seconds.<br>• Standalone operation of ultimate on site practicality<br>• Self contained, needs no gases, flames, lamps or expensive reagents.<br>• Battery or mains power<br>• Less than 5Kg for the complete analyser with batteries, analysis cup and carry case.<br>• Multi metal capability when linked to PC via VAS Analyser<br>• Upgradeable internal software to allow new application menus to be loaded for standalone use. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | arsenic |
| **Source/URL:** | http://www.monitoring-technologies.com/pdv6000.html |
| **Other:** | |



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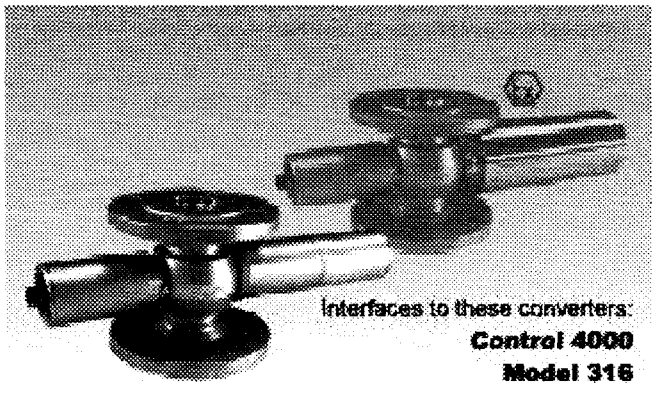
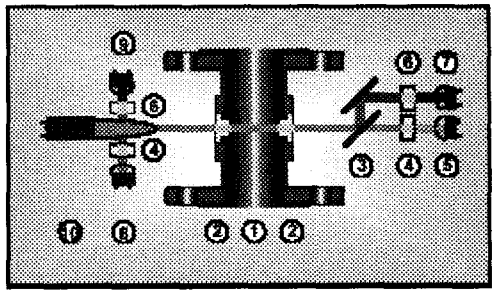
| **Instrument/Testing Kit:** | Dual Channel UV Absorption Sensor |
| **Model/Product No.:** | AF46 |
| **Manufacturer:** | Optek |
| **Description:** | Optek's highly precise in-line UV Absorption sensors measure UV-absorbing compounds, from high concentrations down to traces in the PPB range. Optek's AF46 dual-channel / dual wavelength UV sensor features lamp intensity compensation for extreme stability and repeatability. |
| **Features:** | • In-line, real time, dual UV wavelength photometric process analysis<br>• Compensates for background solids/species<br>• Dual reference detection circuits<br>• Modular and easy to install, set-up, and operate<br>• Extremely low maintenance, 2-4 year lamp life<br>• 24-hour technical support<br>• Superior product warranty<br>• NIST-traceable validation accessories for absolute measurement confidence<br>• Broad variety of line sizes, process connections and wetted materials<br>• Options for all Hazardous area classifications<br>• For CIP/SIP and Ultra-sanitary applications<br>• Sapphire Optics provide superior resilience to all abrasive and corrosive media |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | concentrations of acetone, aniline, benzene, halogens, HMF, hydrogen peroxide, ketones, trace mercury, nitric acid, ozone, phenols/phenates, sulfur dioxide, toluene, tracers, xylene |
| **Source/URL:** | |
| **Other:** | http://www.optek.com/pdf/810-AF46-00-EN-A.pdf |



(1) Sensor Body (2) Sapphire Windows (3) Beam-Splitter (4) Ch.1 Filters (5) Ch.1 Measurement Detector (6) Ch.2 Filters (7) Ch.2 Measurement Detector (8) Ch.1 Reference Detector (9) Ch.2 Reference Detector (10) Low Pressure Mercury Light Source

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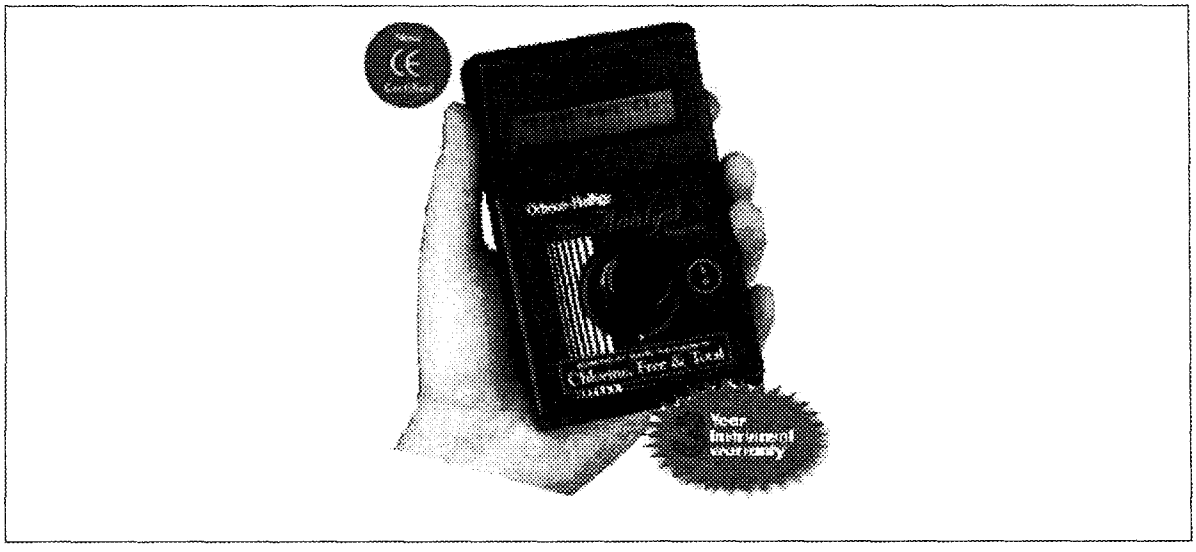
| **Instrument/Testing Kit:** | Portable Cyanide Analyzer |
| **Model/Product No.:** | Mini-analyst Model 942-032 (Cyanide, Free) |
| **Manufacturer:** | Orbeco-Hellige |
| **Description:** | Mini Analysts are ideal for use when a specific test is frequently performed. All are easy-to-use and easy-to-carry for fast, precise water tests. All read directly in Concentration (mg/L or ppb) and are economically priced.<br>Mini Analysts feature 1 touch operation and are factory calibrated, microprocessor controlled and incorporate automatic zero and standardization. All models come complete with reagents (except COD models), batteries, and carrying case and industry leading 3 year warranty. |
| **Features:** | • Direct-reading digital display of procedure prompts, test result, low battery level.<br>• LED narrow-band light source assures high sensitivity and long bulb & battery life.<br>• 1 touch operation and read test result in concentration units.<br>• Factory calibrated, no user adjustments are ever needed.<br>• Microprocessor controlled self diagnostics of power, circuitry and lamp readiness.<br>• Auto zero & standardization by microprocessor eliminates need for a light shield.<br>• Auto-blank, insert blank once for faster multiple testing.<br>• Uniform, flat bottomed, large diameter tubes for eproduceability, convenience and high sensitivity.<br>• Powered by 4 AA batteries (included).<br>• Auto shut-off after 15 minutes of non-use.<br>• 3-year instrument warranty with toll-free technical backup.<br>• Complete with all reagents, compact labware and directions. Carrying case included.<br>• Precision made in the U.S.A. |
| **Cost:** | $299.00 |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | cyanide |
| **Source/URL:** | http://www.orbeco.com/prodPages/minianalyst.html |
| **Other:** | |



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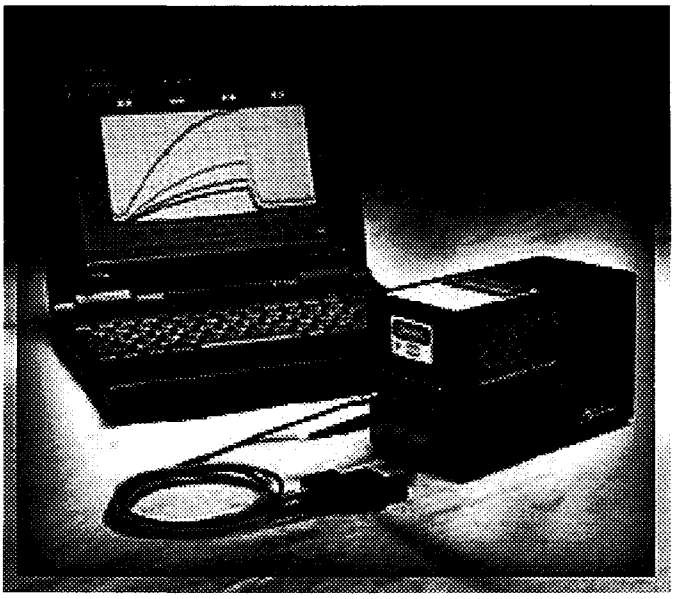
| **Instrument/Testing Kit:** | Fiber Optic Fluorometer |
| **Model/Product No.:** | Analyte 2000 |
| **Manufacturer:** | Research International |
| **Description:** | The Analyte 2000 is a 4-channel, single wavelength fluorometer optimized for performing evanescent-wave fluoroimmunoassays that was developed in conjunction with the Naval Research Laboratory for biomolecule detection. This low-power, microprocessor-controlled instrument provides parts-per-billion sensitivities to biochemical antibody/antigen reactions on tapered glass waveguides. The instrument is controlled from a remote computer leading to a system size of only 20 cm L x 8.5 cm H x 11.2 cm W. The Analyte 2000, coupled with a separate fluidics box, has been flown and operated in small, unmanned air vehicles (UAVs) using a remote RF link to a ground-based portable computer. |
| **Features:** | • Analyte Adapter -- The Analyte Adapter is a small optoelectronics module that serves as an interface between the Analyte 2000 and the inexpensive, injection-molded polystyrene waveguides developed for use with the RAPTOR fluoroimmunoassay system. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | performs evanescent-wave fluoroimmunoassays |
| **Source/URL:** | http://www.resrchintl.com/analyte2000.html |
| **Other:** | |



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| **Instrument/Testing Kit:** | Eclox™ |
| **Model/Product No.:** | |
| **Manufacturer:** | Severn Trent Services |
| **Description:** | The ETV-verified Eclox water test kits are rapid and portable field water quality assessment systems for use in detecting intentional or accidental contamination of water for civilian or military applications.<br><br>**Eclox Rapid Response Water Test System**<br>This is a comprehensive test system and includes a luminometer and associated equipment required for chemiluminescence testing of a water sample. In addition to the luminometer, the test system also includes equipment and specific tests to measure arsenic, pesticides /nerve agents, pH, total dissolved solids (TDS), color and chlorine content. An optional mustard gas test is also available. This equipment is currently in service with the UK armed forces and is fully NATO codified.<br><br>**Eclox Water Test Kit**<br>Includes a luminometer and associated equipment required for chemiluminescence testing. Applications include environmental monitoring and mapping, industrial site evaluation, water treatment monitoring, wastewater strength evaluation and many others. Pesticide/nerve agent tests strips are available as an option. |
| **Features:** | • Rapid Detection of contaminated water<br>• Reliable indicator of relative water quality<br>• Easy to use with minimum training<br>• Chemically hard and de-contaminable<br>• Replacement consumables packs available with 2-year shelf life<br>• Use in a wide range of environmental conditions<br>• Low weight to be carried by one person<br>• Downloadable data for an auditable record<br>• Sensitive to heavy metals, poisons and CW agents<br>• Usable in full NBC protective clothing |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | chemiluminescence testing, also includes equipment and specific tests to measure arsenic, pesticides /nerve agents, pH, total dissolved solids (TDS), color, chlorine |
| **Source/URL:** | http://www.severntrentservices.com/instrumentation_products/portable_water_assessment/index.jsp |
| **Other:** | |

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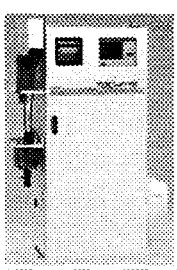
| **Instrument/Testing Kit:** | On-line Water Quality Analyzer |
| **Model/Product No.:** | TOC-4110 |
| **Manufacturer:** | Shimadzu North America |
| **Description:** | TOC is used in a variety of applications from management of waste water treatment plant influent and effluent, to drinking water supply management and monitoring of impurities in process and natural waters. And the range of applications in which this type of on-line technology is used is expected to continue expanding.<br>In addition, because nitrogen is considered to be one of the factors which contributes to the over-proliferation of organisms in enclosed bodies of water, management of these public water sources and of treatment plant influent and effluent also includes demand for monitoring of nitrogen levels.<br>• Process management for waste stream influent and effluent at treatment facilities.<br>• Operation management of all types of plant waters (i.e.: cooling water, recirculating water, boiler water, wash/rinse water, condenser water)<br>• Continuous monitoring of drinking/ process water, and natural water<br>• Continuous monitoring or organic contamination in water streams that must be reported to regulatory agencies. |
| **Features:** | • Automatic dilution expands the analysis range and allows the reduction in salt, acid and alkali concentrations to help reduce maintenance and extend catalyst life<br>• A complete line of options designated to accommodate samples with suspended particles, slime or seaweed reduces the occurrence of trouble and remedial maintenance in on-line TOC measurement.<br>• Optional multi-stream selectors allow analysis of 2 streams, or up to 6 different streams, of varying carbon concentrations.<br>• Measurement condition and measurement interval of each sample stream individual programmable<br>• User defined calibration check or re-calibration. Automatic calibration is incorporated using standard solutions stored on-board.<br>• On-board carrier/combustion gas purification allows use of air supplied from a compressor, thus eliminating expensive and potentially dangerous cylinder gases.<br>• High performance on-line TOC analyzer using the established 680°C catalyst-aided combustion and non-dispersive infrared detection method<br>• Wide measurement range is variable from 0-5ppm full scale to 0-1000ppm full scale. Measurements up to 20000ppm are possible using the on-board dilution function<br>• Measurement mode selectable between TC/NPOC (standard), TOC=TC-IC (optional) or TOC=POC+NPOC |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | NPOC(acidify/sparge removal of IC) and TC (standard). NPOC, TOC (TC-IC) (option). NPOC,TOC (TC-IC and POC + NPOC) (option) |
| **Source/URL:** | http://www.ssi.shimadzu.com/products/toc/index.cfm |
| **Other:** | |



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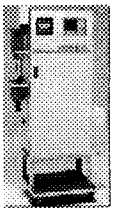
| **Instrument/Testing Kit:** | On-line Water Quality Analyzer |
| **Model/Product No.:** | TOCN-4110 |
| **Manufacturer:** | Shimadzu North America |
| **Description:** | TOC is used in a variety of applications from management of waste water treatment plant influent and effluent, to drinking water supply management and monitoring of impurities in process and natural waters. And the range of applications in which this type of on-line technology is used is expected to continue expanding.<br>Because nitrogen is considered to be one of the factors which contributes to the over-proliferation of organisms in enclosed bodies of water, management of these public water sources and of treatment plant influent and effluent also includes demand for monitoring of nitrogen levels.<br>• Process management for waste stream influent and effluent at treatment facilities.<br>• Operation management of all types of plant waters (i.e.: cooling water, recirculating water, boiler water, wash/rinse water, condenser water)<br>• Continuous monitoring of drinking/ process water, and natural water<br>• Continuous monitoring or organic contamination in water streams that must be reported to regulatory agencies. |
| **Features:** | • Automatic dilution expands the analysis range and allows the reduction in salt, acid and alkali concentrations to help reduce maintenance and extend catalyst life<br>• A complete line of options designated to accommodate samples with suspended particles, slime or seaweed reduces the occurrence of trouble and remedial maintenance in on-line TOC measurement.<br>• Optional multi-stream selectors allow analysis of 2 streams, or up to 6 different streams, of varying carbon concentrations.<br>• Measurement condition and measurement interval of each sample stream individual programmable<br>• User defined calibration check or re-calibration. Automatic calibration is incorporated using standard solutions stored on-board.<br>• On-board carrier/combustion gas purification allows use of air supplied from a compressor, thus eliminating expensive and potentially dangerous cylinder gases.<br>• Compact, unique water quality analyzer allowing both TOC analysis by combustion oxidation/ infra-red detection and TN analysis by the combustion/ chemiluminescence detection method in a single unit<br>• The TOC measurement range is from 0-5 ppm full scale to 0-1000 ppm full scale with the dilution function up to 20000 ppm<br>• The TN measurement range is from 0-5 ppm full scale to 0-200 ppm full scale with the dilution function up to 4000 ppm |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | NPOC (acidify/sparge removal of IC) and TC (standard). NPOC, TOC(TC-IC) (option). NPOC,TOC(TC-IC and POC+NPOC) (option) |
| **Source/URL:** | http://www.ssi.shimadzu.com/products/toc/index.cfm |
| **Other:** | |



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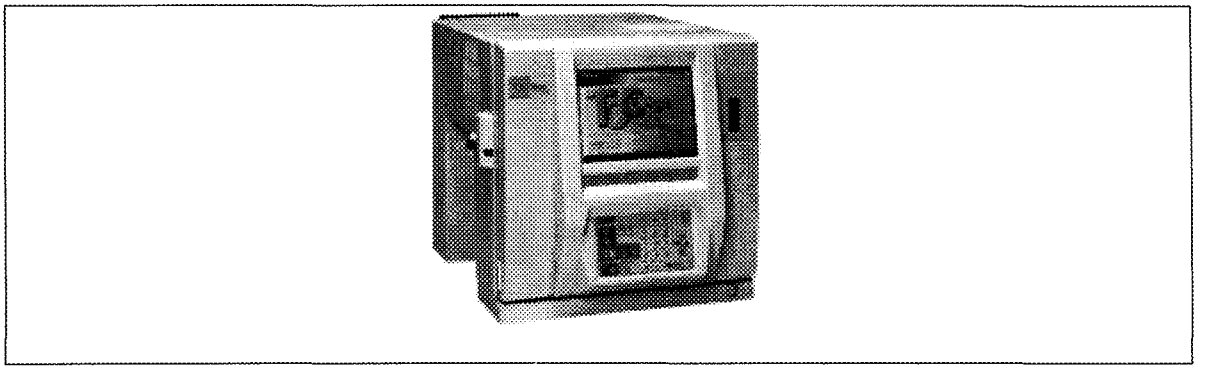
| **Instrument/Testing Kit:** | On-line TOC analyzers |
| **Model/Product No.:** | TOCvsh |
| **Manufacturer:** | Shimadzu North America |
| **Description:** | In addition to the high performance and advanced functions of the TOC-VCSH laboratory model, this ON-LINE TOC-VCSH is equipped with the functionality to perform continuous automatic sampling. It can be used in a wide range of applications to continuously monitor the water used in the pharmaceutical and semiconductor industries, as well as boiler water, mains water, and wastewater. The addition of this model further broadens the range of application of the TOC-V series. |
| **Features:** | The ON-LINE TOC-VCSH has inherited the high performance characteristics of TOC-V combustion-type models. These analyzers boast a wide range of organic substance detection capability based on 680°C combustion catalytic oxidation. In addition, the following features have been added:<br>• Fast measurement time, flexible measurement cycle settings, and automatic calibration functions<br>• Built in software for pharmaceutical water management applications<br>• Off-line measurement<br>• Data I/O functions – Measurement values output via an analog output circuit (capabilities: 4 to 20 mA, 0 to 16 mA, or 0 to 1 V) or digital data via an RS-232C port -- Measurement values and conditions can be output by a built-in printer or external printer. Alarm output functions: instrument status, instrument errors, and measurement value. External control using contact input signals (sample measurement, automatic calibration start/stop).<br>• Running costs can be reduced using optional inboard air purifier kit. (Applications above 1ppm)<br>• There are many applications where the ON-LINE TOC-VCSH's high sensitivity and the ability to detect all types of organic substances offer significant advantages: Quality control of raw water used in the food industry (food, drinks, etc.); Monitoring/Control of organic contaminates in process plant water systems (cooling water, recycled water, and boiler water); Monitoring/Control of organic-impurity in recycled water for cleaning systems. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Wide variety of measurement methods -- NPOC (TOC measurement by IC removal using acid sparging), TC (total carbon), and IC (inorganic carbon) measurements are all possible. Adding the optional TNM-1 allows continuous monitoring of TN (total nitrogen) in samples. |
| **Source/URL:** | http://www.ssi.shimadzu.com/products/toc/index.cfm |
| **Other:** | |



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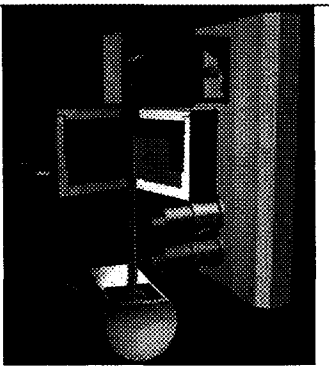
|---|---|
| **Instrument/Testing Kit:** | On-line Turbidimeter |
| **Model/Product No.:** | WTM500 |
| **Manufacturer:** | Sigrist |
| **Description:** | The WTM500, a turbidimeter for potable water applications, is the first of a new generation of low-maintenance instruments. Non-contact measurement of the 90° scattered light to DIN/EN 27027 / ISO 7027 in a free-falling water stream together with automatic adjustment using a fixed internal reference standard enhance measurement reliability and minimize cleaning and calibration chores. The nominal range covers 0 to 500 FNU in 8 scale ranges with a maximum resolution of 0.001 FNU. The SIREL control unit, with its two-line LC display and plain-text operator guidance, provides extremely easy access for operation, configuration and servicing. Outputs include one current output, two switching contacts and an optional RS485 interface.<br>These advanced features for reliable, low-maintenance turbidity measurement are offered exclusively by Sigrest:<br>• Non-contact measurement in a free-falling water stream -- Elimination of the flow cell and windows gets rid of dirt as a cause of falsified results and cuts out the need to clean regularly. One less maintenance chore!<br>• Automatic adjustment using a solid internal reference standard -- The formazine calibration is checked at regular intervals against a built-in solid reference, and any deviations are corrected automatically. To assure quality, the operator can check the calibration anytime merely by pressing a key.<br>• Nominal range 0.001 to 500 FNU -- The nominal range of 0.001 to 500 FNU in 8 automatically switchable scale ranges and a maximum resolution of 0.001 FNU is achieved with optimal stray light suppression, optical compensation features, and ultramodern, microprocessor-controlled electronics. |
| **Features:** | • Easy to service, high sensitivity, stability and accuracy<br>• Optical color compensation<br>• Non-contact free-fall flow cell: contamination-free<br>• Automatic adjustment using a fixed internal reference standard<br>• Wide nominal range<br>• Integral sample deaeration |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | turbidity |
| **Source/URL:** | http://www.johnmorris.com.au/html/Sigrist/wtm_500.htm |
| **Other:** | |



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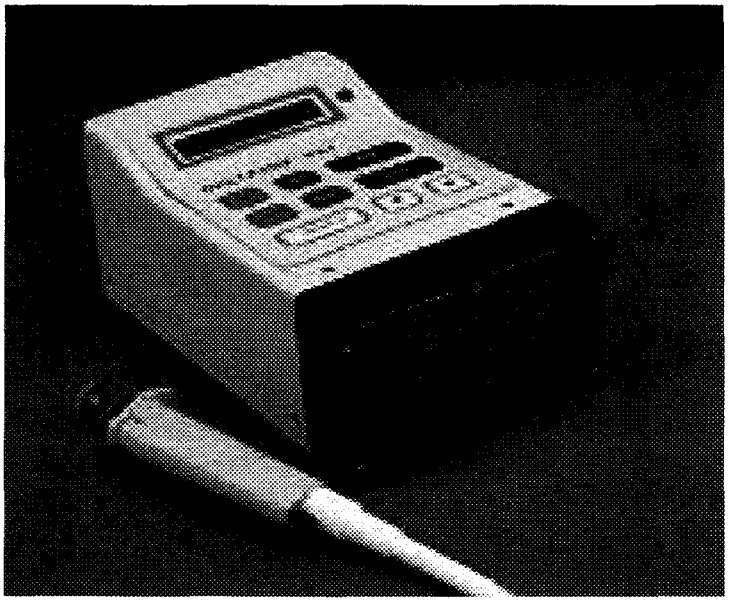
|---|---|
| **Instrument/Testing Kit:** | Deltatox® |
| **Model/Product No.:** | AZF50A000 |
| **Manufacturer:** | Strategic Diagnostics Inc. / Azur Environmental |
| **Description:** | The DeltaTox® Analyzer is a very sensitive analyzer for the measurement of light from the luminescent bacterial reagent. The luminescent bacterial reagent used in the DeltaTox® Analyzer is exactly the same as that used in the Microtox® Model 500. The Microtox® Model 500 has a temperature control for the bacterial reagent and the DeltaTox® Analyzer does not. The procedures used by the DeltaTox® Analyzer are simplified screening procedures used with the Microtox® Model 500. Since the DeltaTox® Analyzer does not have temperature controls its reproducibility is not as good as the screening procedures used with the Microtox® Model 500. |
| **Features:** | • Results available in minutes<br>• Broad range of toxins detected (∃2,000 compounds)<br>• Microbial detection level in drinking water (100 cfu/mL)<br>• Excellent correlation with HPC methods<br>• Inexpensive<br>• Portable |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Partial list: phenol, lead, arsenic, mercury, sodium cyanide, selenium, potassium cyanide, chromium, PR-toxin, copper, aflatoxin, ochratoxin, rubratoxin, chloroform, ammonia, sodium lauryl sulfate, benzoyl cyanide, lindane, DDT, cresol, formaldehyde, malathion, carbaryl, flouroacetate, trinitrotoluene (TNT), parathion, 4-phehnyl toluene, carbofuran, pentachlorophenol, patulin, paraquat, diazinon, cyclohexamide, cadmium, quinine, dieldrin |
| **Source/URL:** | http://www.sdix.com/PDF/Products/SDI_DeltaTox_Flyer%20color.pdf |
| **Other:** | |



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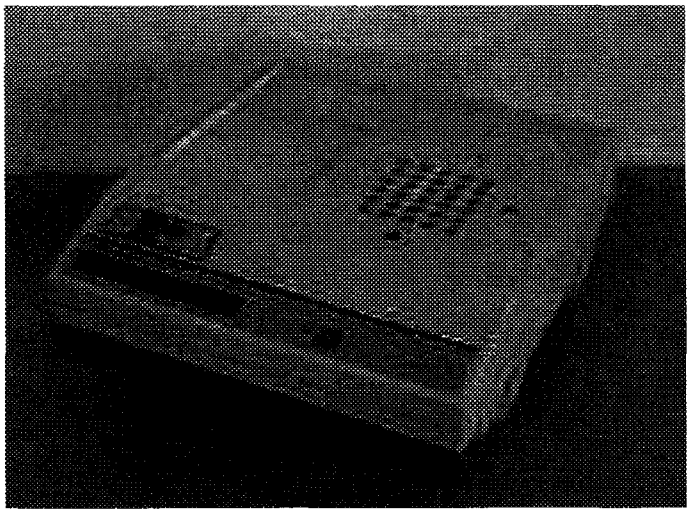
| **Instrument/Testing Kit:** | Microtox® |
| **Model/Product No.:** | Model 500/AZF848503 |
| **Manufacturer:** | Strategic Diagnostics Inc. |
| **Description:** | Microtox® is the worldwide standard for rapid and accurate toxicity monitoring. The use of living test organisms is the only way to reliably measure the toxicity of water. Microtox systems combine the advantage of whole-organism toxicity testing with the speed and precision of analytical instruments to produce a reliable test system that provides you with results quickly. The Microtox Test System is based upon the use of a luminescent bacteria *(Vibrio fischeri)*, to accurately measure toxicity from water and other environmental samples. Test data are generally available in about 30 minutes The Microtox Model 500 Analyzer is a laboratory-based temperature controlled photometer that maintains the luminescent bacteria reagent and test samples at optimum test temperatures. This self-calibrating instrument can also be used with MicrotoxOmni™ software and a PC to efficiently collect, analyze, track and store test data. |
| **Features:** | |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Microtox Acute Toxicity, Microtox Chronic Toxicity, Mutatox, ATP |
| **Source/URL:** | http://www.sdix.com/ProductSpecs.asp?nProductID=7 |
| **Other:** | |



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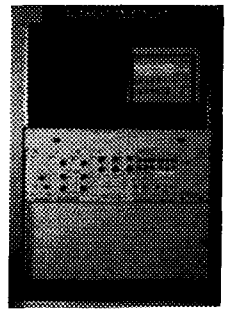
| **Instrument/Testing Kit:** | Drinking Water Rad-safety Monitor |
| **Model/Product No.:** | SSS-33-5FT |
| **Manufacturer:** | Technical Associates |
| **Description:** | The problem is that drinking water sources are vulnerable to accidental or knowing contamination by individuals, groups, industry, medical labs, terrorists and from naturally occurring radioactive materials (NORM). Very few water districts have real-time radiation monitors in place to protect the water and the public.<br>Model SSS-33-5FT solves this problem by continuously monitoring the water using both ion exchange resin beads and charcoal filter. The ion exchange resin collects and concentrates ions from dissolved metals, these are measured for activity by the 3" X 3" gamma spectrum detectors. The charcoal filter collects and concentrates any non-ionized stray chemical or particulate radioactives. The charcoal filter is monitored by a second scintillator. A final detector consists of crushed anthracene scintillation crystals through which the sample water flows. This detector measures alpha, beta and gamma from any non-ionized radioactive liquids. Measurements of radiation concentration and total discharge are logged 24hr/day 7day/week.<br>This sensitive, fail-safe system utilizes flow-thru, anthracene crystals and gamma detectors which continuously measure and record, concentration in microCuries/ml (or other units) and total microCuries. It uses its own metering pump and controller to measure, record and alarm based on the precise number of microCuries per minute which you have set it for. It stops when daily, monthly or annual limit is approached. Applications are:<br>• Monitor drinking water against any & all Radioactive contaminants<br>• Monitor for leaks in Candu / heavy water reactors<br>• Monitor for contamination in ground or surface water<br>• Monitor liquid-waste-stream from laboratory or plant |
| **Features:** | • real time, in-line, continuous<br>• true fail safe design<br>• no liquid scintillant<br>• easy calibration<br>• measures tritium to 100 picoCurie/ml<br>• plus 3" X 3" NaI, gamma spec channel |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | This detector measures alpha, beta, and gamma from any non-ionized radioactive liquids. |
| **Source/URL:** | http://www.tech-associates.com/dept/sales/product-info/sss-33-5ft.txt |
| **Other:** | |



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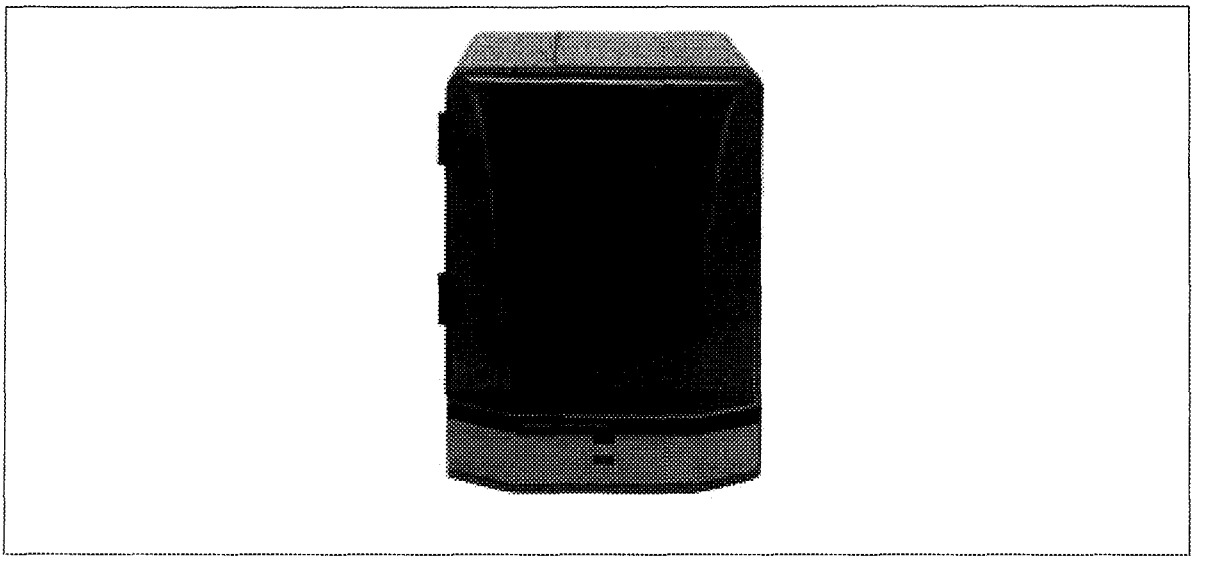
| **Instrument/Testing Kit:** | HS Combustion TOC Analyzer |
| **Model/Product No.:** | Apollo 9000 |
| **Manufacturer:** | Teledyne Tekmar |
| **Description:** | When throughput is critical, and your instrument must be dependable and durable to minimize downtown, the Apollo 9000 is your answer. The Apollo 9000 is best for applications requiring particulate analysis such as wastewater and industrial effluents, as well as drinking, surface, seawaters, brines and certain Clean-In-Place applications. This TOC technique has the characteristics of being effective for difficult to oxidize compounds such as proteins, particulates and samples with high chloride content.<br>For difficult particulate and brine applications, Apollo employs a unique self-rinsing TOC methodology that minimizes carryover and long-term maintenance. Rinsing sample transfer lines with clean water during each analysis ensures the best performance for your analyzer now and in the future.<br>Many applications require both TOC and TN analysis. To meet this need for our customers, Tekmar can provide an optional TN module with our Apollo 9000 line of TOC instruments. This compact module will measure TN simultaneously with TOC using a chemiluminescence detector and in accordance with water requirements such as EN-12260 and DIN-EN-ISO 11905-2.<br>To meet all your analytical needs, the Apollo 9000 has a flexible furnace temperature range. This wide analytical range makes the Apollo 9000 a must-have for your lab.<br>With the patented reusable platinum catalyst, the Apollo 9000 provides low detection limits while maximizing TOC recovery. |
| **Features:** | • Rugged and dependable for difficult applications<br>• Self-rinsing TOC methodology<br>• Total nitrogen capability<br>• Flexible furnace temperature<br>• Low detection limits |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.teledynetekmar.com/products/model_apollo.asp |
| **Other:** | |



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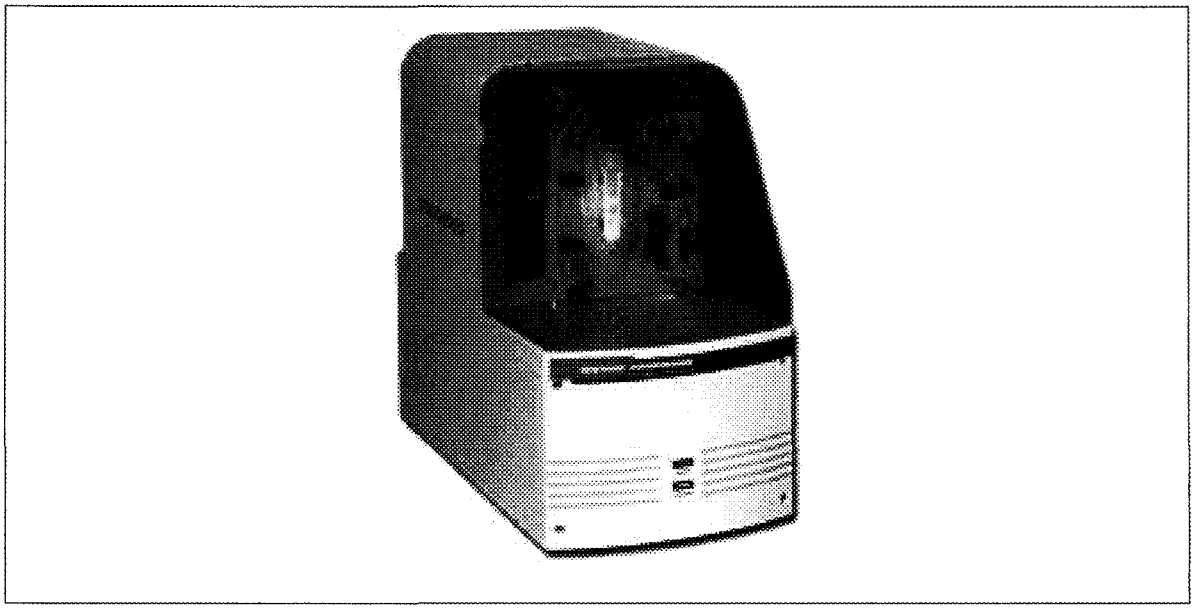
| **Instrument/Testing Kit:** | UV-Persulfate TOC Analyzer |
| **Model/Product No.:** | Phoenix 8000 |
| **Manufacturer:** | Teledyne Tekmar |
| **Description:** | With superior low-level detection, Phoenix 8000 is perfect for applications requiring high sensitivity such as drinking, pharmaceutical grade, Clean-in-Place, Water-for-Injection, ground, surface, semiconductor grade, steam power and ultra-pure water.<br>The UV persulfate method of TOC analysis technique achieves outstanding analytical accuracy, precision and long-term calibration stability due to its ability to inject high sample volumes (up to 20 mL) and low system background.<br>Virtually any component can be accessed in less than two minutes. Glassware is placed at the front of the unit for easy access and monitoring. Sample and gas lines are color coded for quick identification. Internal components are carefully laid out with the customer in mind. As a result, down time and cost of operation is kept to a minimum.<br>Arranged in three simple menus -- Setup, Run, and Results -- TOC Talk's user interface is easy to use. Set up system parameters and configure user preferences. Run predefined methods or customize your own. View, print, and export sample data and calibration curve results.<br>To help the industry comply with 21 CFR protocols, Tekmar offers software packages for CFR compliance for our line of TOC analyzers for use in monitoring Water-for-Injection and Clean-in-Place applications. |
| **Features:** | • Outstanding Accuracy, Precision, Calibration Stability<br>• Revolutionary Open Architecture Design<br>• Easy-to-Use TOC Talk Software<br>• 21 CFR Part 11 Compliant<br>• Reliable, High Throughput STS 8000 TOC Autosampler |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | TOC measurement |
| **Source/URL:** | http://www.teledynetekmar.com/products/model_phoenix.asp |
| **Other:** | |



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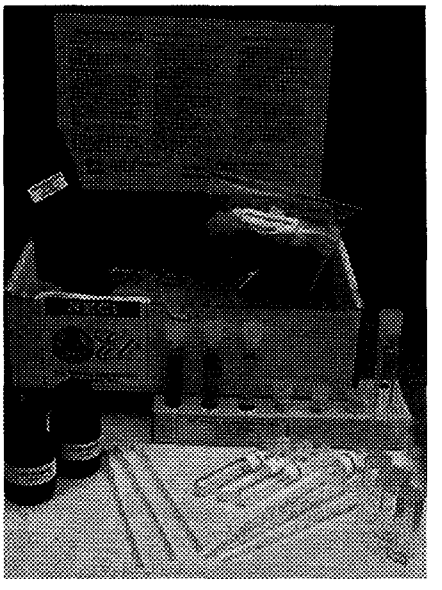
| **Instrument/Testing Kit:** | NECi Environmental Field Nitrate Test Kit |
| **Model/Product No.:** | F-NTK |
| **Manufacturer:** | The Nitrate Elimination Co., Inc. |
| **Description:** | Portable Field Nitrate Test Kits:<br>• Semi-Quantitative Results<br>• Accurate within 1 ppm NO3-N for Standard Range and 0.1 ppm for Low Range<br>• No Equipment Needed<br>• All Reagents Provided<br>• User Safe and Environmentally Friendly |
| **Features:** | • Easier to Use – Fewer Steps to Get Results<br>• Reagents Now Combined so You do Fewer Transfers<br>• Still Accurate, Reliable, Inexpensive and Safe<br>• Self-contained Kit -- Everything Provided<br>• F-NTK uses a Natural Process for Nitrate Testing!<br>• F-NTK is a "Sustainable" Product for Nitrate Testing |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | nitrate |
| **Source/URL:** | http://www.nitrate.com/fntk2.htm |
| **Other:** | |



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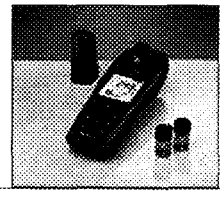
| **Instrument/Testing Kit:** | Portable Cyanide Analyzer |
| **Model/Product No.:** | AQUAfast® IV AQ4000 with AQ4006 Cyanide Reagents |
| **Manufacturer:** | Thermo Orion (Thermo Electron Corporation) |
| **Description:** | The Orion AQUAfast IV AQ4000 multi-wavelength colorimeter stores up to 189 pre-programmed methods. As new tet are available, a simple upload procedure updates the colrimeter with the most current programs. The upload takes but a few minutes and keeps the AQ4000 always current.<br>Thermo Electron introduces the Orion AQ4000 Advanced Field Colorimeter, packed with features which make water analysis as simple as 1, 2, 3:<br>• Place the sample in the Auto-TestTM cuvette,<br>• Position the cuvette in the AQ4000. The AQ4000 automatically identifies your species of interest,<br>• Read the result from the display.<br>The Orion AQ4000 features Auto-ID, which when used with Orion Auto-Test cuvettes, automatically identifies the species to be measured, selects the method, wavelength and reaction timer. The user never needs to push a button! The Auto-ID ensures the reagent is matched to the method.<br>The Auto-test cuvettes are specially designed to work with the Orion AQUAfast AQ4000 colorimeter. They take all the guesswork out of sample preparation because the reagent is pre-measured. The Auto-Test cuvettes are opened only when a measurement is about to be taken; reagent quality is never an issue.<br>The Orion AQUAfast IV AQ4000 can store up to 189 pre-programmed methods. As new tests are available, a simple upload procedure updates the colorimeter with the most current programs. The upload takes but a few minutes and keeps the AQ4000 always current.<br>This rugged and attractive unit is waterproof to IP67 standards. It is so advanced that a user can create a custom method and customize calibration. Up to 5 data points can be used to define a custom method. Ten custom methods can be stored in the colorimeter's memory. The simple interface steps a user through setup and measurement.<br>Selection of display units is push-button easy: concentration, absorbance or percent transmittance. Datalog 100 points in the field with a time and date tage and then download to a printer or computer in the lab. In addition to the Auto-Test cuvettes, the AQ4000 accepts round cuvettes with diameters of 13, 16 and 24 mm. Best of all, the Orion AQ4000 carries a two-year warranty! |
| **Features:** | |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | cyanide |
| **Source/URL:** | http://www.thermo.com/com/cda/product/ |
| **Other:** | |



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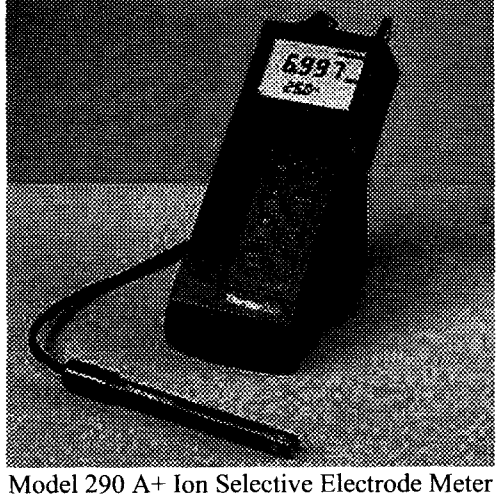
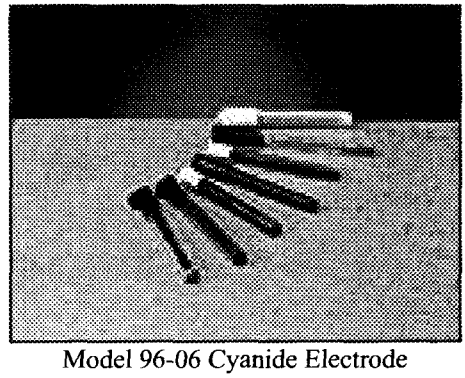
| **Instrument/Testing Kit:** | Portable Cyanide Analyzer |
| **Model/Product No.:** | Model 96-06 Cyanide Electrode (09606PR)<br>with<br>Model 290 A+ Ion Selective Electrode Meter (0290A4) |
| **Manufacturer:** | Thermo Orion (Thermo Electron Corporation) |
| **Description:** | The Orion 290Aplus adds concentration measurements and an internal datalogging function to make a truly versatile meter for pH or ISE analysis. Ideal for field, plant or laboratory use, each meter is lightweight and designed to fit comfortably in the hand.<br>The Orion 290Aplus portable, handheld ISE/pH meter is the ultimate portable meter for performing pH and concentration measurements. Perform up to a five point pH autocalibration, employing built-in buffer/temperature tables, automatic calculation and display of electrode slope value. Up to a five point concentration calibration can be performed with your choice of significant digits. Autoblank correction makes low level measurements easier. Blanks are automatically calculated and measurements are corrected based on your standards. Record results in the field using the internal datalogger, then transfer to the optional Orion 900A printer or computer via the bi-directional RS232 interface when you return to the laboratory. Replaceable battery, 9 V; order line adapter 020125 (110V), 020130 (220V) or 020135 (240V) separately.<br>New package of the 290Aplus meter and the Orion ionplus® 96-06 electrode to detect cyanide in drinking water for Homeland Security! |
| **Features:** | Product detail:<br>• 5 Point pH and Concentration Calibration<br>• 25 Point Internal Datalogger<br>• Autoblank Correction in Concentration<br>• Three (3) year meter warranty. |
| **Cost:** | Model 96-06 Cyanide Electrode (09606PR) -- $1,353<br>Model 290 A+ Ion Selective Electrode Meter (0290A4) -- $721.00 |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | cyanide |
| **Source/URL:** | http://www.thermo.com/com/cda/product/ |
| **Other:** | |



Model 290 A+ Ion Selective Electrode Meter



Model 96-06 Cyanide Electrode

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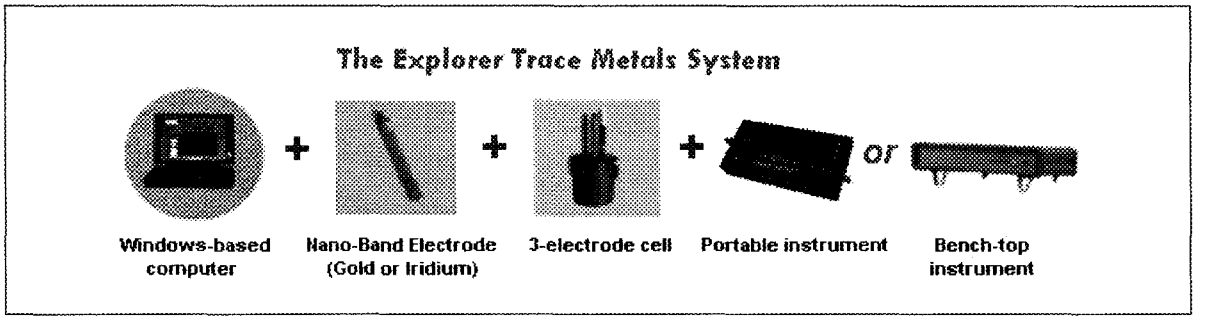
| **Instrument/Testing Kit:** | Arsenic Test Kit |
| **Model/Product No.:** | Nano-Band™ Explorer |
| **Manufacturer:** | TraceDetect |
| **Description:** | • Windows™-based computer: The Nano-Band™- Software runs on Windows 95 or later (including Windows ME) and Windows NT or later. The software displays, in real time, the results of each measurement. It performs calibrations and sophisticated analysis, and you can write measurements to a log file (convenient for importing into any database program).<br>• Nano-Band™ Electrodes: Patented Nano-Band™ Electrodes represent a breakthrough in electrochemical analysis: each Nano-Band electrode is an array of 100 sub-electrodes, each less than 0.5 microns thick. The increased mass transport rate allows ppb measurements in seconds, 10 to 30 times faster than ion-selective electrodes. Iridium electrodes measure Lead, Mercury, Copper, Zinc, Cadmium, Thallium, Bismuth, Tin, Antimony, Arsenic, and Silver Gold electrodes measure Arsenic<br>• 3- Electrode Cell: The 3-electrode cell combines a Nano-Band™ electrode (also referred to as the "working electrode" when used as part of an electrode cell) with a reference electrode and auxiliary electrode. The auxiliary and reference electrode work to manage the current as it is passed through the working electrode. The optional sample cup holds the 3-electrode cell in the stainless steel sample cup, and is a convenient way to work with the electrode cell in the field or on-site.<br>• Explorer Portable: The new Explorer Portable weighs only 8 ounces, and requires no power source: the USB connection to your Windows™ -based computer powers the system. Take it anywhere! It's optimized for trace metals analysis, and also provides researchers with many electrochemical techniques: Cathodic Stripping Voltammetry (CSV), Normal Squarewave Voltammetry, Amperometry, Cyclic Voltammetry (CV), temp, pH, conductivity, transient analysis, and long-term data logging.<br>• Explorer: The Nano -Band™- Explorer Instrument is optimized for trace metals analysis, and also provides researchers with many electrochemical techniques: Cathodic Stripping Voltammetry (CSV), Normal Squarewave Voltammetry, Potentiometric Stripping Analysis (PSA), Amperometry, Cyclic Voltammetry (CV), temp, pH, conductivity, transient analysis, and long-term data logging. |
| **Features:** | |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | arsenic |
| **Source/URL:** | http://www.tracedetect.com/products/products.htm |
| **Other:** | |


The Explorer Trace Metals System
Windows-based computer
Nano-Band Electrode (Gold or Iridium)
3-electrode cell
Portable instrument
or
Bench-top instrument

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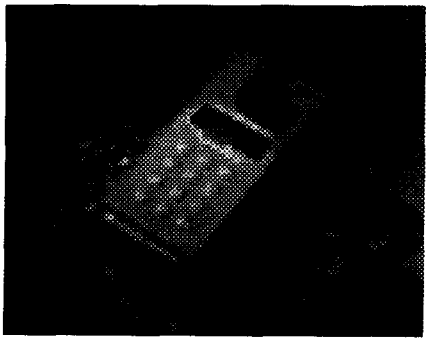
| **Instrument/Testing Kit:** | Fluorometer/Turbidimeter |
| **Model/Product No.:** | Aquafluor |
| **Manufacturer:** | Turner Designs |
| **Description:** | The Aquafluor™ is a lightweight, inexpensive, handheld fluorometer/turbidimeter. It is ideal for the user who needs quick measurements away from the laboratory. Its dual-channel capability allows the user to measure both fluorescence and turbidity in one sample.<br>Available in three models: in vivo chlorophyll a/turbidity, rhodamine WT/turbidity and ammonium/extracted chlorophyll a. While small in size, performance has not been compromised. The Aquafluor™ brings a new level of simplicity and economy to Turner Designs' line of fluorescence instrumentation. |
| **Features:** | • Sensitive: Can detect sub ppb levels for in vivo chlorophyll a, extracted chlorophyll a, and rhodamine WT, 0.1 mM ammonium, and 0.5 NTU turbidity.<br>• Dedicated Dual Channels: The press of one button easily toggles between the two applications.<br>• Compact: Small and lightweight, it easily slips into a shirt or jacket pocket and is easy to store when not in use.<br>• Watertight Design: No need to worry when measuring samples in the field. It even floats!<br>• Convenient: Uses AAA batteries (included), and with a 5-second warm up, the Aquafluor™ is ready any time.<br>• Three decade dynamic range. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | chlorophyll a, histamine, DO matter, ammonimum, cyanobacteria, DNA, RNA, LIVE/DEAD® BacLight™ Bacterial Viability Assay, alkaline phosphatase fluorescence |
| **Source/URL:** | http://www.flourimeter.com/ |
| **Other:** | |



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| **Instrument/Testing Kit:** | Self-contained Underwater Fluorescence Apparatus |
| **Model/Product No.:** | SCUFA |
| **Manufacturer:** | Turner Designs |
| **Description:** | Turner Designs extends its family of field and laboratory fluorometers with the introduction of the SCUFA™ Submersible Fluorometer. Available in chlorophyll a and rhodamine WT versions, the SCUFA™ is a versatile and easy-to-use in situ fluorometer with innovative features such as a simultaneous turbidity channel, analog and digital signal outputs, Windows interfacing software and automatic range control. Optional accessories, such as internal data logging, flow-through cap, and a solid calibration standard allows the SCUFA™ to be customized for your specific research needs. |
| **Features:** | • Typical temperature fluctuations in natural waters can result in significant changes in fluorescence values. The SCUFA, with its integrated temperature probe and software, automatically corrects fluorescence data of temperature effects.<br>• Turbidity can also cause errors in fluorescent readings. The SCUFA II and SCUFA III utilize a dedicated secondary channel for a turbidity measurement that provides valuable data for potential correlation and correction.<br>• User-selectable 0V and 5V values result in optimal range selection and improved resolution of analog data.<br>• Superior ambient light rejection eliminates the effects of sunlight and allows the SCUFA to be used in surface waters without the need for external pumps or light shields.<br>• The SCUFA's menu-driven software provides the interface for instrument configuration and data analysis. The software walks the user through easy-to-follow steps for functions such as calibration and data collection.<br>• The Auto-Ranging capability provides an extremely wide dynamic range, allowing the SCUFA to be used in dramatically different environments without manually changing gain settings or going over range.<br>• The SCUFA's solid secondary standard allows the user to verify instrument calibration quickly and easily and to re-calibrate if necessary.<br>• The optional Copper Anti-Fouling System enables unattended deployment for extended periods without the performance suffering from the effects of biofouling.<br>• 0-5V and RS-232 signal outputs are standard features, so the SCUFA can be mated to a variety of CTDs and data collection devices.<br>• Open optics eliminates the need for a pump, but a pump can be used with the optional flow-through cap.<br>• The SCUFA can be programmed for user-defined sampling rates and times with the purchase of the Internal Data Logging (IDL) Package. IDL also reduces power consumption through the use of Sleep Mode between sampling intervals. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | chlorophyll a and rhodamine WT versions |
| **Source/URL:** | http://www.flourimeter.com/ |
| **Other:** | |

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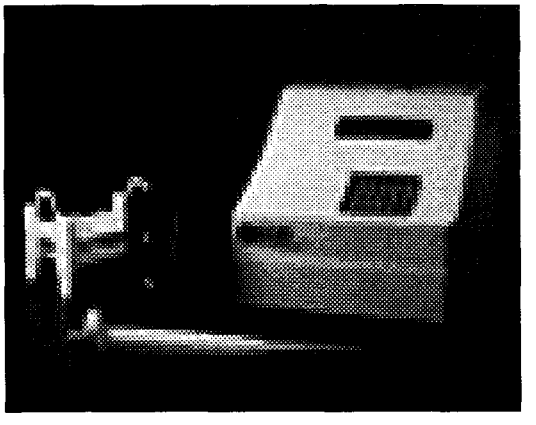
| **Instrument/Testing Kit:** | Laboratory Fluorometer |
| **Model/Product No.:** | TD-700 |
| **Manufacturer:** | Turner Designs |
| **Description:** | The TD-700 Laboratory Fluorometer is a compact, low-cost benchtop fluorometer that features a unique multi-assay filter cylinder, wide wavelength range, menu-driven software, and multi-point calibration. A variety of compounds can be easily measured using application-specific optical filters available from Turner Designs. |
| **Features:** | • Multi-Assay Filter Cylinder houses eight easily-changeable filters for four different applications.<br>• Wide wavelength range: measures fluorescence from UV to red range<br>• Automatic Range Optimization: range, gain, and resolution are set automatically - eliminates operator error from working in the wrong range.<br>• Multi-point calibration: stores a 1-to-5 point calibration curve for quantitative determinations.<br>• Kinetics Software: outputs data to a computer or printer at selectable intervals.<br>• Versatile Sample Compartment accommodates 25 x 150 mm round, 13 x 100 mm round, 10 x 10 mm square cuvettes, 100 µl minicell, or 9 µl microcell.<br>• Menu-Driven Software guides the user through calibration and analysis.<br>• RS-232 for serial data output to a printer or computer. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | fluorescence, turbidity in one sample; available in three models: in vivo chlorophyll a/turbidity, rhodamine WT/turbidity, ammonium/extracted chlorophyll a |
| **Source/URL:** | http://www.flourimeter.com/t2/instruments/td700.html |
| **Other:** | |



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| **Instrument/Testing Kit:** | In-situ Nutrient Analyzer |
| **Model/Product No.:** | NAS-2E |
| **Manufacturer:** | WS EnviroTech |
| **Description:** | The NAS-2E is an in-situ nutrient analyzer for high-frequency time-series determination of nutrient concentrations in marine and fresh waters. Four versions are available for the measurement of nitrate (and/or nitrite) phosphate, silicate and now ammonia. The NAS-2E is typically deployed unattended for periods of 60 days, although much longer deployments can be achieved. The NAS-2E may be used near surface in buoy and riverine applications or deployed at depths to 250m in taut-line mooring scenarios. The NAS-2E is a robust submersible wet-chemistry robot for nutrient analysis. The system utilizes a syringe pump and novel rotary valve to acquire and react discrete water samples. Once the reaction takes place the sample is injected into the colorimeter where optical beam attenuation is measured. An integral system controller drives the syringe and valve via stepper motors and records the colorimeter readings. Flexible user programmable controls make the system versatile. A macro language allows the operator to easily reprogram the complete chemistry analysis and sequencing. The analysis routines include blank measurements for turbidity and optical fouling. An on-board calibration standard is periodically analyzed to ensure the continuous integrity of the results. All raw data are recorded as voltages representing beam transmission through the sample within the colorimeter pathlength. The NAS-2E is extremely resistant to the effects of biofouling and high turbidity. The internal chemical system provides an environment with intrinsic anti-fouling characteristics and all the moving parts have been carefully designed to be self-cleaning. The pressure balanced design of the NAS-2E chemical system enable its deployment to depths of 250 m. Data may be downloaded to any PC or laptop computer and quickly converted to absobance units and nutrient concentration in either µMol or mg/l using NutrientDATA software supplied as standard. Deployments in excess of eight weeks are routinely achieved with the NAS-2E. Applications: phytoplankton blooms; eutrophication; TMDL assessment; monitoring run-off; detection of environmental change |
| **Features:** | • Captures episodic events and complex dynamics<br>• Enables greater understanding of ecosystem function<br>• Provides accurate high frequency nutrient data<br>• Allows cost-effective monitoring programs<br>• Reliability as the only field proven device of its kind |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Four versions are available for the measurement of nitrate (and/or nitrite) phosphate, silicate, and now ammonia. |
| **Source/URL:** | http://www.geosphera.com/OS_sensors.htm |
| **Other:** | |

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| **Instrument/Testing Kit:** | Portable Cyanide Analyzer |
| **Model/Product No.:** | Cyanide Electrode CN 501 with Reference Electrode R503D, (electrodes not discussed) and Multi-parameter handheld 340i |
| **Manufacturer:** | WTW Measurement Systems |
| **Description:** | WTW's rugged, waterproof handheld multiparameter meters allow the user to monitor and record several important water quality parameters with one instrument. SETs include all electrodes, calibration solutions, accessories, and maintenance supplies in a durable carrying case – a convenient all-in-one portable field laboratory. |
| **Features:** | **Multi 340i**<br>• Measure pH, mV, ORP, DO, % saturation, conductivity, salinity, temperature<br>• pH/DO/Temp or pH/Cond/Temp measured simultaneously<br>• Waterproof to IP 66 and IP 67<br>• RS 232 interface<br>• Datalogging and storage of 500 GLP data sets (pH, DO or Cond, temp, time, date, ID)<br>• SET includes meter, rubber meter casing, probe holders, neck strap, plastic body/gel electrolyte pH electrode (3 m cable), CellOx® 325 DO electrode (3 m cable), TetraCon® 325 conductivity cell (3 m cable), buffers, calibration solution, maintenance supplies, accessories, and field carrying case.<br>• Operates on line power or 4 x AA batteries<br>**Multi 340i SET includes**<br>• Multi 340i instrument and pH, DO, Conductivity probes • Professional case with built-in measurement stations, two electrode stands, two beakers, SM 325 protective armoring and carrying strap with two electrode holders<br>• Plug-in line power supply, calibration and maintenance supplies, operating instructions |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | pH, DO, temperature or pH, cond., cyanide |
| **Source/URL:** | http://www.wtw-inc.com/pages/product.html |
| **Other:** | |

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| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | 600 OMS |
| **Manufacturer:** | YSI Environmental |
| **Description:** | In response to the growing need for a low-cost, "single parameter" optical measurement system in a smart sonde, YSI has released the 600 Optical Monitoring System (OMS). The 600 OMS, developed from the 600 platform (1.6 in. dia.), can measure chlorophyll, rhodamine, or turbidity in combination with temperature, conductivity, and depth in fresh, sea or polluted water.<br>The 600 OMS utilizes the field-proven YSI 6136 turbidity sensor, YSI 6025 chlorophyll sensor or YSI 6130 rhodamine sensor, and incorporates innovations in sensor configuration such as a conductivity and temperature module that fits into the sonde body.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • ISO 7027 nephelometric method: turbidity<br>• Wiped optics: prevents fouling<br>• Ideal for long-term deployments<br>• Low power requirements<br>• Sensors (turbidity, rhodamine, and chlorophyll) are field replaceable<br>• Larger memory: 150,000 readings<br>• Integrate with DCPs<br>• EcoWatch™ for Windows™ data analysis software<br>• Compatible with YSI 650 MDS display/logger |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | chlorophyll, rhodamine, or turbidity in combination with temperature, conductivity, and depth in fresh, sea or polluted water |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |
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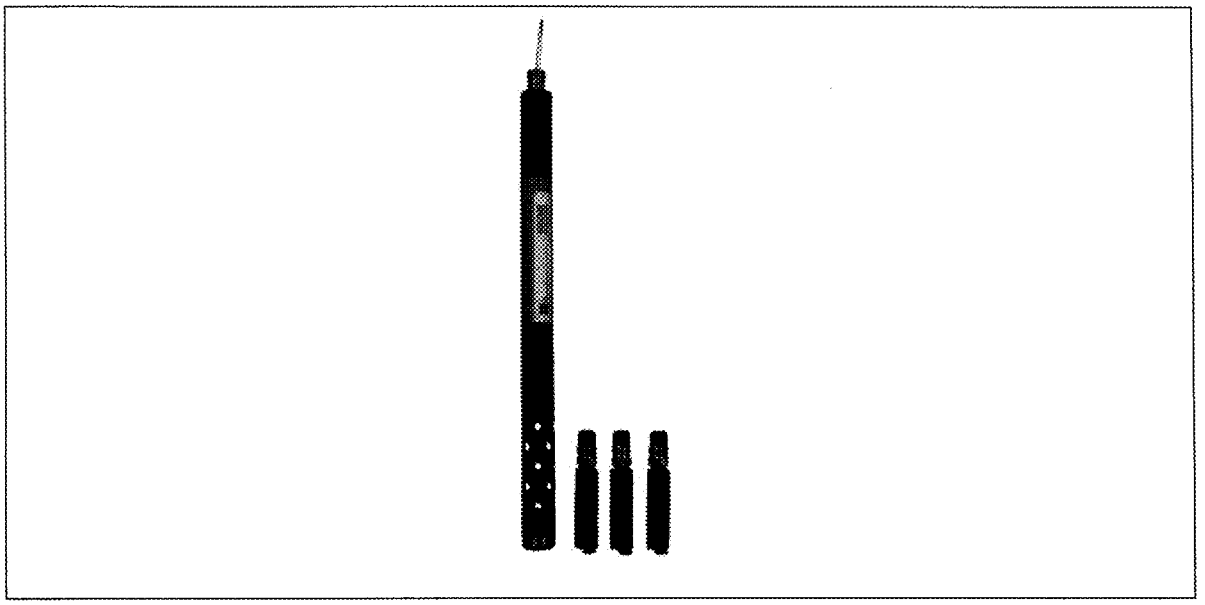

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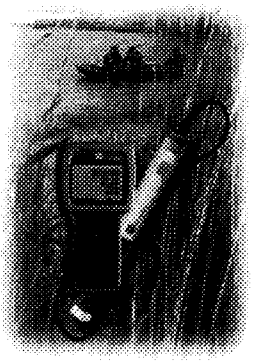
| **Instrument/Testing Kit:** | Multi-parameter Display-datalogger System |
| **Model/Product No.:** | YSI 600 QS (QUICK SAMPLE™) |
| **Manufacturer:** | YSI Environmental |
| **Description:** | Packaged for convenience, the combination of the YSI 650 MDS display-datalogger and the YSI 600R sonde allows you to collect 11 parameters simultaneously in real time. Designed for reliable field use, the 650 MDS features a waterproof IP-67, impact-resistant case, and utilizes internal, non-volatile flash memory that prevents data loss and stores 150 data sets. The 600R sonde is compact, submersible to 61m (200 ft) and employs YSI's unprecedented sensor reliability and parameter measurement systems. The 600QS provides a reliable way to quickly sample fresh, brackish, sea, and polluted waters. |
| **Features:** | • Rapid Pulse™ stirring-independent dissolved oxygen, accepted for compliance<br>• Collect 11 parameters simultaneously in real time<br>• Dissolved oxygen in mg/L, dissolved oxygen % saturation, temperature, conductivity, pH, ORP and depth are measured simultaneously<br>• Specific conductance, salinity, total dissolved solids and resistivity are calculated and displayed with measured parameters at the users descretion<br>• Small compact sonde fits easily into 2-inch wells<br>• Compatible with EcoWatch™ for Windows™ data analysis software<br>• Menu-driven, easy-to-use interface for 650 MDS and 600R to PC<br>• Sonde communicates via RS-232 to 650 MDS and PC, and via SDI-12 to data collection platforms.<br>• Easy-to-use sensor diagnostics that help insure accurate, high quality data acquisition<br>• Battery Life – With the standard alkaline battery configuration of 4 C-cells, the YSI 650 MDS will power itself and the sonde continuously for approximately 30 hours. Or, choose the rechargeable battery pack option with quick-charge feature.<br>• Optional GPS Interface – Designed to NMEA protocol, the YSI 650 MDS will display and log real-time GPS readings with a user-supplied GPS.<br>• Memory – Standard memory with 150 data sets with time and date stamp and can be downloaded to a PC via RS-232 interface. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | dissolved oxygen in mg/L, dissolved oxygen % saturation, temperature, conductivity, pH, ORP and depth are measured simultaneously |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |



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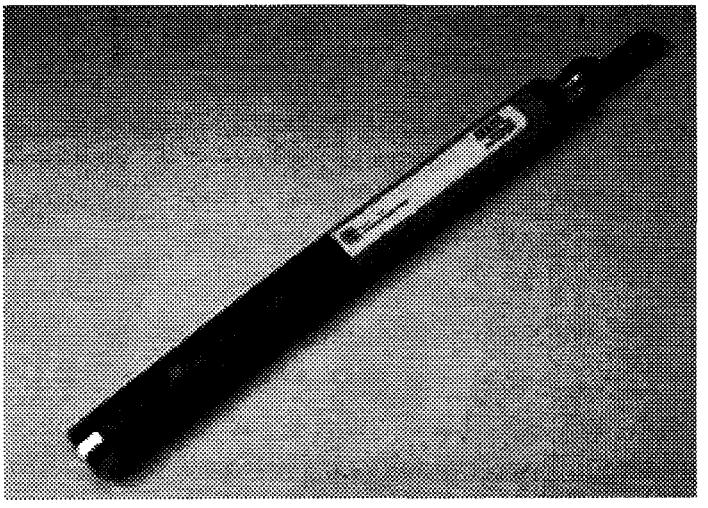
| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 600 R |
| **Manufacturer:** | YSI Environmental |
| **Description:** | The YSI 600R provides water quality sampling in a small package for both surface water and groundwater. With less than a 2-inch (4.2 cm) diameter, the 600R easily fits into wells. This sonde measures dissolved oxygen using the Rapid Pulse™ stirring-independent dissolved oxygen sensor, conductivity, temperature, and pH. The pH reference electrode is field-replaceable.<br>The YSI 600R interfaces with the YSI 6500 Environmental Process Monitor, the YSI 6200 Data Acquisition System, and many other data collection platforms for long-term unattended monitoring; and with the YSI 650 Multiparameter Display System for sampling.<br>YSI 6-Series sondes can be used with YSI EcoWatch for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. You'll see the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • Easily fits in a 2-inch well<br>• Measures dissolved oxygen, conductivity, temperature, and pH<br>• pH reference electrode is field-replaceable<br>• Can be used with YSI 650 Multiparameter Display System |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | dissolved oxygen, temperature, conductivity, salinity, pH |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |



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| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 600 XL |
| **Manufacturer:** | YSI Environmental |
| **Description:** | Measure up to six water quality parameters, including water level that is vented to the atmosphere. Achieve an unprecedented accuracy of ±0.01 feet from 0 to 10 feet, ±0.06 feet from 10 to 30 feet.<br>Connect the YSI 600XL easily to the YSI 6200 Data Acquisition System, the YSI 6500 Environmental Process Monitor, or the YSI 650 Multiparameter Display System.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • Small, compact instrument easily fits into 2-inch wells<br>• Salinity and total dissolved solids are also calculated parameters<br>• Stirring-independent Rapid Pulse oxygen sensor saves energy<br>• Measures to depths of 200 feet (61m)<br>• CE compliant |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | dissolved oxygen, temperature, conductivity, ORP, salinity, vented level, depth, pH, TDS, specific conductance |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |

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| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 600 XLM |
| **Manufacturer:** | YSI Environmental |
| **Description:** | The YSI 600XLM provides economical logging in a small package for both surface water and groundwater. It easily fits into 2-inch wells and measures a range of fundamental parameters, including oxygen with the YSI Rapid Pulse™ stirring-independent dissolved oxygen sensor, and level using a highly accurate vented sensor.<br>The YSI 600XLM will log all parameters at programmable intervals and stores 150,000 readings. At 15-minute intervals, it will log data for about 30 days.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • Measures dissolved oxygen, conductivity, temperature, pH, ORP and vented level or depth<br>• Logs all parameters at programmable intervals and stores 150,000 readings<br>• Logs data for about 30 days at 15-minute intervals<br>• Probes are field-replaceable<br>• Salinity and total dissolved solids are also calculated parameters<br>• Stirring-independent dissolved oxygen sensor<br>• Measures to depths of 200 feet<br>• Easy-to-change internal batteries<br>• CE compliant |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/Sampled:** | dissolved oxygen, open-channel flow, temperature, conductivity, vented level, salinity depth, ORP, pH |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |
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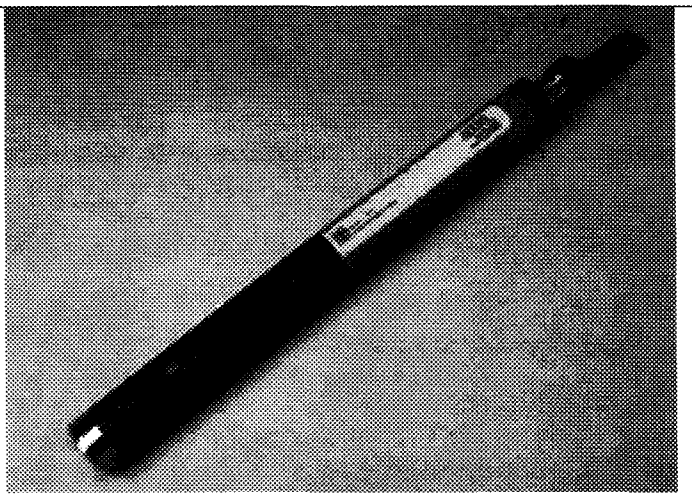

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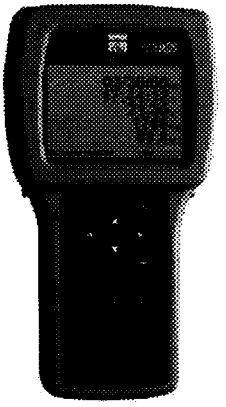
| **Instrument/Testing Kit:** | Multi-parameter Display-datalogger System |
| **Model/Product No.:** | YSI 650 MDS |
| **Manufacturer:** | YSI Environmental |
| **Description:** | Rugged and Reliable Display and Data Logging System. Log real-time data, calibrate YSI 6-series sondes, set-up sondes for deployment, and upload data to a PC with the new, feature-packed YSI 650 MDS (Multiparameter Display System). Designed for reliable field use, this next generation display and data logger features a waterproof IP-67, impact-resistant case. |
| **Features:** | • Compatible with EcoWatch ™ for Windows ™ data analysis software<br>• User-upgradable software from YSI's website<br>• Menu-driven, easy-to-use interface<br>• Three-year warranty<br>• Battery Life – With the standard alkaline battery configuration of 4 C-cells, the YSI 650 will power itself and a YSI 6600 sonde continuously for approximately 30 hours. Or, choose the rechargeable battery pack (YSI Part # 6118) option with quick-charge feature.<br>• Optional Barometer – Temperature-compensated barometer readings are displayed and can be used in dissolved oxygen calibration. Measurements can be logged to memory for tracking changes in barometric pressure.<br>• Optional GPS Interface – Designed to NMEA protocol, the YSI 650 MDS will display and log real-time GPS<br>readings with a user-supplied GPS interfaced with YSI 6-series sondes.<br>• Memory Options – Standard memory will allow for approximately 150 field readings. Exact logging capacity is dependent on the number of active parameters in the 6-series sonde. Optional high memory (1.5 mB) would make it possible to easily upload the data from 7 sondes, each of which have data files in excess of 200 kB or approximately 75 days at a 15-minute sampling interval. |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | handheld, rugged, waterproof display for all 6-series sondes |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |



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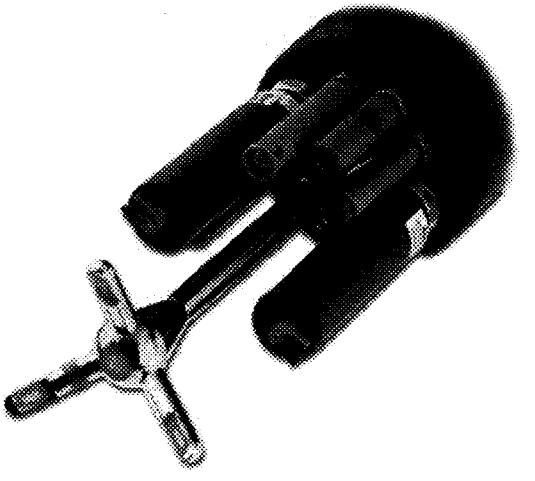
| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI ADV6600 Sonde |
| **Manufacturer:** | YSI Environmental |
| **Description:** | YSI is pleased to introduce the ADV6600. The ADV6600 water quality monitor combines the acoustic Doppler velocity (ADV) capability of the established SonTek Argonaut$^{R}$ ADV instrument with the highly accurate water quality sensors in the YSI multiparameter sondes. This powerful instrument has the capability to measure DO, conductivity, temperature, pH, ORP, pressure, velocity, direction, turbidity, chlorophyll, rhodamine, chloride, ammonia, and nitrate along with calculated parameters such as specific conductance and salinity.<br>The ADV6600 interface will be accessible via the highly powerful software; ADVantage 6600. Perfect for estuary monitoring! |
| **Features:** | • Measure multiple parameters simultaneously and internally log data<br>• Acoustic Doppler Velocimeter provides accurate, high-precision water velocity measurements<br>• Ideal for extended, long-term deployments and multiple sampling strategies<br>• Integrated compass/tilt and pressure sensor<br>• Automatic sound speed compensation<br>• Acoustic altimeter<br>• Integrates with DCPs (RS232 and SDI-12) |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | dissolved oxygen, conductivity, temperature, pH, ORP, pressure, velocity, direction, turbidity, chlorophyll, rhodamine, chloride, ammonia, and nitrate along with calculated parameters such as specific conductance and salinity |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |



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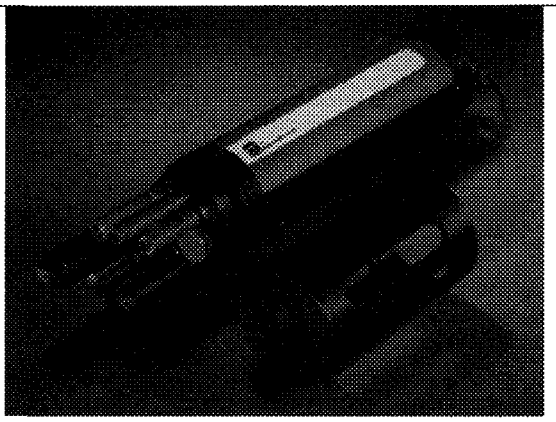
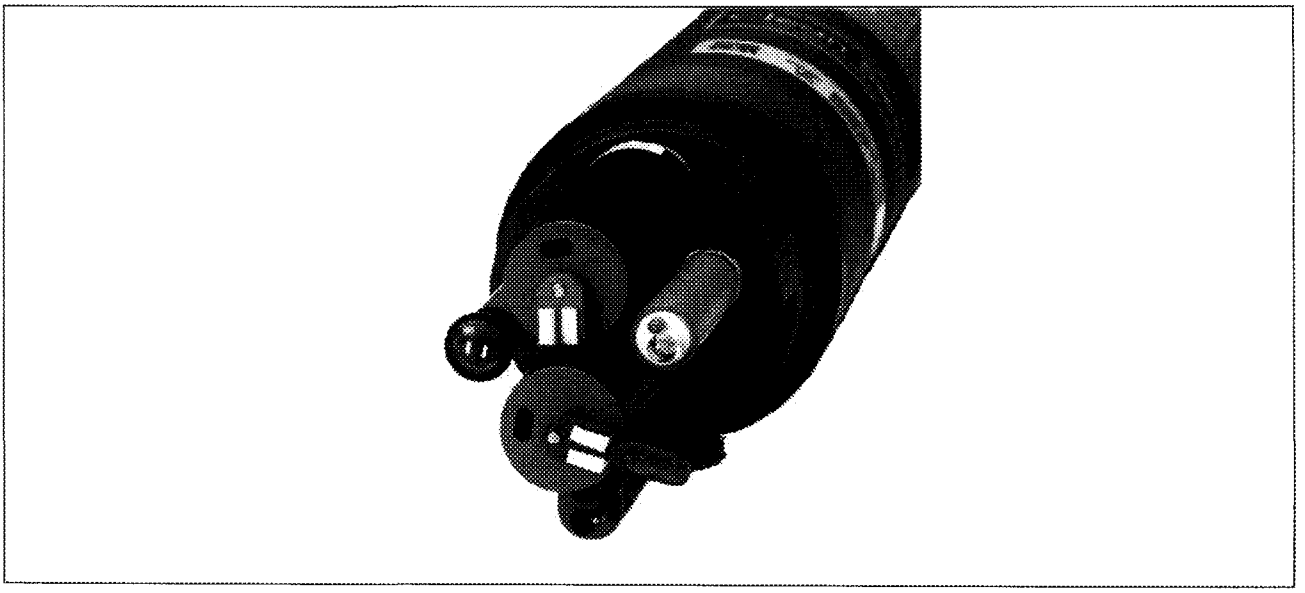
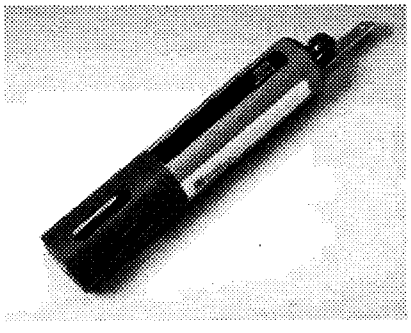
| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 6600 Sonde |
| **Manufacturer:** | YSI Environmental |
| **Description:** | The YSI 6600, YSI's newest multiparameter instrument, is designed for long-term *in situ* monitoring and profiling. This sonde offers the longest battery life and the largest probe configuration of any YSI 6-Series Sonde. It is the only YSI instrument that can be deployed to 656 feet (200 meters). It contains two optical port for chlorophyll, turbidity, or rhodamine.<br>The YSI 6600 uses standard YSI 6-Series probes, including YSI's Rapid Pulse™ stirring-independent dissolved oxygen sensor, and self-cleaning turbidity which is not affected by variations in ambient light.<br>It will log all of the parameters at programmable intervals and store 150,000 readings. At 15-minute intervals, it will log data unattended for about 75 days.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • Measures all parameters<br>• Longest Battery Life - 75 days!<br>• Deepest Depth - 200 Meters (656 Feet)!<br>• Largest Memory - stores up to 150,000 readings!<br>• New parameter - open-channel flow<br>• Two optical ports<br>• All probes are field replaceable and usable with all YSI 6-Series sondes (except the YSI 600R)<br>• Will log up to 15 parameters every 15 minutes for about 75 days<br>• Instrument software is included in both English and French<br>• CE compliant |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | dissolved oxygen, open-channel flow, temperature, TDS, rhodamine, chlorophyll conductivity, vented level, specific conductance, nitrate-nitrogen, ammonium-nitrogen, ammonia, turbidity, chloride, salinity, depth, ORP, pH |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |
| | |

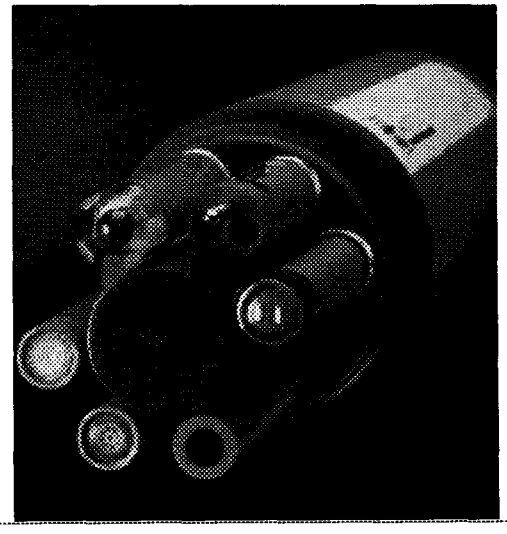


| | |
|---|---|
| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 6600 EDS (Extended Deployment System) |
| **Manufacturer:** | YSI Environmental |
| **Description:** | Building upon the unprecedented accuracy and reliability of YSI's *stirring independent* Rapid Pulse™ dissolved oxygen system, as well as on the improved and proven wiped turbidity sensor, YSI, Inc. has produced the 6600 EDS (Extended Deployment System). The 6600 EDS provides the monitoring community with a multiparameter sonde capable of accurately measuring 10 parameters in severe fouling environments for extended periods.<br>Initial field studies of the 6600 EDS indicate that the system provides DO accuracy in aggressive fouling environments.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • Provides unprecedented DO accuracy and longevity in aggressive fouling environments<br>• Wiped fouling protection for turbidity, chlorophyll, DO, pH and ORP sensors<br>• Ideal for extended, long-term deployments<br>• Virtually maintenance free<br>• Sensors are field-replaceable<br>• Integrates with DCPs |
| **Cost:** | |
| **Maintenance Requirements:** | The Rapid Pulse™ DO sensor performed within specifications throughout this deployment *without* the need for recalibration or cleaning. During this deployment the 6600 EDS was removed once for battery replacement; none of the sensors were cleaned or recalibrated. |
| **Parameters Observed/ Sampled:** | temperature/conductivity, turbidity, Rapid Pulse™ dissolved oxygen sensor, chlorophyll, pH/ORP |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |
| | |

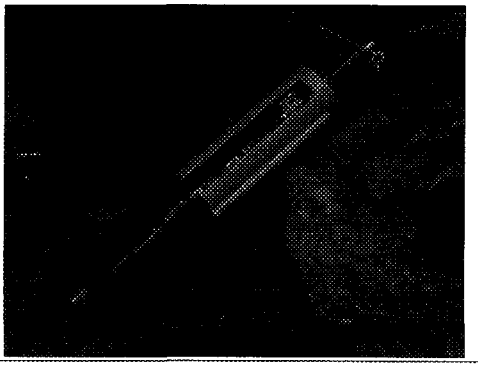


| | |
|---|---|
| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 6820 |
| **Manufacturer:** | YSI Environmental |
| **Description:** | A cost-effective sampling system with 14-parameter reporting capability, the YSI 6820 is ideal for profiling and spot-checking in lakes, rivers, wetlands, wells, estuaries, and coastal waters. The YSI 6820 measures nine parameters simultaneously, including dissolved oxygen, using the YSI Rapid Pulse™ stirring-independent sensor and turbidity or chlorophyll, using a sensor with a self-cleaning feature for long deployments, or a standard sensor for simple sampling. Even though the YSI 6820 is small in size it is designed to sink without additional weight.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features:** | • RS-232 and SDI-12 are standard; the YSI 6820 easily interfaces with a YSI 6200 Data Acquisition System, many other data collection platforms for long-term deployment, or a YSI 650 Multiparameter Display System for sampling.<br>• Retrieve data on-site or remotely via radio, phone or satellite.<br>• Ideal for sampling<br>• Easy connection to the YSI 650 Handheld Multiparameter Display System or YSI 6200 Data Collection Platform<br>• Field-replaceable probes<br>• CE compliant |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Water Quality Parameters Observed/Sampled:** | dissolved oxygen, temperature, conductivity, TDS, vented level, nitrate-nitrogen, chlorophyll, rhodamine, ammonium-nitrogen, specific conductance, ammonia, turbidity, chloride, salinity, depth, ORP, pH |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |





| | |
|---|---|
| **Instrument/Testing Kit:** | Multi-parameter probe |
| **Model/Product No.:** | YSI 6920 |
| **Manufacturer:** | YSI Environmental |
| **Description:** | A cost-effective logging unit rated at 200 feet, the YSI 6920 can monitor up to 14 parameters simultaneously, including oxygen with the YSI Rapid Pulse™ stirring-independent sensor and turbidity sensor not affected by variations in ambient light that has a self-cleaning feature. A self-cleaning chlorophyll sensor may be installed instead of the turbidity sensor.<br>The YSI 6920 is an economical logging system for long-term, *in situ* monitoring and profiling. It will log all parameters at programmable intervals and store 150,000 readings. At 15-minute intervals, it will log data for about 30 days.<br>Battery cells in a sealed compartment provide up to 3-months deployment (depending upon number of parameters). Non-volatile flash memory (384K) prevents data loss. RS-232 and SDI-12 are standard; the unit interfaces with the YSI 6200 Data Acquisition System, your own data collection platform, or a YSI 650 Multiparameter Display System for long-term deployment. Retrieve data on site or remotely via radio, phone, or satellite.<br>All the YSI 6-Series sondes can be used with YSI EcoWatch® for Windows software. EcoWatch is communication and data processing software that is fast and easy-to-use. See the whole picture with a single program, obtain statistics easily, merge data files, and run large studies. |
| **Features** | • Provides unprecedented DO accuracy and longevity in aggressive fouling environments<br>• Wiped fouling protection for turbidity, chlorophyll, DO, pH and ORP sensors<br>• Ideal for extended, long-term deployments<br>• Virtually maintenance free<br>• Sensors are field-replaceable<br>• Integrates with DCPs |
| **Cost:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | dissolved oxygen, open-channel flow, temperature, conductivity, vented level, nitrate-nitrogen, rhodamine, TDS, specific conductance, chlorophyll, ammonium-nitrogen, ammonia, turbidity chloride, salinity, depth, ORP, pH |
| **Source/URL:** | http://www.ysi.com/ |
| **Other:** | |



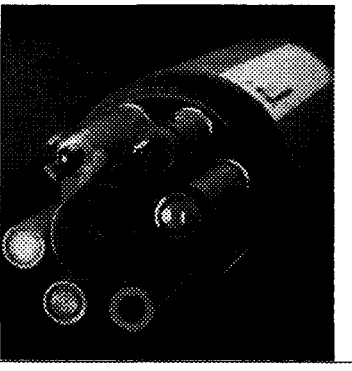


**Table A.2:** Database of experimental-stage instruments.

| | |
|---|---|
| **Title/Project:** | Heterogeneous Integration of CdS filters with GaN LEDS for Fluorescence Detection Microsystems |
| **Author(s):** | Chediak, J.A., L.Zhongsheng, S Jeonggi, N. Cheung, L.P. Lee, T. D. Sands |
| **Organization:** | Purdue University |
| **Abstract:** | Microassembly of a hybrid fluorescence detection microsystem by heterogeneous integration of a CdS thin-film filter, an (In,Ga)N thin-film blue LED, and a disposable PDMS microfluidic device onto a Si PIN photodetector substrate is described. The CdS thin film filter was deposited directly onto a photodetector by pulsed-laser deposition. A thin-film (In, Ga)N LED was then transferred by a novel "pixel-to-point" laser lift-off process from the sapphire growth substrate to the silicon photodetector substrate. The final integrating step was achieved by positioning a disposable polymer microfluidic device onto the excitation/detection subsystem. Pixel-to-point transfer is potentially an enabling microassembly process for the fabrication of multicolor fluorescence-based bioassays and chemical detection microsystems. |
| **Citation:** | Volume 111, Issue 1, Pages 1-144 (1 March 2004) – Micromechanics section of Sensors and Actuators, based on contributions revised from the Technical Digest of the 16th IEEE International conference on Micro Electro mechanical Systems (MEMS 2003) |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | fluorescence |
| **Source/URL:** | http://news.uns.purdue.edu/UNS/html4ever/2004/040212.Sands.detector.html |
| **Other:** | |

| | |
|---|---|
| **Title/Project:** | MEMS Bio-Chemical Transducer -- Calorimetric MEMS Sensor Array Platform |
| **Author(s):** | Britton, C. L. |
| **Organization:** | Oak Ridge National Laboratory |
| **Abstract:** | In response to the growing interest in the areas of non-homogeneous chemical reactions and microsensors, we propose a revolutionary approach to signal transduction in which we not only sense chemical reactions with a fine-mesh pixilated array (200 μm pixel spacing), but also control the local reaction rates with the mesh elements. This combines our expertise in the areas of CMOS integrated circuit processing, MEMS fabrication, chemical and biochemical sensing, and advanced theoretical chemistry. This technology will provide an interface between conventional ICs and chemical and biochemical reactions by not only monitoring, but also providing highly localized control of the reactions. Direct application to a variety of sensor requirements as well as fledgling disciplines including bioelectronics will be feasible. We intend to develop this concept as an integrated circuit and then apply it in two areas: (1) sensing and control of chemical and biological reactions such as those produced by glucose and cholesterol; and (2) real-time analyses of non-linear oscillating chemical reactions. This technology has been issued U. S. Patent No. 6,436,346 (August, 2002).<br>Numerous applications of such an integrated thermometric array can be envisioned.<br>Biological macromolecules, such as proteins or nucleic acids, could be directly attached to these structures and their reactivity directly monitored and controlled. Specific micro-sensors for glucose or cholesterol could be created for blood monitoring. Antibodies could be attached for sensing of particular metabolites for pharmacological dose monitoring or even for detection of biowarfare agents. Additionally, this may have eventual application to chemical or biochemical logic devices where reaction states can be switched and monitored in parallel. This can also be useful for directed, *in-situ* microsynthesis. Libraries of chemical compounds could be constructed and functionally assessed enabling, for example, rapid drug discovery, materials research, or advanced catalyst development.<br>Features:<br>• MicroSensor Array – Tens of sensors on a single substrate<br>• Capable of mapping inhomogeneous reactions<br>• General analytical utility<br>• Variety of applications – vapors, catalysis, biochemicals, pharmaceuticals |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | (1) sensing and control of chemical and biological reactions such as those produced by glucose and cholesterol; and (2) real-time analyses of non-linear oscillating chemical reactions |
| **Source/URL:** | http://www.ornl.gov/sci/eere/PDFs/Calorimetric MEMS FactSheet.pdf |
| **Other:** | |

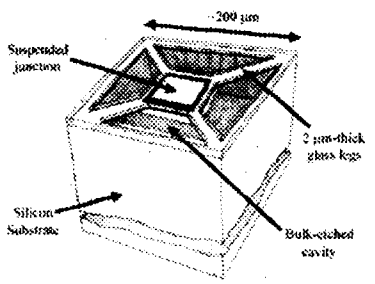



Figure 1. Single element of a bulk-etched thermal sensor array

| | |
|---|---|
| **Title/Project:** | Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting |
| **Author(s):** | Wagner, R. J., H. C. Mattraw, G. F. Ritz, and B. A. Smith |
| **Organization:** | U.S. Geological Survey |
| **Abstract:** | The U.S. Geological Survey uses continuous water-quality monitors to assess variations in the quality of the Nation's surface water. A common system configuration for data collection is the four-parameter water-quality monitoring system, which collects temperature, specific conductance, dissolved oxygen, and pH data, although systems can be configured to measure other properties such as turbidity or chlorophyll. The sensors that are used to measure these water properties require careful field observation, cleaning, and calibration procedures, as well as thorough procedures for the computation and publication of final records. Data from sensors can be used in conjunction with collected samples and chemical analyses to estimate chemical loads. This report provides guidelines for site-selection considerations, sensor test methods, field procedures, error correction, data computation, and review and publication processes. These procedures have evolved over the past three decades, and the process continues to evolve with newer technologies. |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | temperature, specific conductance, dissolved oxygen, and pH data, although systems can be configured to measure other properties such as turbidity or chlorophyll |
| **Source/URL:** | |
| **Other:** | |

| | |
|---|---|
| **Title/Project:** | Real-Time Remote Monitoring of a Distribution System – A Case Study in Washington D.C. |
| **Author(s):** | Panguluri, S., R. M. Clark, and R. C. Haught |
| **Organization:** | |
| **Abstract:** | Following of the events of September 11, the newly created Water Protection Task Force (WPTF) of U.S. Environmental Protection Agency (USEPA) has conducted several studies to identify various areas of vulnerability so that appropriate measures can be implemented to protect the nations' water supplies. The preliminary reports indicate that WPTF has identified water distribution networks as a major area of vulnerability. Therefore, there is a need to predict and monitor the movement and concentration(s) of contaminants within distribution systems at various points in the network. Real-time monitoring when combined with network modeling can play a pivotal role in tracking and containing the spread of contaminant(s) through the distribution system.<br>However, establishing and maintaining a real-time monitoring network requires a through understanding of the various elements involved for implementing a real time monitoring system. This paper focuses on the lessons learned from a field real-time remote monitoring study conducted by USEPA in Washington DC. Although the focus of this field study was not security but, the lessons learned during this study will provide insights to the various steps involved in establishing a real-time network. This paper outlines: the steps involved in selecting an appropriate online real-time sampling system, the data acquisition system selection/setup criteria, security and dissemination of monitoring data and costs associated with the project. This paper also provides a brief narrative of the field problems encountered during the study. |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | This paper outlines: the steps involved in selecting an appropriate online real-time sampling system, the data acquisition system selection/setup criteria, security and dissemination of monitoring data and costs associated with the project. |
| **Source/URL:** | |
| **Other:** | |

| | |
|---|---|
| **Title/Project:** | Continuous Monitoring of Nitrate and Chlorophyll a in North Carolina Estuaries |
| **Author(s):** | Bales, J. D. |
| **Organization:** | U.S. Geological Survey |
| **Abstract:** | In September – October 1999, Hurricanes Dennis, Floyd, and Irene produced prolonged record flooding in eastern North Carolina. Floodwaters from coastal rivers severely affected the hydrologic and chemical characteristics of North Carolina's estuaries. Freshwater inflow to the Pamlico River estuary during September 1999, was more than 90 percent of the mean annual inflow, and September inflow to the Neuse River estuary was about 60 percent of average annual inflow. More than half the average annual nitrogen load was carried in floodwaters of the Neuse River and Tar River, which drains to the Pamlico River estuary, between mid-September and mid-October. The long-term effect of the nutrient and organic matter loading to the Pamlico River and Neuse River estuaries from these floods was a matter of great concern to water-quality and fishery resource managers in North Carolina.<br>For one year following the flooding, the U.S. Geological, in cooperation with the North Carolina Division of Water Quality, monitored the effects of the flooding on estuarine water quality while testing the application of advanced water-quality monitoring instrumentation. Two sites were established—one each on the Pamlico River estuary and the Neuse River estuary—and were equipped with sensors to measure near-surface and near-bottom nitrate concentration, fluorescence (chlorophyll *a* concentration), salinity, temperature, dissolved-oxygen, and pH. Nitrate and chlorophyll *a* were measured hourly and other parameters were measured at 15-minute intervals.<br>The new nitrate and chlorophyll sensors were challenging to operate in the estuarine environment, and there were several periods during which data were of unacceptable quality. Most of the nitrate data were collected during the spring and summer, when concentrations were low—typically less than the sensor detection limit of 0.07 milligrams per liter. Nitrate concentrations were greater than 0.1 milligrams per liter during June 2001 in the Neuse River estuary, when river flows were higher than normal. A statistically significant relation ($p < 0.05$) between fluorescence and sampled chlorophyll *a* concentration was developed for the Pamlico River estuary, but the relation was much weaker for the Neuse River estuary. The data are being analyzed to evaluate relations among freshwater inflow, nitrate concentrations, density stratification, dissolved-oxygen concentration, and algal production. |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Sensors to measure near-surface and near-bottom nitrate concentration, fluorescence (chlorophyll *a* concentration), salinity, temperature, dissolved-oxygen, and pH. Nitrate and chlorophyll *a* were measured hourly and other parameters were measured at 15-minute intervals. |
| **Source/URL:** | |
| **Other:** | |

| | |
|---|---|
| **Title/Project:** | Sequential Injection Analysis-based System for On-line Monitoring of Nitrite and Nitrate in Wastewater |
| **Author(s):** | Lapa, R. A. S., J. L. F. C. Lima, and I. V. O. S. Pinto |
| **Organization:** | Universidade do Porto |
| **Abstract:** | A sequential injection analysis system has been developed for on-line monitoring of nitrite and nitrate in wastewaters, based on the Griess-Llosvay reaction and spectrophotometrical measuring of the absorbance of 543 mm. Nitrate is previously reduced to nitrite in a copperized cadmium column and analyzed as nitrite. The proposed system is fully automatized and is able to monitor nitrite and nitrate, simultaneously, in samples at a frequency of about 24 samples per hour with a relative standard deviation (RSD) better than 2.0% for nitrite and 1.3% for nitrate. The calibration graph was linear between 0.05 – 25 mg $dm^{-3}$ for nitrite and 0.05 – 16 mg $dm^{-3}$ for nitrate. |
| **Citation:** | 2000, *Analytical Sciences*, 16:1157-1160 |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | nitrite and nitrate, simultaneously |
| **Source/URL:** | |
| **Other:** | |

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|---|---|
| **Title/Project:** | Continuous Water Quality Monitoring in Southern Kaneohe Bay: Linking Fluvial Nutrient and Sediment Inputs with Bay Water Quality and Reef Degradation |
| **Author(s):** | |
| **Organization:** | HCRI-RP (Hawaii Coral Reef Initiative Research Program) |
| **Abstract:** | Why do we need continuous monitoring? Water quality changes can be key contributors to degradation of coral reef ecosystems.<br>• Water quality changes associated with wind, waves, and especially storm runoff of fresh water and sediments may directly impact reefs<br>• Nutrient rich storm runoff may enhance the growth, spread, and persistence of macroalgae smothering reefs<br>• Development of coastal watersheds, especially urbanization, generally increases sediment and nutrient fluxes to coastal waters<br>Traditional manual sampling is poorly suited for monitoring reef ecosystems subject to rapid water quality changes.<br>• Grab samples are "snapshots" that cannot resolve short-term variability or capture infrequent, intermittent events<br>• Coastal ecosystems are not at steady-state, and responses to perturbations have inherent delays that decouple perturbations and responses. For example, Bay chlorophyll-a levels should be closely linked to nutrient supply, but analysis of grab-sampling results shows very poor correlation between nutrients and chlorophyll-a. Continuous monitoring can capture perturbations and responses, revealing the processes controlling ecosystem response |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | nutrients and chlorophyll-a |
| **Source/URL:** | |
| **Other:** | |

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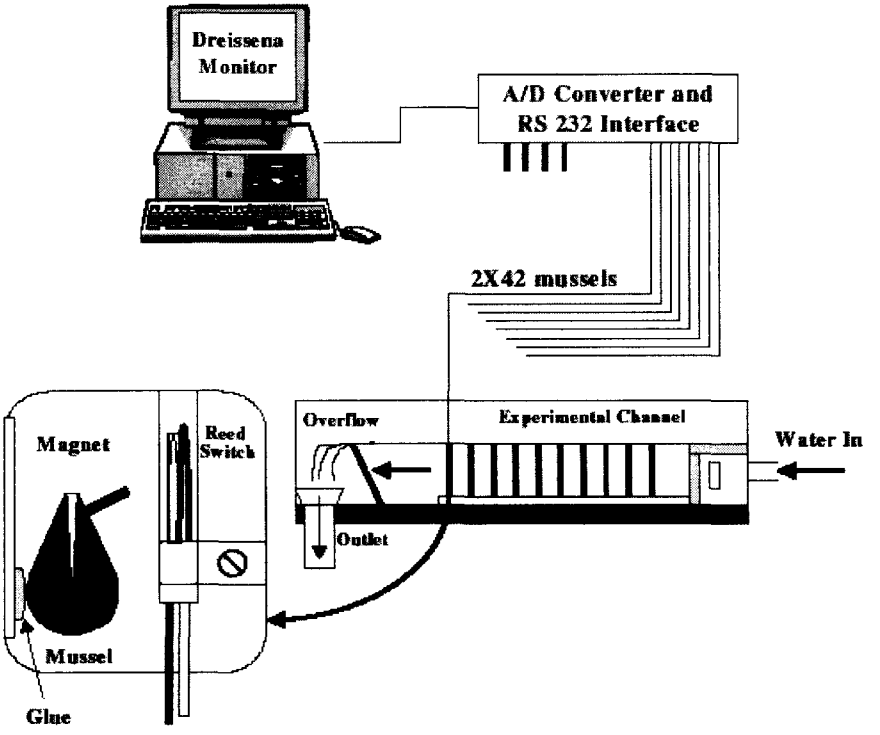
|---|---|
| **Title/Project:** | Use of Biosensors for Bacterial Water Quality Monitoring |
| **Author(s):** | McLaughlin, J. |
| **Organization:** | Ontario Forest Research Institute, Ontario Ministry of Natural Resources |
| **Abstract:** | • Presentation Outline: Biosensor application to water quality monitoring; biosensor technology, biosensor types, summary<br>• Biosensor Application: monitoring water quality in situ is critical to understand and manage risks to human health; Biosensors show great promise for in situ, real-time monitoring of water quality<br>• Biosensor Technology: Sensing element: enzymes, antibodies, DNA or RNA, microorganisms; Transducer: electrochemical, optical acoustic<br>• Biosensor Constraints in Water Quality Monitoring: Sensor sensitivity, selectivity, miniaturization/portability, robustness, instability of biological agents, drift in sensor signals<br>• Biosensor Types: Biocatalysis-based: requires use of enzymes; Bioaffinity-based: requires use of antibodies; Molecular biology-based: requires the use of DNA or RNA<br>• Advances in Biochemistry and Fiber Optics: Biochemical advances – expand the range of biological recognition elements; Fiber optic and microelectronic advances – expand the capability of signal transducers<br>• Summary: Biosensors show a great potential for identification and enumeration of microorganisms; Interfacing a biological assay to a signal transducer can reduce the time and complexity involved with microbial analyses; Biosensor technology provides a robust, cost-effective method for rapid detection and monitoring of biological agents; Further advances in genetics and miniaturized optics will impact future monitoring and detection strategies |
| **Citation:** | Presentation |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | enzymes, antibodies, DNA or RNA, microorganisms |
| **Source/URL:** | |
| **Other:** | |

| | |
|---|---|
| **Title/Project:** | Pattern Recognition – Laser Scattering for Low Cost Bacteria Identification and Counting in Water Treatment |
| **Author(s):** | Rodrigues, M.A., D. Cooper, L. Alboul, J. Penders, A. Chamski, and G. Chliveros |
| **Organization:** | Trident Management Ltd/Rusteck Ltd (UK); The University of York (UK; General Physics Institute (Moscow, Russia) |
| **Abstract:** | Water companies must ensure that the drinking water they provide is free from bacteria. Also, the bacteria content of wastewater must comply with current health and environmental regulations. Because determining precisely how much bacteria a water sample contains is difficult and time consuming, water companies currently use "worst case" methods to kill bacteria. These methods require large amounts of expensive chemicals and are environmentally unfriendly. Laser scattering can be used to determine the nature and the amount of bacteria in water samples through motion analysis. We are investigating an approach in which a laser beam directed through a water sample is used to determine the movement of particles in the sample as any moving particle will scatter the laser forming a picture of scattering. Because of light coherence, the resulting intensity at any point of the picture depends not only on laser intensity but also on phase relations between the scattered beams. If the scattered particles move in different directions and at different speeds the resulting intensity at each point of the picture will fluctuate in time. The more particles the higher the amplitude, and the faster the particles move the higher the frequency. The amplitude and frequency of intensity fluctuations can thus be measured and used to discriminate particle content in the sample. A laser scattering device operating according to the principle above has been patented by Rustek Ltd, the industrial partner in this project. We are investigating pattern recognition techniques for identification and counting of bacteria in water treatment using the Rustek equipment pursuing the ultimate aim of the water industry which is to detect one bacteria per 100ml of solution! The primary users of such technology are water companies, bottled water industry, brewery industry, and a large number of medical applications. |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | Laser scattering can be used to determine the nature and the amount of bacteria in water samples through motion analysis. We are investigating pattern recognition techniques for identification and counting of bacteria in water treatment using the Rustek equipment pursuing the ultimate aim of the water industry, which is to detect one bacteria per 100ml of solution! |
| **Source/URL:** | http://www.shu.ac.uk/scis/artificial_intelligence/biospeckle.html |
| **Other:** | |

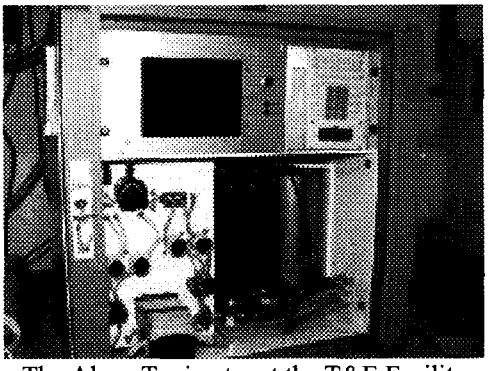
| | |
|---|---|
| **Title/Project:** | The "Dreissena-Monitor" – First Results on the Application of this Biological Early Warning System in the Continuous Monitoring of Water Quality |
| **Author(s):** | Borcherding, J. and M. Volpers |
| **Organization:** | |
| **Abstract:** | |
| **Citation:** | In: "Proceedings of the International Conference on the Rehabilitation of the River Rhine," Arnhem, March 1993, J. A. van de Kraats (Ed.); *Water Science Technology*, 29(3):199-201. |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | biological early warning system in the continuous monitoring of water quality |
| **Source/URL:** | |
| **Other:** | |



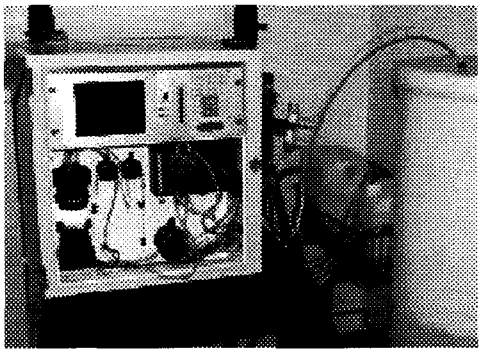

(Illustration from "AWWARF Online Seminar, Design of Early-Warning and Predictive Source-Water Monitoring Systems")

| | |
|---|---|
| **Title/Project:** | Drinking Water Early Warning Detection and Monitoring Technology Evaluation and Demonstration |
| **Author(s):** | VonderHaar, S. S., D. Macke, R. Sinha, E.R. Krishnan, and R. C. Haught |
| **Organization:** | IT Corporation and U.S. EPA |
| **Abstract:** | Drinking water sources have in recent years come under increasing scrutiny, with issues ranging from ecological impacts to public health and national security. In response to these concerns and facilitated by advanced electronics and fast computers, biomonitors are being developed that can assess the toxicity of water samples by monitoring living organism behavior. The U.S. EPA is currently in the process of conducting research on various biosensors at the U.S. EPA Test and Evaluation (T&E) Facility in Cincinnati, Ohio.<br>The purpose of this research is to evaluate and demonstrate the ability to reliably monitor source water quality using living biological organisms as sensors. Biological organisms such as *Daphnia magna (D. Magna)* change behavior dramatically from calm movement typically observed in non-polluted water to hyper-activity in water with certain pollutants. It is known that different organisms vary in their sensitivity to different substances. Other organisms, such as clams or algae, exhibit changes to various pollutants. The U.S. EPA is currently evaluating several sensors including a Daphnia Toximeter, Algae Toximeter, Clam Monitor and other Fish Monitors. These sensors measure subtle responses of these organisms and use the measured information to calculate a "toxicity index." The instrument can be set to provide "alert" and "alarm" status at predetermined toxicity index values or limits. Test pollutants that are being evaluated include cadmium, atrazine, and dieldrin. These investigations should provide the ability for real-time monitoring of the quality and safety of source water and watershed ecology. |
| **Citation:** | |
| **Maintenance Requirements:** | |
| **Parameters Observed/ Sampled:** | The instrument can be set to provide "alert" and "alarm" status at predetermined toxicity index values or limits. Test pollutants that are being evaluated include cadmium, atrazine, and dieldrin. |
| **Source/URL:** | http://www.nwqmc.org/NWQMC-Proceedings/Papers-Alphabetical%20by%20First%20Name/Rajib%20Sinha%20Early-Warning.pdf |
| **Other:** | |

Two of the four technologies the USEPA evaluated:



The Algae Toximeter at the T&E Facility



The Daphnia Toximeter at the T&E Facility

# 5.2 Candidate Instruments and Observables

Karl King, Terry Engelhardt, Kenneth Ogan
Hach Company, Loveland, CO

## 1.0 Introduction

The vast majority of our populace relies on a local water utility for delivery of clean, safe drinking water. Poisoning or contamination of this system would strike deep into our citizens' lives, potentially killing many and leaving the others without a source of a life essential. Consequently, our water infrastructure is a prime target for terrorist attack, and we must develop an effective means of thwarting such an attack. In this section we focus on means of rapidly detecting the occurrence of a biological or chemical attack on a water system, such that immediate steps could then be taken to limit the extent of public exposure, and limiting the extent of infrastructure contamination as well, in order to contain the amount of subsequent decontamination required.

Rapid detection of the introduction of a toxic agent is a significant challenge – on two fronts. First, the growing list of potential threat agents spans a wide range of chemical and biological characteristics, which requires analytical systems with high flexibility and diverse detection capabilities. Second, because most experts agree it is the water distribution system that is the most likely point of attack (rather than a large reservoir ), a large number of these analytical systems need to be deployed throughout the distribution system, requiring that they be field capable (rugged, unattended operation), and relatively inexpensive.

The number and variety of potential agents presents a significant challenge – while sophisticated systems that could accomplish detection across the range do exist, these require multiple runs under varying conditions, highly trained operators, and in addition, are fairly expensive. The analytical challenge is boosted further by the low concentrations expected for some agents.

Why is the distribution network of primary concern? The large volumes and location ahead of the water treatment plant make it less likely that water sources would be poisoned ("dilution is the solution"). The physical security measures being implemented at the water treatment plant will reduce the probability of contamination there. Also, the disinfectant concentration is highest at the treatment plant, and the standard disinfection processes will destroy many agents. However, "backflow" events have demonstrated that the distribution system can be easily breached. Also, the smaller volume of water in a length of distribution line means the terrorist needs a smaller amount of an agent to achieve the necessary concentration for his purposes. In a simple but plausible scenario, a terrorist working from within a rented house (few residential connections are equipped with backflow prevention devices), pumps agent from the bathtub back into the water line coming into the house. Injection within the distribution system circumvents the security measures put in place at the treatment plant and negates the benefit of dilution upstream of the treatment plant. Hence, the distribution system is the weakest link; this is where we need to concentrate our monitoring efforts.

One, or even a few monitoring systems cannot adequately monitor a distribution system. As noted above, the agent could be introduced anywhere in the system (although some areas might

be deemed more probable if they contain "icon facilities" – hospitals, sports centers, government centers, etc.). Most distribution networks have multiple branches and are cross connected, so adequate monitoring requires a large number of points throughout the network. This adds yet one more challenge – the monitor units need to have a low enough cost so that widespread monitoring is economically feasible. Furthermore, monitoring the system only with grab samples is inadequate to catch a short-term contamination. The distribution system needs to be monitored continuously to detect a brief but lethal dose. Continuous monitoring also provides a better understanding of the baseline conditions, and thereby offers a more sensitive and reliable detection capability.

A possible approach is to use the military tactic of relying on a sensitive, rapidly responding trigger system that then initiates the more time-consuming agent identification methods. Such triggers can be lower cost and more rugged than the sophisticated analytical systems, and better suited for continuous monitoring. The demand for rapid detection and reliable operation in a "trigger" for contamination events directs us to the use of multiple sensors that respond to a wide range of agents. This approach does not eliminate the need for powerful analytical systems suitable for field use, but it does reduce the demands on their operation frequency and immediacy of results. Nevertheless, as time is critical in these situations, as much information as possible must be extracted from the trigger systems. Data fusion methods need to be developed in order to extract more information than is available from any one sensor individually.

The need for a large number of monitoring points across the distribution network is demanding. In addition to the data fusion methods needed to extract information from the multiple sensors, methods are needed to extract the important information from the pattern of data from multiple monitor points (and hence, the added need for efficient, secure communication systems, together with a detailed knowledge of the hydraulic characteristics of the distribution network). One option is to establish a hierarchy of monitor systems, with more sophisticated systems located at key points, where operating conditions are maintained within tighter ranges, and simpler monitors placed in less controlled conditions.

**Threat Agents**

The list of potential threat agents is long, and continuously growing. The following short list of agents shows the inherent range of their chemical nature.

| | |
|---|---|
| Pesticides | Oxymal, nicotine |
| Chemical warfare agents | Sarin |
| Biotoxins | Various biotoxins |
| Heavy metals | Thallium, mercury |
| Predatorcides | Sodium fluoroacetate |
| Organic poisons | Strychnine |
| Inorganic poisons | Cyanide |
| Biological agents | Shigella |

The range of potential agents and concentrations to be sensed gives guidance as to the necessary sensing capabilities. There are numerous types of chemicals and biological agents that could be used as threat agents, and because they can be toxic by many different biochemical mechanisms in the body, there is no common denominator for sensing.

One implication of this diversity of agent chemistries is that measurement of just one or two parameters is insufficient. It will take several parameter sensors to provide confidence that harmful agents are truly being sensed. Further, if there is any hope of telling one agent from another, the sensor set needs to generate useful information content from multiple parameters in order to classify the type of agent present. Thus, a complex of sensors will be needed.

Some potential agents are known to be effective at very low concentrations, so it is important to consider what agent concentrations can be sensed by a selected parameter suite, and compare this to the needed sensitivity. A widely used measure of the toxicity of a particular agent is the $LD_{50}$ value, which is the concentration that would kill half of an exposed group. (Different individuals respond differently to agents due to variations in their metabolism.) One needs to know the response of a sensor to the introduction of an amount equivalent to the $LD_{50}$ of the agent, or lower, per liter of drinking water. Such data is not generally available, so there cannot be an exact recommendation in this white paper. This is an area in which further and deeper study is underway. Nevertheless, perusal of known LD $LD_{50}$ values indicates that highly sensitive sensors are warranted.

A further requirement for the sensor set is that the various sensor responses need to be based on a wide range of physical principles, or in mathematical terms, their responses need to be orthogonal. The responses from fully orthogonal sensors provide the widest possible range of data possible, and hence, better likelihood that there is sufficient data to provide a reliable trigger signal. In the perfect case, one might seek a sensor uniquely responsive to each possible agent, but this would require a very large battery of sensors, and possibly be blind to a new, heretofore unknown agent. Also, the use of a great many sensors would increase the cost and maintenance needs. A balance needs to be achieved between highly specific sensors and broad-spectrum sensors (which respond to many of the agents, but not in a unique way). Mathematical methods can be used to extract the orthogonal information from combinations of different broad-spectrum sensors. The key is to find the balance between too few non-orthogonal sensors and too many highly specific sensors, while also considering the task of the mathematical data interpretation. The technology in this field is changing, and we can expect better choices in years to come.

**Sensor choices**

Consideration has moved from sophisticated analytical systems to single-parameter sensor systems. Thus the determination of which sensors would be most useful for monitoring needs to be explored. Selected sensors must be capable of quickly determining when there is a deviation from the "normal" condition. The determination of "normal" conditions is anything but simple, since not only is there the usual electronic noise and variability inherent in the sensor system, but there are also natural changes in the water itself, examples being diurnal, seasonal, source water changes, operational anomalies (*i.e.,* fire flows, major pipeline failures, etc.), and storm events. These effects must be recognized as "normal" and not initiate a trigger response (*i.e.,* no false positives). "Water quality" is the core concern of water utilities, and this serves as a good baseline from which upsets need to be judged. The set of common water quality sensors can provide an initial set of sensor choices.

The following section examines those common water quality parameters that can currently be sensed, and would serve as good candidates to respond to intentional contamination.

# 2.0 Candidate list of measurement parameters

### 2.1 Acid/Base relationships: pH or Alkalinity

A number of possible threat agents can affect the acid/base relationship in water. While alkalinity may be of interest, pH measurement is clearly the better parameter to measure because pH has become a simple and reliable measurement. Further, pH sensors do not require reagents in the analysis. It should be noted that the pH of drinking water seldom changes abruptly, or over wide ranges, so any changes that are found are usually indicative of abnormal conditions. That makes pH a potentially useful measurement.

This is not to say alkalinity may not be useful in some systems. In higher alkalinity (well buffered) water it is possible that a significant amount of a contaminant may be introduced without appreciably affecting the pH of the water. In these instances it would be prudent to consider measurement of alkalinity as well as pH but never instead of pH.

### 2.2 Ionic dissociation: Conductivity

Many threat agents will dissociate into ions when placed in drinking water. Like pH, the conductivity of drinking water typically does not change abruptly, making any major change a significant event. Conductivity is also normally related to the concentration of the added substance, making it useful in determining the concentration of added agents that are ionic in nature.

### 2.3 Oxidation/Reduction status: Chlorine/ORP/ Dissolved Oxygen

**Chlorine**

Many potential threat agents are reducing agents when placed in chlorinated water, and will produce a significant drop in chlorine concentration in drinking water, even at low agent concentrations. If one considers that chlorine is usually present in the water at < 1 ppm, only small amounts of a reducing agent, in the ppm range, may be required to change the chlorine concentration. Thus, measuring the chlorine residual as a sentinel is attractive.

Chlorine is often fed to obtain residuals set by law. Thus, the levels are known. Further, plant people are often familiar with chlorine residual analyzers and their maintenance.

There are many methods used to measure chlorine: wet chemistry (DPD, or titration), amperometric, and polarographic ( with or without membrane ). Thus there are many sensor configurations from which to choose. Some require reagents, and some do not. There are differing grades of performance and maintenance to consider. Measurement sensitivity and instrument reliability are significant concerns for this measurement.

In addition to measurement techniques for a particular analyte, different analytical techniques may provide similar response to the intended analyte (i.e. chlorine) but different responses to introduction of a threat agent. Some evidence exists that in this regard the DPD method may have some benefit over the other analytical methods.

**Dissolved Oxygen**

Dissolved oxygen is another oxidizing analyte that could be monitored to show the introduction of reducing agents. However, unlike chlorine, there are no requirements that certain levels of DO be maintained in drinking water. It is thus an uncontrolled and inconsistent parameter. DO levels from near zero to near saturation may be acceptable. That would complicate data interpretation. If the DO were to change, what would be the significance of that change? Would it necessarily be a sign of agent addition, or some other cause?

If sufficient baseline information is available on the DO concentration at a particular monitoring point it may still be useful in indicating significant changes in water quality and/or introduction of a threat agent. Interpreting DO information would likely rely heavily on examination of changes in DO concentration and simultaneous change to one or more other parameters such as pH and chlorine residual.

**Oxidation Reduction Potential**

ORP sensors look attractive for measurement of oxidation-reduction status in drinking water because the sensor is simple and requires no reagents, and it measures the ratio of oxidants to reductants in water. What is less known, is that the noble metal sensing electrode can be poisoned by metals in the water, or it can be blinded by any coating which may form on the electrode's surface. In long-term use, the electrode could become coated with either inorganic or organic films (bio-film) that would modulate the actual ORP of the water. Unfortunately, there is no simple way to detect those films.

ORP is also not an orthogonal measurement to chlorine when it is used as a disinfectant. The ORP reading is not only a function of the ratio of the reduction status of hypochlorous acid, but also pH, chloride and other oxidants/reductants present in the water. Changes in ORP caused by coatings forming on the metal electrode are especially frequent, which complicates the utility of ORP as a parameter.

### 2.4 Suspended particles

**Turbidity**

Turbidity measurement should be useful in drinking water because it is a direct measure of suspended particulate matter. Some threat agents do not dissolve immediately in water when introduced, or they react with carbonates in the water to form precipitates. Such particulate matter can be signal that an agent has been added. It is also possible that toxic materials in a water line could kill biofilms in the pipes and lead to biofilm material sloughing off, increasing the turbidity.

Turbidity also bears some quantitative relationship to undissolved materials.

**Particle counters**

Since particles are typically distributed on an inverse 3rd power function and it is unlikely that any contaminant would be introduced in sufficient quantity to appreciably affect the particle counts. The only possibility is if the contaminant was uniform in particle size and introduced in sufficient quantity to create an abnormal particle distribution. This seems unlikely, and therefore particle counters would not be useful in the sensor suite, particularly if turbidity is included. Particle counters are used by some as a surrogate measurement of filtration efficiency, but actually cannot distinguish between non-viable particles and individual organisms in the finished water. They could be used to monitor a change in the general particulate background, especially an increase in algal cells sloughing off of the wall in response to a toxic agent killing the biofilm, such as noted above in the discussion on turbidity. However, turbidimetric measurements achieve the same indication but with a simpler instrument, so we have elected not to include a particle counter in the sensor suite.

### 2.5 Organic molecules: Total Organic Carbon content / UV absorbance

Many threat agents are organics with significant carbon content. It would surely be useful to know if the drinking water suddenly had more carbon from organic components. While there might be seasonal variation to the natural carbon content, any short-term changes could signal introduction of an organic agent. Two possible measurements would be Total Organic Carbon (TOC), and/or UV absorbance.

**TOC**

TOC is highly attractive as it is an orthogonal measurement of the property of interest. The drawbacks are that the equipment to make the measurement is moderately expensive, and requires reagents. TOC analyzers generally require more than casual maintenance.

**UV absorbance**

This is a much simpler measurement, but less general, as not all molecules containing organic carbon absorb UV radiation at 254 nm, the traditional measurement wavelength. Furthermore, most published work on UV absorbance has focused on raw water content, whereas water treatment leads to much lower concentrations of organic compounds. Where practical, one would be well served to employ TOC.

UV absorbance might be considered for locations where installation of a TOC analyzer is impractical. In these instances it would be prudent to study the site to establish a correlation between TOC and UV absorbance at that particular monitoring point.

**Fluorescence**

Studies have shown that fluorescence monitoring can be used in a manner similar to UV absorbance, as a continuous indicator of organic content. However, similar to the work with UV absorbance, this work has been directed at raw water, and very little is known as to its utility in finished water, where the organic content has been greatly reduced. Hence, we have not included this technique.

**Color**

Very few agents will produce noticeable color in water, especially in the concentrations that would be harmful to people. If the intention is to introduce an agent to kill people, then it is likely that colorless agents would be selected. If the intention is to introduce a colored agent for psychological effect, then a strongly colored chemical would be used, and the color detection would be immediate to the user. Therefore it does not seem justifiable to include color in the sensor suite.

**Streaming potential**

Streaming potential is primarily applicable only to post-addition monitoring of the coagulation process at the treatment facility. It is unlikely it will be beneficial in monitoring introduction of threat agents that other analytical parameters would not also detect.

**Ion Selective Electrodes**

Ion Selective Electrodes (ISEs) are fairly specific to a target ion. Because of the breadth of monitoring needed, a multitude of ISEs would be required to span the various ions that might be used. Furthermore, conventional ISEs require frequent calibration and maintenance. The selectivity of ISEs makes this is a fertile area for future exploration. It is possible that an ISE targeting a class of agents could be developed. Another interesting possibility is the development of miniaturized ISEs such that many sensors could be mounted in a single probe, to give a wide range of responses. (Calibration demands and stability of response would need to be addressed.)

**Biosensors, Toxicity monitors**

"Bioassays" based on whole animals (*e.g.,* water fleas, fish, etc.) are in use in several plants. However, these tests are usually done with grab samples, or possibly in-line in the influent streams. The presence of chlorine or other disinfectant in the treated drinking water, together with the frequent maintenance precludes their continuous use in distribution systems.

Several interesting concepts involving the use of biological systems as a means of sensing specific parameters, or more generally, toxicity, have been explored, and a few have actually been commercialized. Thus, several investigators have developed monitoring systems based on luminescent bacteria, e.g. *Vibrio fischeri.* The luminescence reflects the health of the bacteria's respiratory process, and decreases when exposed to toxic agents (due to disruption of the bacteria's respiration). This system has been commercialized; however, this is a batch system, for use in a laboratory, and not for continuous monitoring purposes. Other investigators have explored monitoring oxygen consumption of captured cells or bacteria, again, to detect the presence of agents that interfere with the cellular respiration. That type of system is an officially approved method in Japan for monitoring BOD in water. Again, these systems are designed for batch operation or for short term monitoring, and have not progressed to the point that we can include them in our sensor suite at the present time. They are, however, attractive options for future development.

### 2.6 Radiation sensors

Traditionally, alpha and beta emitting ions are not monitored in flowing systems, but samples to be analyzed are taken and analyzed under laboratory conditions. In-line gamma monitors do exist, but usually for special facilities handling radioactive materials. At this time, further

evaluation is needed to determine the suitability of radiation detectors for routine monitoring of distribution systems. This is an active area of exploration and development.

# 3.0 Suggested suite of instruments

The following suite of instruments is suggested as a minimum for characterizing water quality parameter disturbances. Notable by absence is a sensor for monitoring biological agents. The present finding is that those available today are either too expensive or not sensitive enough for the task at hand. This is a fertile area for scientific and commercial advancement.

| | |
|---|---|
| Acid/base relationships | pH |
| Ionic chemicals | Conductivity |
| Oxidation/Reduction relationships | Chlorine |
| Suspended solids | Turbidity |
| Organic content | TOC |

With the exception of TOC, these measurements are simple, and typically reagent-free. They have low maintenance requirements and are understood by many water plant instrument people.

The pH parameter has become a standard water quality measurement, and many systems are available. These are generally robust, and sufficiently accurate for good analysis results.

Electrical conductivity sensors are very robust, simple to use and maintain. If the given application site has problems with coatings, there are non-contacting conductivity sensors that can be used.

Turbidity measurement is common, robust and does not require reagents. While many potential agents will fully dissolve at effective concentrations, and not register any turbidity, some agents will introduce turbidity far in excess of the low levels commonly found in drinking water. The parameter thus provides a fundamental measure for such agents.

TOC requires reagents and regular maintenance, which are drawbacks, but the importance of knowing the organic content of the water is profoundly important. It is therefore included in the suggested instrument suite.

### 3.1 Secondary instruments

While the list of sensors above is considered of primary importance, others are certainly possible to include, and may provide useful information in certain installations and circumstances. Those sensors would be:

Alkalinity
ORP
UV absorbance, fluorescence monitors

These are non-orthogonal to the sensors of the primary set, so analysis via Principal Component Analysis of the signals could be useful to extract the essential information from the data set.

Future sensor developments will improve some parameter measurements and add new ones. When those appear, they can be added to the suggested set.

# 4.0 Gap analysis - Directions for the future

**Sensors on a chip**

The idea of a sensor suite on a chip is obviously attractive, and considerable work is underway to develop such products. While great progress has been made, such products currently do not provide the reliability and quality of analytical measurement that can be achieved with an optimized set of individual sensors. The authors expect advances in this type of integrated sensor to be made, but must at this time recommend individual sensors be selected. Suppliers of individual instruments have been able to concentrate their efforts to obtain the best performance from their product, in contrast to developers of integrated sensors who must spread their efforts across a suite of sensors.

**TOC**

As noted above, measurement of Total Organic Carbon (TOC) in drinking water serves as a very useful parameter for agent detection. However, current TOC analyzers are moderately expensive and require frequent maintenance. Development of more rugged and compact TOC systems represents a key opportunity for future systems.

**Bio-sensors**

In principle, a biological system is the ideal detection system for this purpose, mimicking the response of our bodies to added agents. However, like our bodies, such systems need care and feeding to remain viable. Nevertheless, such systems warrant further exploration and development due to the directness of their response.

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# Appendix 1

# Site, Sensor and Analyzer Characteristics to Consider

1.0 Introduction

2.0 Considerations for Equipment Selection
- 2.1 Site Characteristics
  - 2.1.1 Utilities
  - 2.1.2 Environmental
  - 2.1.3 Regulatory Requirements
- 2.2 Instrument Characteristics
  - 2.2.1 Physical
  - 2.2.2 Performance
- 2.3 Operations Considerations

3.0 Practical Compromises
- 3.1 Performance/cost
- 3.2 Full Suite of Instruments or Reduced Set
- 3.3 Maintenance
- 3.4 Commercial Availability

### 1.0 Introduction

Selection of a particular monitoring technique or suite of monitoring devices must of necessity be tailored to the monitoring location.

### 2.0 Considerations for Instrument Selection

A number of characteristics of the environment and the instrument must be considered to be sure that the instruments to be selected match the requirements of the application and the site environment. Listed below is a set of characteristics to be considered in site planning and selection of monitoring equipment. The list is unlikely to be exhaustive, and each site should be considered for unique requirements.

### 2.1 Site Characteristics

Water distribution systems have many types of sites throughout the system, especially in larger cities. One suite of instruments may be appropriate for a relatively clean environment with adequate access to utilities (sewer, electrical, etc.), but an entirely different suite may be appropriate when the monitoring location offers limited utilities, cramped space, and hazardous entry procedures.

#### 2.1.1 Available Utilities ( water, electricity, sewer, communication )

**Water**

Given that water is being analyzed, the site will have access to water, but will there be taps that can be used to draw water for miscellaneous use at the site? Has a backflow prevention device been installed so that site itself cannot be used to create a backflow event?

**Electricity**

What electrical power exists at the site? Is the power limited? What provisions does the monitoring and communication equipment have to operate from backup supplies? Will battery power be available so that the supply is not interrupted?

**Sewer/Drain**
If the equipment produces a waste stream, is there a drain to which the waste stream can be plumbed? Will waste have to be collected and disposed of off-site?

**Communications**
What communications exist at the site ( e.g. phone lines, RTU, internet connection, fiber optics )? Will new communication lines need to be added? The instrumentation must be compatible with the communication requirements ( Type and Protocol ).

#### 2.1.2 Environmental characteristics and considerations

**Space Available**
Is there adequate space to mount the instrumentation and associated accessory equipment and supplies? If the equipment must be placed down a manhole, will it fit in the space available?

**Mounting Scheme**
It is desirable for a suite of instruments to have all instruments mounted on a common back plane.

Multiple parameter probes may be more practical in some locations than individual instruments (e.g. lack of drain, lack of space). Devices for in-pipe mounting of such probes should be readily available.

**Accessibility for Maintenance**
Instruments should be located where access is safe and easy. Where two sites are available having the same analytical merit, the site offering the best accessibility should be chosen. When possible, avoid sites requiring special procedures for confined space entry. Invariably, such restrictions will limit the amount of maintenance that the instruments receive.

**Temperature**
Temperature ratings of instruments, for both sample temperature and ambient temperature, should be appropriate for the installation environment. Very high and very low temperatures are detrimental to most analytical instruments.

Sensors or sensor assemblies may see extreme temperatures in outdoor or unheated locations. Solar radiation may overheat, or winter weather may freeze the sensors. Many water quality sensors cannot tolerate freezing conditions.

**Sunlight**
Direct sunlight will degrade many plastic materials and may cause degradation of reagents. Direct sunlight may also cause solar heating of instrument enclosures shortening the life of electronic components. Sites selected should be out of direct sunlight.

**Humidity**
Select instruments designed to accommodate the humidity expected in the environment. Where possible avoid sites where condensing humidity is present. When those sites cannot be avoided, one should anticipate the need to provide a dry-air purge to the instrument.

**Altitude**
Altitudes from sea level to over 7000 feet above sea level are seldom a problem. When high altitude installation is desired, one will need to carefully check instrument specifications to ensure that they will operate properly at high altitudes, e.g. 10,000 feet.

**Sample pressure**
High and low pressure, as well as frequent pressure fluctuations, can adversely affect instrument performance. Sample conditioning may be required to provide a consistent sample pressure. It is best to avoid pumping a sample.

Pressure control is critical to instrument performance and in some cases measurement accuracy. Careful attention needs to be paid to this detail. It would be prudent to monitor sample pressure to instruments to ensure proper sample is being applied to the instruments. This may be especially useful when monitoring instruments from a remote location.

Both mechanical pressure reducers and barometric loops are frequently used to provide sample in the proper pressure range. Select the method most appropriate for the instrument designs and sample locations.

#### 2.1.3 Regulatory Requirements

What regulatory requirements exist at the site? Users should insist that instrumentation comply with appropriate and regionally applicable design standards for electrical safety including UL, CSA, and CE.

### 2.2 Instrument Characteristics

#### 2.2.1 Physical

**Dimensions**
Overly large assemblies may not fit in the space available, or may be troublesome during insertion or removal.

**Weight**
If sensor assemblies will be inserted into a flowing line, the weight of the assembly should be considered during installation, maintenance and service.

**Enclosure environmental ratings**
Instrument enclosures should, at minimum, be designed for NEMA 4 indoor installation.

To the extent possible corrosion resistant materials should be utilized for instrument enclosures, plumbing connections, and mounting back planes.

**Connection to the water**
To simplify installation and maintenance, suites of instruments should be clustered to permit use of a single power input and single instrument drain manifold.

It also is prudent to have a single sample manifold connected to a single sample tap so that all instruments are receiving the same sample.

**Wetted materials**
Drinking water is not highly corrosive but can contain significant amounts of chlorine that may damage some plastics and metals, such as steel.

**Non-wetted materials**
The area of installation will often have high humidity, so materials should be moisture resistant.

**Power Requirements**
It is preferable to have sensors that are powered from common voltage supplies such as 110 VAC or 24 VDC. Brown-out conditions should be considered. If the line voltage falls to 85 VAC, will the system still provide accurate readings?

Sensors that must operate from backup batteries should not take excessive power.

**Electrical Isolation and connections**
Ground loop currents can lead to erroneous readings, so there must be electrical isolation between the sensors and any electrical devices that receive their signals ( recorders, SCADA systems, PLCs, modems, RTUs, etc )

Electrical connections should be water tight and corrosion resistant.

A single connection for data transmission also is desirable. Both analog and digital data transmission options are desirable, but preference should be given to instruments and sites where digital communication is possible.

**Pressure rating**
Nominal line pressure rarely exceeds 100 PSI, but pressures to over 200 PSI are not uncommon. Water hammer in a line can produce pressures far above that figure with resultant damage to in-line sensors. In some cases, the sensor mounting could be destroyed by over-pressures, with catastrophic or dangerous results. Sensor packages should include a pressure sensor so that local pressure conditions can be monitored.

**Min/Max flow**
Nominal line flow rates would be 3-5 feet/second, but sensors should be able to survive flow rates of at least 10 feet/second.

### 2.2.2 Performance Characteristics (also see worksheet)

**Repeatability**
Repeatability must be good if the signals are used for analysis. Compare candidate sensors to those for process use.

**Accuracy**
Required sensor accuracy should be stated before the selection process.

**Non-linearity**
While generally not critical for water quality analysis, non-linearity or conformance values should be known.

**Warm-up time**
This could be significant when power to the sensors is interrupted ( lightning, power line drop-outs, etc. ). Sensors that require long periods to return to normal operation should be avoided.

**Supply voltage effects**
This criterion is often overlooked. Sensors should be robust with respect to accuracy under varying supply voltage.

**Response time**
Fast response is generally not needed in monitoring applications, but response times > 2 minutes should be avoided.

**Temperature drift**
Sensors may be mounted in areas where temperature varies considerably. Temperature drift specifications for Zero and Span should be known.

**Temperature compensator temperature range**
A range of 0 to 70 degrees Centigrade should be adequate, although temperatures would rarely exceed 50 degrees Centigrade at most sites.

**EMI/RFI influence**
Sensors may be mounted in proximity to pumps and other electrically actuated equipment. The sensors must not be susceptible to interference from those devices.

### 2.3 Operations Considerations (also see worksheet)

Certain general characteristics are desirable for instruments at all monitoring locations. Maintenance cost, type and frequency should be carefully considered, as sensors that are not on-line with a high probability jeopardize system operation. Long maintenance periods could be used as a time when the system is vulnerable to attack.

**Low maintenance**
Ideally instruments should require minimal operator intervention and service. Where practical, instruments requiring not more than monthly maintenance should be selected. It is unreasonable to expect analytical instruments to be maintenance-free. It is reasonable to expect that the instruments should be looked at once or twice per month, but require active maintenance only monthly.

**Easy operation**
When deployed in a water distribution system, the instruments will likely be operated by persons with limited analytical training. Thus to the greatest practical extent the instruments should be plug-and-play with simple menu-driven operation and set up.

**Cleaning method**
Sensors should be cleaned during maintenance. Cleaning methods and solutions should be clearly identified for maintenance personnel. It should be noted if the cleaning solution for one type of sensor is not suitable, or incompatible with any of the other sensors in the sensor package.

**Reagents**
When reagents are required for a particular analytical instrument, they should be available from the manufacturer, and their quality assured by the manufacturer.

# 3.0 Practical Compromises

Many water quality sensors are readily available, yet the ideal choice may not be among them. Compromises may have to be made, and the associated risks evaluated.

### 3.1 Performance (Analytical Merit ) / Cost

There are likely to be tradeoffs made between performance and cost. It may not be justifiable to use the highest performance instruments if doing so would greatly reduce the number of points in the system that could be monitored. Some instruments may not need reagents, yet they may not deliver adequate performance. Available space may dictate that a bulky analyzer cannot be used. Some parameters can be measured by a number of methods. There may be tradeoffs to consider and the best choice forced by local conditions. In any tradeoff, one should be concerned that a choice of reduced analytical capability does not degrade overall system performance to a significant degree.

### 3.2 Full Suite of instruments or Reduced set

In some situations it may be more cost effective to install sensing platforms of two types, where one type has a complete set of sensors and a second type has a reduced set of those sensors. Some sites may not be readily accessible and be better served with only those sensors that have low maintenance requirements, even though some data content is reduced.

### 3.3 Maintenance

Some of the sensors or analyzers that are highly desirable from a technical viewpoint may have high maintenance requirements. An alternate type of sensor, or an alternate parameter may be a better choice if the maintenance costs and/or frequency are much lower.

### 3.4 Commercial availability

Some sensors that are technically desirable may have only source, or a source that is not reliable. There would be a level of risk in basing a measurement system on sensors that may not be supported or available at a later date. Alternates may be chosen to reduce that level of risk.

## Distribution Monitoring Instrument Rating on Performance Criteria

| **Scoring Criteria: 1 to 5**<br>**5 = Highest rating** | **Importance of Criteria?** (Weighting)<br>**1 to 5** | Notes | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 | Product 6 | **Criteria Score** |
|---|---|---|---|---|---|---|---|---|---|
| **Sensitivity** | | | | | | | | | |
| **Resolution** | | | | | | | | | |
| **Accuracy** | | | | | | | | | |
| **Specificity** | | | | | | | | | |
| **Interferences** | | | | | | | | | |
| **Repeatability** | | | | | | | | | |
| **Accuracy** | | | | | | | | | |
| **Non-linearity** | | | | | | | | | |
| **Warm-up Time** | | | | | | | | | |
| **Supply voltage effects** | | | | | | | | | |
| **Response time** | | | | | | | | | |
| **Temperature drift** | | | | | | | | | |
| **Temperature Compensation** | | | | | | | | | |
| **EMI/ESD/RFI influences** | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| **System Score** | | | | | | | | | |
| **Max System Score** | | | **70** | **70** | **70** | **70** | **70** | **70** | |
| **System Percent Score** | | | | | | | | | |

| **Scoring Criteria:** 1 to 5<br>5 = Highest rating | Notes |
|---|---|
| **Importance of Criteria:** 1 to 5<br>5 = Critical, 1 = Unnecessary | |

## Distribution Monitoring Instrument Operations Rating Criteria

| **Scoring Criteria: 1 to 5**<br>**5 = Highest rating** | **Importance of Criteria?** (Weighting) **1 to 5.** | Notes | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 | Product 6 | **Criteria Score** |
|---|---|---|---|---|---|---|---|---|---|
| **Maintenance frequency** | | | | | | | | | |
| ***Ease of Operation*** | | | | | | | | | |
| **Cleaning methods** | | | | | | | | | |
| ***Use of Reagents*** | | | | | | | | | |
| **Ease of calibration** | | | | | | | | | |
| **Calibration frequency** | | | | | | | | | |
| **Downtime required for maintenance** | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| **System Score** | | | | | | | | | |
| **Max System Score** | | | **35** | **35** | **35** | **35** | **35** | **35** | |
| **System Percent Score** | | | | | | | | | |

| | |
|---|---|
| **Scoring Criteria:** 1 to 5<br>5 = Highest rating | Notes |
| **Importance of Criteria:** 1 to 5<br>5 = Critical, 1 = Unnecessary | |

**ASCE WHITE PAPER #4**

# PLACEMENT OF MONITORING INSTRUMENTS IN WATER DISTRIBUTION AND WASTEWATER COLLECTION NETWORKS

by

**Yakir J. Hasit, Ph.D., PE, M. ASCE[1], Gary Jacobson, PE[2], Perrin Niemann, PE[3], David E. Stangel, PE[4], CH2M HILL**

## ABSTRACT

The methods for selecting sampling locations to detect contaminants within a distribution system network have been either intuitive or academic. Intuitive methods cannot account for the variability and uncertainty inherent in the intentional or unintentional contamination of water distribution systems. On the other hand, academic approaches such as mathematical programming are currently too complicated for the water utilities to implement on their own. For water distribution systems, hydraulic/water quality network models are currently the most practical tools for identifying the candidate locations for monitoring instruments and sensors. Regardless of the method used for selecting sampling sites, local conditions will ultimately determine exactly where an instrument can be installed.

For wastewater collection networks, however, little, if any, information was found for locating sampling or monitoring stations for contamination. However, the local site conditions discussed in this paper should help identify locations for sewer systems also.

## INTRODUCTION

The objective of this white paper is to provide an overview and guidance on the placement of early warning system instruments, sensors, and other devices within water distribution and wastewater/stormwater collection networks. This document is the 4th white paper among nine that will be used by ASCE in developing guidance in the design of water distribution and wastewater collection system contamination detection and monitoring systems. These white papers cover all the elements required in the design of a comprehensive early warning system, namely:

1. Contaminants and concentrations of concern
2. Selection of instruments and platforms
3. Models for use in data analysis

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[1] Yakir J. Hasit, Ph.D., PE, Principal Project Manager, CH2M HILL, 1700 Market St., Suite 1600, Philadelphia, PA 19103-3918

[2] Gary Jacobson, PE, Senior Instrumentation & Controls Engineer, CH2M HILL, 25 New Chardon Street, Suite 500, Boston, MA 02114-4774

[3] Perrin Niemann, PE, Water Resources Engineer, CH2M HILL, 9193 S. Jamaica St, Englewood, CO 80112

[4] David E. Stangel, PE, Project Engineer, CH2M HILL, 700 Clearwater Lane, Boise, ID 83712-7708

4. Siting of instrument platforms
5. Data analysis requirements
6. Communications system requirements
7. Responses to contamination events
8. Interfacing with existing water quality surveillance systems
9. Operations, maintenance, and upgrades

It should be noted that the design of early warning systems in distribution and collection networks is still evolving, and some of the nine areas listed above are still in the early stages of their development. Fundamental questions touching on these areas are presented by Pikus and Haimes (2003).

The objectives of the overall ASCE guidance document are to:

- Identify key elements of methodology for design of online contaminant monitoring systems
- Provide checklists and discussions of issues to be addressed and decisions to be made by water utilities in establishing online contaminant monitoring systems
- Provide advice and guidance on how utilities should resolve these issues and make the decisions needed
- Be pertinent to water supply and wastewater/stormwater systems
- Be pertinent to small, medium, and large systems

Consistent with these objectives, this white paper:

- describes the placement of instruments,
- discusses the important factors in the placement of instruments,
- shows the relationship between placement of instruments and other topics included in the ASCE guidance,
- provides an analysis of tradeoffs and options,
- reviews relevant documents,
- provides guidance language on the placement of instruments

This guidance covers both water distribution and wastewater collection networks. The use of early warning devices for contaminant monitoring in sewer systems, however, is not as prominent as in distribution systems, primarily due to a) their differences in the end uses of the networks, and b) the contaminants already in wastewater. As a result, sewer systems have received less attention than water distribution systems in relation to the design and implementation of early warning systems.

Water distribution systems are considered to be the most vulnerable part of potable water systems, due to their wide coverage, numerous locations that are possible points of intrusion, limited protection, and proximity to end users. Thus, the primary purpose of early warning instruments has been to minimize the consumption of contaminated water by the public. On the other hand, early warning devices for sewer systems have been used primarily to avoid damage

to receiving facilities or waters. These have included alerting for overflows and avoiding spills (Wong et al. 2003), avoiding treatment system upsets (especially biological treatment systems that are susceptible to toxic contaminant overloads), and ensuring the safety of sewer workers. Additional concerns have included economic disruption and physical destruction (and associated loss of life) of facilities and buildings. Because sanitary and storm sewers run near or beneath key buildings and public areas, and are in close proximity of other utilities such as gas, water, communication, and transportation networks, early warning systems in sewer networks have to be part of the emergency response plans of wastewater utilities.

As discussed below, the engineering literature reviewed provides some guidance for locating sensors in water distribution systems, but offers little information on their placement in sewer networks. Therefore, this white paper focuses primarily on water distribution systems; however, when appropriate, it also discusses issues relevant to wastewater collection systems.

## BACKGROUND ON THE PLACEMENT OF INSTRUMENTS

Primarily there are two categories of factors used in the selection of instrument locations, local site conditions and system wide considerations, including network topology. Use of local site conditions is more prevalent, and is used to develop intuitive approaches on where to locate instruments within the networks. These two categories are applicable to both water distribution and wastewater collection networks.

Prior to the recent attention given to detection monitoring for intentional or unintentional contamination, monitoring has been mostly conducted for ambient/background water quality monitoring, regulatory compliance monitoring and operational purposes. For water utilities, background water quality monitoring sampling locations have been selected before raw water intakes or at well heads to monitor raw water quality and adjust treatment, as necessary. Similarly, for compliance monitoring, sampling sites have been located in clear wells prior to delivery into the transmission and distribution systems, and at distribution system locations identified through regulatory requirements. Because the objective has been compliance, the types of constituents monitored have been known beforehand and the path taken by the water within the distribution network has been relatively predictable under expected flow conditions. Guidance on where to locate sampling sites for compliance monitoring is provided by Kirmeyer et al. (2002). Similarly, some results from an AWWA survey on how utilities select their monitoring stations are reported by Lee et al. (1991).

The problem becomes more complicated when intentional contamination is considered. In this case, the source, type, concentration and injection time of contaminants are unknown, adding further complexity to the problem. The ideal solution would be to locate sampling sites at all possible nodes of a distribution system to detect a contamination. Of course, this would be cost prohibitive, especially when sample collection has to be frequent or continuous, and instruments have to be a) highly accurate, b) capable of detecting a wide range of contaminants at low enough concentrations. It is obvious that the use of intuitive methods for locating sampling sites would be ineffective in meeting all these objectives. To address some of these concerns, academicians have typically used mathematical programming (optimization) methods, sometimes together with hydraulic/water quality network models, to tackle this problem. They have tried to identify the cost optimal sampling sites given certain constraints on the distribution system, and treating it as a form of "facility location" problem in mathematical programming and

operations research literature. A main disadvantage in the use of such models by utilities has been the sophistication needed to develop such models.

However, with the enhancements being made to current hydraulic/water quality network models, promising tools for identifying potential sampling sites have been emerging. Currently, there are a few integrated hydraulic/water quality network models with varying capabilities that can be used to develop strategies for locating sensors in distribution systems. These include EPANET/PipelineNet (from USEPA), H2OMAP (from MWH Soft, Inc.), WaterCAD (from Haested Methods, Inc.), MIKE NET (from DHI, Inc.), AQUIS (from Seven Technologies A/S) and OptiMonitor (from OptiWater).

## SELECTION OF SENSOR LOCATIONS

This section addresses the factors and tradeoffs considered in the selection of sensor locations. The relationships among sensor locations and the other topics of the ASCE guidance are highlighted, as appropriate. Among all the elements covered by the ASCE guidance, due to current limitations, the one that has the biggest impact is the type of instrument and platform that can be used for early warning systems. While the instrument selection is based on contaminants of concern, local conditions could preclude the use of some instrument platforms, in turn limiting the type of contaminants that can be monitored. Thus, the type of instrument(s) that can be used determines a) the type of contaminants monitored, b) the detection limits and accuracy, c) installation and operational requirements (periodic versus continuous sampling, data collection, communications, maintenance requirements, etc.), d) the integration of the instruments with existing water quality monitoring systems, and e) number of instruments that may be installed.

As mentioned above, when selecting sensor locations, both local site conditions and system wide considerations must be taken into account. The local site conditions that a utility should consider include:

- *Easy access to the instrument site is important,* because all instruments require periodic maintenance, the frequency of which may vary with the particular technology, manufacturer, or the quality of the water being measured. For example, many chlorine analyzers require periodic replenishment of the various reagents that are necessary for their operation. Weekly to monthly service is required for this activity, depending upon the stored quantity of reagent. An instrument calibration should be conducted at the same time that reagents are refilled, and site access must facilitate this activity. This factor is directly related to the 9th topic of the guidance, "Operations, maintenance and upgrades."
- *Available space for the instruments and auxiliary equipment* (e.g., within a utility owned valve pit or manhole) must be considered. In some cases, early warning instrumentation may be installed in appropriate host facilities. Municipal buildings, public schools, and fire or police stations may provide space for an instrument cabinet, a sample supply, and a drain to the sanitary sewer. Private, large-use facilities such as hospitals, hotels, sports arenas, or convention centers may be willing to provide space for an instrumentation cabinet, although some financial or water/sewer billing compensation may be requested in return. Lee et al. (1991) report that the most frequently chosen locations are commercial and public buildings. In selecting a host facility for an early warning system instrumentation cabinet, easy 24-hour access by utility technicians must be assured, as well as security against tampering. This

factor also is related to the 9th topic of the guidance, "Operations, maintenance and upgrades."

- *Suitability of candidate instruments or sample collection method for the sampling site,* including the discharge of waste stream, access to electricity/power, and data transfer and telecommunication equipment, must be taken into account. Many of the important process instruments, such as chlorine analyzers, require a slipstream from the water supply pipe for injection of sample treatment reagents. These instruments generate a waste stream that must be disposed of. Turbidimeters are generally configured as flow-through devices, and therefore require a slipstream, although the sample stream could be re-injected into the distribution flow. Other instruments, such as pH, conductivity, and dissolved oxygen sensors, as well as the multi-parameter probes, may be inserted directly into the distribution flow stream. In order to facilitate maintenance or avoid decontamination requirements, many utilities may elect to install these instruments in a slip-stream rather than into the actual distribution system flow. Thus selected locations for early warning system instruments will likely include consideration of waste stream disposal. In environments where sanitary sewers exist, it may be possible to route sample drains into the sewer with proper attention given to backflow prevention. In some suburban or rural environments, this may not be possible. In the absence of in-ground vaults, roadside instrument cabinets may be installed with a gravity drain to the sewer. Either option may result in significant costs for sample drain installation under sidewalks and roads.

  Another requirement is ready access to electric power. To host early warning system instruments in appropriately sized valve vaults, waste stream disposal may require use of a pump to move the liquid to the sewer. Electric power will be required for pump operation, but since some power will be required for operation of any instrument, power supply will be a consideration for all monitoring locations. Depending upon particular site conditions and installed equipment, solar/battery operation of the equipment may be possible or required at some locations.

  Similarly, communication methods for remote data collection and alarming must be supported. Suitability for SCADA radio communication must be determined, if applicable, including an assessment of whether required radio antennae will be feasible or permitted. Alternately, availability of telephone communications or fiber optic data lines must be considered.

  This factor is related to the 2nd (Selection of instruments and platforms), 6th (Communications system requirements) and 9th (Operations, maintenance and upgrades) topics of the guidance.

- *Physical security of the instrument site* is important to guard against unauthorized access or tampering. The monitoring site must be reasonably secure to prevent tempering with the instrumentation, injection of contaminants, falsification of SCADA data, and disruption of the power supply or data communications. Areas that can provide some intruder deterrence by being close to police stations, fire departments, schools, etc where any suspicious activity can be more easily detected are recommended.

- *Hydraulic conditions at sampling sites* are important in the suitability of the site for the installation of instruments because turbulence in the pipe might affect sample collection or measurement.

- *Existing sampling sites* for baseline or compliance monitoring are good candidates for installing additional sampling instruments.

System wide and topological factors include:

- *Potential areas or entry points of contamination (*such as reservoirs, blow off valves, pump stations), ease of intrusion at these locations (i.e., lack of physical security), and ease of insertion of contaminants must be taken into account because locations closer to such sites are candidates for sampling locations. This factor also affects the type of contaminant that might be used by an intruder and thus relates to the 1st topic of the ASCE guidance, "Contaminants and concentrations of concern"

- *Likely contaminants* need to be considered by utility personnel. Water and wastewater systems can be contaminated by a wide array of chemicals, microbial contaminants, and biotoxins. In addition to acts of intentional contamination, unintentional events may also be the source of contamination and should be considered when designing monitoring systems. Sampling in an industrial area may, for example, include a stronger focus on sensing chemical contaminants, although monitoring for all potential contaminants remains necessary at all monitoring locations. Because most online sensors do not monitor for specific contaminants but surrogates instead, utilities need to determine which contaminants and their surrogates to monitor, which in turn will determine which candidate instruments should be considered. These instruments will then define the requirements for the installation location. This factor is also the topic of the first white paper in ASCE's guidance, "Contaminants and concentrations of concern."

- *Contaminant transport time and concentration* also influence where and how many sensors need to be installed. Likely contaminant transport rates in the network (due to flow, dilution and decay), changes in contaminant properties due to bulk water properties, wall effects (pipe material, tuberculation, biofilm), and mixing all affect the time required for the contaminant to reach consumers at a certain concentration. This in turn determines the time a utility has to detect and analyze the situation, and respond as appropriate. The delivery time and concentration also determine where and how many sensors need to be installed. This factor is directly related to the 3rd topic of the guidance, "Models for use in data analysis."

- *Instrument accuracy and detection limits* have a direct impact on the number of instruments that need to be installed, and consequently on their locations (related to 2nd topic in ASCE guidance, "Selection of instruments and platforms"). As instrument accuracy and sensitivity increases, fewer instruments may need to be installed (Ostfeld and Salomons 2003). Early warning system instruments must provide stable measurement signals and must be able to quickly and reliably detect significant swings in the measured parameter. If the instruments can detect lower concentrations of contaminants, they can effectively increase the area monitored by the number of instruments that a limited budget may support. A key factor is the commercial availability of instruments with the proper detection limits.

- *Vulnerable populations* (such as children, elderly, sick) at different parts of the network must be taken into account. Areas that serve such populations are candidates for siting instruments.

- *Relative water demand and associated flow characteristics* are critical in identifying sampling locations, because the temporal and physical characteristics of the network must be taken into account in selected sampling locations. Temporal factors include diurnal (e.g.,

morning vs. noon), daily (e.g., weekday vs. weekend) and seasonal (summer vs. winter) variations. Physical factors include pipe length, size, condition, material, appurtenances, bends, T-s, etc. This factor is directly related to the 3rd topic of the guidance, "Models for use in data analysis."

- *Frequency of sampling,* i.e., periodic vs. continuous sampling, will impact both the number and locations of the instruments selected. The more common monitoring methods for microbiological contamination rely on periodic grab samples that typically take hours or days to analyze. These methods are usually sufficient for compliance monitoring but are inadequate for early warning systems because by the time the results are known, a considerable portion of the contaminants could be consumed. Thus, if periodic sampling needs to be performed, then the frequency of sampling and the number of sampling locations should be increased to improve the likelihood of detection and timely response. This topic is related to 2nd (Selection of instruments and platforms), 5th (Data analysis requirements) and 6th (Communications system requirements) topics in the ASCE guidance.

An assessment of the factors discussed above and the literature reviewed lead to the identification of the following tradeoffs in the placement of instruments:

- Minimize contamination detection time for a given number of sensors (or budget), versus minimize number of sensors (or budget) for a specified time of detection
- Maximize monitoring coverage for all consumers versus maximize coverage for vulnerable (at risk) consumers such schools, nursing homes, hospitals, etc.
- Continuous monitoring versus periodic monitoring
- Automated sampling versus manual sampling
- Use of few expensive monitors (e.g., miniaturized gas chromatographs or mass spectrometers) versus use of many less-costly instruments (e.g., chlorine residual and other surrogate parameter analyzers)
- Instrument life cycle costs
- Instrument ease of use and maintenance by utility

## REVIEW OF LITERATURE ON THE PLACEMENT OF INSTRUMENTS

This section provides an overview of the three methods for determining instrument locations mentioned previously:

1. Intuitive methods
2. Optimization/mathematical programming methods
3. Hydraulic/water quality network simulation methods

### *Intuitive Methods*

When using intuitive methods to select sampling sites, local site conditions plus some system wide factors such as proximity to critical customers (e.g. schools), or water mains serving large number of customers are critical considerations.

There are several documents that provide general information on early warning systems for water supply, some of which cover source water. Though these documents do not focus on distribution systems, they provide sufficient guidance on intuitive criteria that can be used for selecting sampling sites in distribution systems. The most important among these is *Online Monitoring for Drinking Water Utilities* (Hargesheimer et al. 2002), which is a study jointly funded by CRS Proaqua (Italy) and AwwaRF. It is a comprehensive reference for online monitoring for water utilities. This extensive reference covers the rationale for online monitoring (e.g., online vs. grab sample collection), selection of various types of online monitors, data management, and validation. This report also includes several case studies. Frey and Sullivan discuss utility practices regarding online monitoring and the types of parameters monitored (2002). An earlier document is *Early Warning Monitoring To Detect Hazardous Events In Water Supplies* (Brosnan 1999) which consolidates the discussions of a workshop held in May 1999 by ILSI Risk Science Institute. This workshop covered three specific areas: (1) threats to drinking water supplies from low probability/high public health impact events; (2) early warning monitoring approaches; and (3) interpretation, risk management, and public communication issues. This report focused primarily on the detection of hazardous events in source water, surface water in particular. However, some parallels are drawn between monitoring at source water and monitoring in other parts of water systems. Similarly, *Design of Early Warning and Predictive Source-Water Monitoring Systems* (Grayman et al. 2001) and its companion study *Monitoring Systems for Early Warning of Source Water Contamination* (Gullick 2001) provide useful information for locating sampling sites.

An example of an intuitive approach for water utilities is provided by Schreppel (2003a, 2003b) and Schreppel et al. (2003) who discuss the development of an early warning system at Mohawk Valley Water, NY. This early warning system included a network of ten sampling stations installed at strategic points in the distribution system. Though no specifics were provided, an intuitive approach was used to locate these sampling stations in the distribution system of over 600 miles of mains covering areas from high population densities to sparsely populated remote areas.

One of the few references related to sewer systems reports an automated on-line sewer monitoring system called "Sewer Sentinel" originally developed by CSIRO for Melbourne Water and Urban Water Research Association of Australia (O'Halloran et al. 1992). The "Sewer Sentinel" is a remote analysis system designed to measure temperature, conductivity, turbidity, pH, and dissolved oxygen of wastewater. Utilizing a submersible pump, the system is installed in sewer wet wells in suburban streets, inlet and outlet locations at treatment plants, and industrial effluent tanks. The analysis system comes equipped with a data logger. The system detects discharge events and can be configured to command an automatic sampler to collect a sample for subsequent examination and laboratory analysis. The "Sewer Sentinel" system has been implemented at several locations in Australia and Indonesia. (Cameron, undated)

### *Optimization Methods*

Optimization methods for identifying the optimal sites within distribution systems have been used for compliance sampling (to find the most representative sites), chlorine booster stations, and contaminant detection. Although compliance sampling and booster chlorination issues are different than the contaminant detection problem, the methodologies all fall under the optimal "facility location" problem in operations research, and thus provide insight into the development of useful approaches discussed in this white paper. Publications that provide relevant discussions

include Al-Zahrani and Moied (2001), Berger-Wolf et al. (2003), Berry et al. (2003), Dantsker et al. (2002), Kim et al. (2002), Laird (2003), Lee and Deininger (1992), Ostfeld and Salomons (2003, 2004), Palmer and MacKenzie (1985), Tryby and Uber (2001), and Woo et al. (2001). Some of these studies have complemented their methodology by using EPANET for simulating the distribution system network contaminant transport.

One such approach is presented by Ostfeld and Salomons (2003). They discuss a methodology for finding the optimal layout of a detection system, taking explicitly into account hydraulics, and contaminant transporting water distribution systems. The methodology provides a set of monitoring stations aimed at capturing contaminant entries within a pre-specified level of service, defined as the maximum volume of polluted water exposure to public at a concentration higher than a minimum hazard level. The sensors were assumed to be sensitive enough to detect the threshold level of contaminant. Their methodology used OptiMonitor, an EPANET based model with a genetic algorithm to find its solutions. The objective of their model was to identify the location of a given number of monitoring instruments that will detect a threshold quantity or less of contaminated water at a concentration higher than a minimum hazard level.

In a paper to be published, Ostfeld and Salomons (2004) extend their previous work by treating the demands and the injected pollution rates quantities as random variables, and by explicitly taking into account a delay between the pollution event and the monitoring equipment response capability.

Berry et al. (2003) present a mixed integer programming model for optimizing the placement of sensors in municipal water networks to detect intentional contamination. The objective is to minimize the expected fraction of the population at risk. The problem was modeled as the release of a large volume of contaminants, at a single point in the network with a single injection. For any particular attack, they assumed that all points "downstream" of the release point could be contaminated. Because where this attack would occur is not known beforehand, their objective was to place sensors that provide a compromise solution across a set of weighted attack scenarios. Flows within the distribution network were modeled with EPANET. They tested their model using synthetic risk and population data in three different networks. The authors found that the predicted sensor configuration was relatively insensitive to uncertainties in the data used for prediction.

Dantsker et al. (2002) discuss the development of a monitoring system including optimal sensor location. They use an inverse modeling algorithm of contaminant propagation that will determine the origin of the toxic discharge propagating through water utility infrastructure. The objective of their algorithm was to determine the best sensor locations for a specific pipe network. It calculated a boundary point on the pipe network where the unique location of contaminant source could be found at least with the nearest sensor. They report that an advantage of their approach was the possibility to use the results for link consecutively. The results calculated from a previous link of the pipe network could be used as input for the calculation in the next link. That made possible the application of the model to a pipe network of any complexity.

In summary, the objectives of the optimal "facility location" problem have been formulated as:

- Minimize the expected fraction of the population at risk
- Minimize the quantity of contaminated water at a concentration higher than a minimum hazard level for a given number of sampling sites
- Minimize detection time for a given number of sensors (or budget)
- Minimize detection time before a certain quantity of contaminants is consumed
- Minimize number of sensors (or budget) for a specified time interval of detection

### *Network Simulation Methods*

One of the earlier studies for locating monitors is by Lee et al. (1991). They developed the concept of contaminant pathways, related it to node demand coverage, and inferred the quality of upstream node from the quality at a downstream node. Although they do not mention the type of network model used, they demonstrated its applicability with two case studies. In a follow up publication, Lee and Deininger (1992) used integer programming to find the optimal locations of the monitoring stations.

At this time, a network simulation tool that explicitly addresses sampling site locations is PipelineNet, a model based on EPANET and tested at East Bay Municipal Utility District (EBMUD). Details of this model can be found in *Case Study for a Distribution System Emergency Response Tool* (Bahadur et al. 2003a), a project funded jointly by EPA and AwwaRF to evaluate the feasibility of using PipelineNet to monitor and predict the fate and transport of contaminants in water distribution systems. Its capabilities are reported to be (1) location of monitoring points in the distribution system, (2) timing and frequency of monitoring, (3) monitoring techniques and water quality parameters, and (4) predicting the fate and transport of contaminants to effectively respond to contamination events.

This methodology uses a hierarchical selection process and employs a stepwise approach to identify sampling locations. Initially, all the nodes of the network model are available for monitoring. This set is reduced based on accessibility of nodes and priorities set by the water utility. These may include priority areas based on flow, velocity, pressure, and water quality, and proximity to critical facilities (e.g., schools and hospitals). Additional information on PipelineNet can be found in *PipelineNet User's Guide* (SAIC 2003), and Bahadur et al. (2003b).

Other hydraulic/water quality network software currently in the market can also be used implicitly to locate sampling sites. Fontenot et al. (2003) provide a discussion of MIKE NET and cover the advantages of using a hydraulic/water quality network model with links to SCADA. This allows the model to be calibrated and validated in real-time with data obtained by the SCADA system. Like other models, MIKE NET also is used for tracking contaminant transport. Hosner (2002) and Hosner and Ingeduld (2003) provide additional information on MIKE NET. Wu et al. (2001) present an overview of WaterSafe (part of WaterCAD) for use in emergency response in distribution systems. WaterSafe combines the standard water quality model features of analyzing contaminant concentration and trace the contaminant from a particular water source throughout the system, and geospatial information of water system assets and customer information.

Panguluri et al. (2002) present the lessons learned from a real-time remote field monitoring study conducted by USEPA in Washington, D.C. Although the focus of this field study was not

security, the lessons learned provide insights to the various steps involved in establishing a real-time network. Their study covered the steps involved in selecting an appropriate online real-time sampling system, data acquisition system, security, dissemination of monitoring data, and costs associated with the project. They also provided a brief narrative of the field problems encountered during the study.

## GUIDANCE ON SENSOR LOCATION SELECTION

To the extent possible, the placement of instruments should be based on a phased approach. An initial stage might consist of expanding monitoring activities that utilities currently perform. A final stage might have an optimal number of appropriately placed sensors tied to a central SCADA system for continuous monitoring and data analysis.

### *Background*

A calibrated and relatively detailed extended period hydraulic model can be used as a tool to help a utility identify potential sampling locations. Functionality present in current hydraulic/water quality modeling packages incorporates GIS, CAD, and image data. GIS data should be available for use as base mapping or for overlay analysis to support the site selection process.

Several secondary benefits are provided by the hydraulic models now available from many commercial vendors. These models enable the user to trace the movement of constituents through the system, isolate portions of the system based on the extent of contamination, calculate volumes of contaminated water requiring flushing, and identify where system redundancy is not adequate in the case of a pipe break or isolation requirement.

This white paper presents a methodology for locating sampling sites based on work by Bahadur et al. (2003b), Lee et al. (1991), and Allmann and Carlson (2003). It recommends a combination of ranking critical facility locations and performing hydraulic analyses such as contaminant source tracing, identifying dominant contaminant pathways, and iterating to identify the best locations for monitoring.

#### Ranking Critical Facility Locations

It is recommended that potential monitoring locations be ranked following the basic methodology of Bahadur et al. (2003b). First, all nodes in the hydraulic model that are not accessible for sampling for any reason are assigned a zero. Other nodes are assigned an appropriate value indicating they are potential monitoring locations. Bahadur et al. suggest using one; the value can be adjusted when fine-tuning the locations, if necessary.

Next, pipes are scored based on hydraulic parameters, including flow and velocity. Bahadur et al. (2003b) recommend scoring using a range of 1 to 10, with 10 indicating the highest level of concern. Appropriate values of the parameters (e.g., velocity) to assign to each rank must be established for each individual system under consideration. (PipelineNet provides some recommendations for the values to be assigned.) Scores assigned can reflect the contaminant of greatest concern; for example, if the potential for disinfection byproduct formation is being

studied, lower velocities can be assigned scores of higher concern. However, since the focus in many cases will be minimizing the population exposed to a particular contaminant, it is likely that pipes with higher flow rates and higher velocities will need to be assigned higher scores. Following the methodology of Bahadur et al. (2003), if the concentration of the contaminant is known, it can also be factored into the ranking of pipes; however, it is expected that this information will not be readily available.

Similarly, pressure data obtained from the hydraulic model output can be used to assign higher scores to nodes that are of concern. Since lower pressures make a distribution system more vulnerable to cross-contamination through backpressure or backsiphonage, lower pressures will be assigned higher scores in this step.

Since the flow, velocity, and pressure data will be obtained from an extended period simulation, the question of when during the simulation to take the snapshot of data used to establish the ranking arises. It is recommended that data be obtained for each hour of an extended period simulation (EPS) and assigned scores as determined above. This way, locations with consistently high flow rates or velocities will clearly stand out from locations with flows or velocities that spike at some point during the diurnal cycle but are generally lower.

Next, critical facilities must be identified. Pipes and nodes within a specified distance of critical facilities can be assigned higher scores (e.g., 10). The appropriate radius around a critical facility can be refined over time. Thus, it is recommended that a preliminary radius be determined (e.g., by system operators) for this initial ranking, and then refined during later analysis. Critical facilities could include water system facilities such as wells, reservoirs, and water treatment plants, as they are locations where physical access to the water system typically exists. In some systems where a high level of security is in place at such locations, they may be deemed unlikely targets for intentional contamination. Other critical facilities could include hospitals, retirement communities, schools, areas of high population density, and areas that are physically vulnerable due to accessibility or lesser surveillance (e.g., on the edge of town where not many people observe activities). Base GIS data layers such as parcels, streets, topography, hydrography, and census tracts are valuable as overlays and reference information for proximity analysis as well as map making and customer notification.

Combining the scores assigned through each of the steps above should begin to yield an overall picture of potential monitoring locations in the distribution system. This step is probably most easily accomplished and is most useful through the use of a GIS.

**Performing Hydraulic Analyses**

The next step in our approach is to perform some hydraulic analyses, specifically source tracing, to confirm or further pinpoint areas where monitoring would be most helpful. A difficult and subjective portion of the overall analysis involves identifying locations in the system that would be likely for introduction of intentional contaminants. Contaminants could potentially be introduced by backflow pumping at nearly any service or hydrant location in the distribution system. However, using the information learned during the ranking effort above, a reasonable number of locations to use as the origin for contaminant introduction can be selected.

The utility should set a target detection criterion for contaminant detection; for example, a maximum amount of time that a contaminant can be in the distribution system before detection.

This criterion may vary between different contaminants being analyzed. Others have focused on setting a maximum amount of contaminant consumed (Ostfeld and Salomons 2003), but this criterion may be difficult to set because of the range of potential contaminants and reaction kinetics.

Trace analyses should be performed, using the contaminant introduction locations selected above. Although reaction kinetics can be included if a specific contaminant is identified for analysis, it is more likely that a utility will want to generalize the analysis. Thus the use of a conservative tracer is recommended. Dominant pathways for different EPS runs should be established, if possible, using the approach recommended by Lee et al. (1991). This will identify pipes with higher concentration of contaminants. Allmann and Carlson (2003) have observed that in their network models, dominant pathways existed in spite of contaminant intrusion from different locations in the network.

Furthermore, the results of the trace analyses should be evaluated to determine whether the utility's target detection criterion is met, and the approach should be refined to vary the criterion, change monitoring locations, or change the number of monitors proposed, as necessary. For example, a utility may set a criterion of detecting any contamination event within 4 hours. The trace analyses will reveal whether proposed monitoring sites are located in the distribution system within 4 hours travel time from each modeled contaminant origin. While it may be that the target detection criterion is met in all the analyzed scenarios, it may become evident that the criterion would allow exposure to an unacceptably high number of people. This step may require iteration to refine the number and location of sampling sites and to ensure that contaminant traces have been performed at enough representative locations to cover the entire system. In addition, varying the time of day of contaminant introduction may be necessary if diurnal variations in water movement through the system are significant. Also, the radius around critical locations established during the previous step may need to be changed during the iterations.

It is important to note that the outcome of these efforts may suggest areas rather than specific locations that may be most appropriate for monitoring sites. The final step would be to confirm the recommended locations through field visits to determine whether sampling equipment could be placed at or near the desired locations. The inability to physically locate monitors may disqualify some locations, and having areas in which to locate the equipment may provide more flexibility than specific locations.

**Phased Implementation**

Depending on the current monitoring capabilities and size of a utility, the guidance provided above can be implemented in phases. Prior to the identification of locations, though, the utility must decide which contaminants (or their surrogates) it prefers to monitor, its budget (capital and O&M costs) for the early warning system, and its personnel resources (both number and skill level). Furthermore, it must assess the tradeoffs mentioned earlier in this paper. The local and system wide conditions may limit the number and type of instruments it will be able to utilize, which then will determine how many sampling sites can be selected. Once these conditions are determined, then the utility can start with the phase that fits its conditions best.

- An initial phase might consist of expansion of current compliance monitoring activities. This might include adding more sampling sites to the current program to get better

coverage of the distribution system. It should also include collecting samples more frequently, and monitoring for additional parameters. The sampling frequency must be more often than the average water age in the distribution system.

- A second phase might consist of changing periodic sampling to continuous sampling at some or all locations.
- A third phase might be upgrading some of the sensors to those that have superior capabilities such as monitoring a wider range of parameters, lower detection limits, fewer false negatives and positives, etc.
- A final stage might have an optimal number of appropriately placed sensors tied to a central SCADA system for continuous monitoring and data analysis.

When selecting the sites, the following recommendations are offered:

1. Using the criteria listed under "local site conditions" and "system wide conditions", the utility should identify as many candidate sites as practical.
2. If the utility has a functional and well-calibrated network model, it should follow the guidance discussed above to determine the dominant contaminant pathways. If the utility does not have such a model, then using its knowledge of the system, it should make educated guesses on where the dominant pathways might be.
3. If the utility has limited resources, it should select existing compliance sampling locations close to the dominant pathways, and start collecting samples there. Alternatively, with state regulatory agency approval, it might be able to move its compliance sampling points to locations that are better suited for contaminant detection monitoring. If the utility is not restricted in its resources, then it could select the best locations based on its hydraulic analysis.

**Summary**

These steps provide a well-rounded approach to identifying appropriate sampling locations. The approach utilizes hydraulic modeling in conjunction with pertinent knowledge of distribution system facilities, critical customers, and dense service areas. The result of considering these variables and ramifications from water contamination is a sampling plan that provides monitoring of key parts of the distribution system in support of minimizing contamination risks to customers. Such a plan will likely place sampling locations at water supply points, near critical customers and areas of dense population, and at key points based on hydraulic tracing analyses. Although the steps and tools presented here offer a methodical approach, the need for engineering judgment and institutional knowledge of a distribution system during the iterative analysis should not be overlooked. It is expected that a utility's sampling plan will be refined over time, as more knowledge of best monitoring practices is learned and monitoring technology improves. However, with many possible contaminants, a large number of potential contamination sites, and limited budgets, this approach will provide utilities with a solid next step towards protecting their customers.

## CONCLUSIONS

The methods for selecting sampling locations to detect contaminants within a distribution system network have been either intuitive or academic. Intuitive methods cannot account for the variability and uncertainty inherent in the intentional or unintentional contamination of water distribution systems. On the other hand, academic approaches such as mathematical programming are currently too complicated for the water utilities to implement on their own. Furthermore, little guidance has been available to utilities that do not have the resources to develop such sophisticated approaches. Currently, for water distribution systems, hydraulic/water quality network models are the most practical tools for identifying the candidate locations for monitoring instruments and sensors.

For wastewater collection networks, however, little, if any, information was found for locating sampling or monitoring stations for contamination. The current practice appears to be locating them in wet wells, manholes, and at key facilities, but no guidance was found on the optimal selection of these locations. Regardless, the local site conditions discussed earlier should help identify locations for sewer systems also.

It is apparent that the identification of sampling locations is an iterative process involving many diverse sources of information and will be different for every utility. A utility will also be able to shape the analysis by identifying policy direction prior to the evaluation. Ultimately a series of steps would be undertaken based on the analysis described above that would allow the utility to identify a number of targeted sampling locations.

The number of sampling points recommended by the analysis will probably be higher than what a utility with a limited budget can implement. In this case, additional prioritization will be required to identify the relative importance of each of the parameters represented by the steps. Several iterations may be required before an acceptable number of locations can be identified. Another option would start with a desired or target number of sampling locations. However, it may prove valuable for the utility to go into the process without any expectation of the target number of locations, allowing the process to identify an appropriate number.

A knowledge-based risk assessment evaluation for each utility of the local site conditions and system wide factors discussed earlier is advised before conducting any detailed hydraulic analysis. Such an assessment will help narrow the number of iterations and analyses and, ultimately, the number of monitoring locations recommended.

It is also important to note that the quality of the predictive information from the utility's network model will be only as good as the investment made in developing that model and the skill and experience of those operating it. Of particular importance is a spatially accurate demand allocation and true model representation of operational settings. The quality of the network model is validated by performing comprehensive steady state and extended period calibration prior to any use of the model as a predictive tool.

Regardless of the method used for selecting sampling sites, local conditions will ultimately determine exactly where an instrument can be installed.

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# Methodology and Characteristics of Water System Infrastructure Security: Section 5.5 - Data Analysis

**Submitted to**

**American Society of Civil Engineers**

**Prepared by**

Kenneth Carlson
David Byer
John Frazey
Department of Civil Engineering
Colorado State University
Fort Collins, CO

John Cook
Charleston Public Works Department
Charleston, SC

Edwin Roehl Jr.
Advanced Data Mining, LLC
Greenville, SC

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## Section I. Introduction and Background

With recent contamination events in drinking water distribution systems causing significant illness in affected communities, and the threat of intentional contamination being of increased concern since September 11th, 2001, a lot of effort has been placed on detecting contamination events in the distribution system real-time. Real-time water quality monitoring raises several questions concerning best management practices for the collection, formatting, and communication of this data. In addition, one of the many advantages of continuously monitoring water quality in the distribution system is having large data sets that will be available for analysis. Given these large data sets, what is the best way to analyze this data to get the most from it? How would alarm triggers be established to prevent false positives or negatives, and to ensure that contamination events are detected at the lowest possible level? Finally, what would the response protocols be for utilities when an alarm is triggered?

This white paper will examine guidelines that could be used in the design of the data analysis plan for continuous monitoring systems. Key components of these guidelines will include best management practices for collecting, formatting, and communicating the data output that is provided by the online instruments, and management issues associated with utilizing the data from these systems. This white paper also includes a data mining case study that used multivariate analysis to detect and characterize contaminants in the distribution system using online monitors. This case study demonstrates the potential of utilizing advanced data analysis techniques to detect and potentially identify credible threat chemical contaminants using on-line monitoring of water quality surrogates.

## Section II. Data Collection/Formatting Guidance

Water suppliers typically use Supervisory Control and Data Acquisition (SCADA) technology to acquire, process, and utilize data on-line. SCADA systems include the means for connecting instruments to other system components, including programmable logic controllers, remote telemetry units, and a host computer, as demonstrated in Figure 1. Monitoring instruments are connected to remote telemetry units or programmable logic controllers to convert instrument outputs to appropriate units, compare the instrument responses to programmed criteria, generate alarms if required, and send control signals to other equipment. The host

computer polls the PLCs and RTUs for data, and in some systems, analyzes this data and provides specified information to system operators.

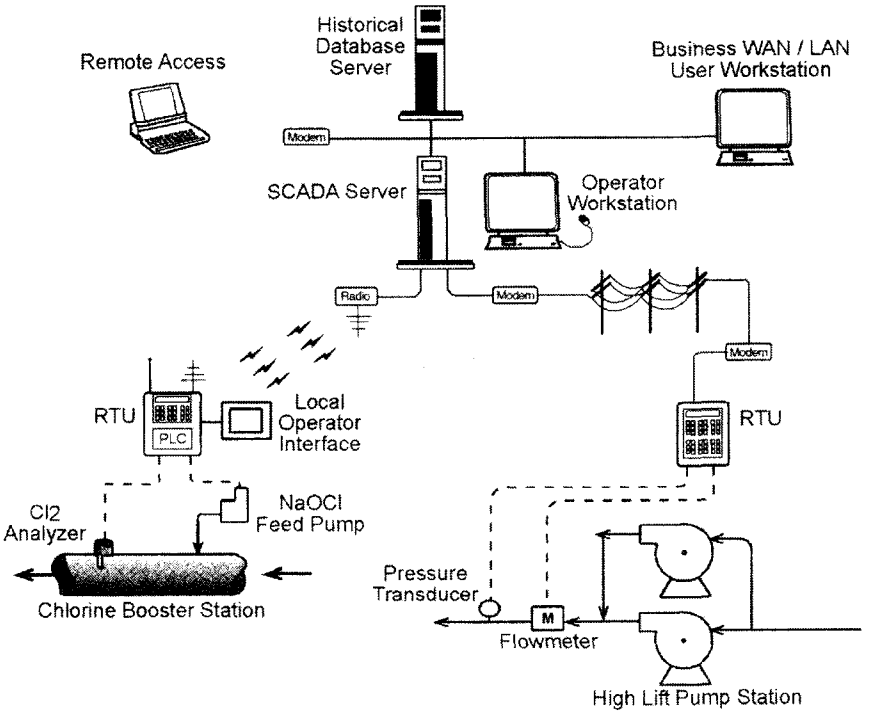



**Figure 1.** SCADA system with typical components (AWWARF, 2002).

Factors important in determining which SCADA system to use include life-cycle cost, ease of use, ability to program locally, redundancy of data and system, cyber security, accessibility from remote locations, ability to store, trend, and transfer data, report generation capabilities, graphics, and the ability to communicate with existing software (Pangulari, 2002). Considering security, care should be taken to separate the SCADA system from other internet based software applications to reduce the chance of introducing viruses, and to eliminate the chance of losing control of the system to outside interests. In addition, isolating SCADA systems from other systems will prevent potential system crashes due to systems competing for bandwidth. Other significant factors include the ability to import electronic data from other sources (e.g. laboratory information management systems LIMS), input grab sample results manually as required, two-way communication between the SCADA system and other software

applications for analysis and graphical interpretation of the data, and capability to interface with GIS systems (AWWARF, 2002).

Additional improvements that should be available in newer systems more aligned with signal technology include: the use of digital rather than analog signals to improve resolution, the use of optical fiber technology to improve signal speed and clarity, and continued development and standardization of advanced data analysis techniques to aid in decision making (AWWARF, 2002). Additionally, closed loop systems should be used to continuously signal that the system is working. Table 1 provides a summary of important considerations that need to be addressed when utilizing a SCADA system.

**Table 1.** Summary of SCADA system considerations.

| General Considerations | Security Considerations | Signal Considerations |
|---|---|---|
| Life-cycle cost | Isolation of the SCADA system from other internet based software applications | The use of digital rather than analog signals |
| Ease of use | Ability to import electronic data from other sources | The use of fiber optics technology |
| Ability to program locally | Input grab sample results manually as required | Advanced data analysis techniques to aid in decision making |
| Redundancy of data and system | Two-way communication between the SCADA system and other software applications | Closed loop systems |
| Cyber security | Capability to interface with GIS systems | Error detection systems |
| Accessibility from remote locations | | Parallel systems |
| Ability to store, trend, and transfer data | | |
| Generation capabilities | | |
| Graphics | | |
| Ability to communicate with existing software | | |

In addition, error detection and the reduction of false alarms needs to be discussed. Error detection systems usually incorporate both hardware and software support. Hardware error detection systems typically incorporate alarms similar to those that would be generated for a

contamination event. A better approach may be the use of parallel systems, especially when trying to detect anomalous behavior. If both systems generate an alarm condition, then some confidence exists that the particular monitor or SCADA system component in not in error. Software error detection looks for and classifies anomalous behavior. This is covered thoroughly in the case study at the end of this paper.

## Section III. Management Issues Associated With Data Analysis

On-line monitors should have the capability to store data at the instrument location before it is transmitted to a centralized location. This will ensure that a back-up of the original data is available in the event that any data is lost or changed during transmission. Data that is received from monitoring sites should be reconciled with the data at the instrument locations regularly to ensure data accuracy and completeness. Centralized data management allows the data to be analyzed, whether automatically or with human intervention, before the data is used to generate changes in processes or generate alarms. This would be an important aspect of reducing false positive and negative signals in a security setting.

**Table 2.** Summary of Management Issues Associated with Data Analysis

| | |
|---|---|
| I | Storage of data at instrument location |
| II | Reconciliation of data at central site with remote locations |
| III | Centralized data management |
| IV | Checklist of known, expected alarm conditions |

Alarms will signal anomalous events, and will be triggered for many potential reasons outside of a system breach or contamination event. Water providers should prepare a checklist of known, expected system changes that will likely generate alarms, with annotations as to how the on-line monitors may respond. Examples include:

- changing the source water
- distribution system flushing
- water treatment plant operational changes
- seasonal water quality changes

- source water blending changes
- invalid data points (missing data, data out of range, peaks, or constant values)
- emergency events (e.g. fire hydrant use)

These events and many others should be captured in the system water quality baseline, so that when these events happen and an alarm is triggered, it is easy to identify the source of the alarm, note it, and continue operations if appropriate. Any system with an unacceptable number of false alarms will be quickly discounted by staff. It is imperative that every feasible measure be taken to ensure that this does not happen.

In the event that the data generates an alarm, a standard format for presentation to decision makers must be decided upon. There is a fine line between presenting useful, timely information, and overwhelming a decision maker with too much information. In general, the following should be presented as a minimum:

- The initial data that generated the alarm including location and time of the event that generated the alarm.
- Verification of this data whether it be in the form of similar instrument responses at multiple locations or secondary analyses like toxicity screening indicators
- Data that would provide information on either the source of the event or a prediction of where the contaminant slug will have the greatest impact -- from hydraulic models or GIS systems
- A brief explanation of exactly what the alarm means in terms that the public would be able to understand
- A list of options that are being considered for mitigation including actions that are required in the short term (e.g. public notification)
- A list of other agencies that need to be informed if the public health of a community is in question. A list containing these agencies and the status of these notifications would be important information for the decision maker to have

## Section IV. Setting Alarm Triggers/Data Analysis Techniques

There are two general areas to consider when establishing alarm triggers: the methodology, and the goal of reducing false alarms. Concerning methodology, the use of univariate data analysis may be considered, as well as the chance to use inputs from all instruments simultaneously to detect anomalous behavior--or multivariate analysis.

Univariate analysis looks at one parameter at a time, with the intent of noting a change in a specific parameter or instrument response due to a change in water quality. For example, there are four instruments at a remote location monitoring chlorine residual, pH, turbidity, and conductivity. In response to a change in water quality, the turbidity reading increases significantly. This may be cause for alarm, but at what level, and after how much time? Did the *peak* turbidimeter response indicate a problem, or was there a pre-established alarm of two or three sigma variation from the baseline that generated the alarm? The important point here is that only the turbidimeter response was considered because it independently set off an alarm, and because it had the most significant instrument response. This single instrument response is can be useful when determining instrument response to different contaminants, and also in validating other similar instrument responses in the distribution system when considering potential false positive and negative alarms.

However, multivariate response opens up several opportunities. Those include utilizing the instrument response from all instruments simultaneously to detect anomalies sooner, and to learn more about the changes in water quality to potentially learn something about the cause of the alarm--notably the type of contaminant that generated the alarm.

Regardless of the methodology used, new data points will need to be compared to a baseline. This baseline should be extensive, covering all known potential expected variations. The minimum established baseline may very well include at least a year of data collection to capture seasonal water quality variation, and operational changes that typically occur. Having this baseline, and documenting the effects of normal system changes will be key to reducing false alarms. Univariate analysis may be as simple as setting alarm triggers on each instrument. (an example of univariate analysis is provided in white paper 2, Candidate Instruments and Observables). If the instrument spikes, and is outside of plus or minus three standard deviations from the baseline mean for example, that could identify either an instrument error, or a true water quality degradation. A second similar system, either in parallel or downstream, may be important

for determining the validity of this signal. If multiple water quality surrogates were being monitored, it should be suspected that if one water quality parameter (e.g. pH) changed, one would expect to see a change in conductivity, chlorine residual, or maybe turbidity. This may provide another potential way of validating an alarm condition. The use of multivariate analysis is more sophisticated and would require software to process the data, and turn the raw data into information that could be used by system personnel. One benefit of multivariate analysis may include the option to lower limits of detection of a contamination event, thus providing an earlier warning, and more response time. It may also include not only the trigger of an alarm, but may be able to provide an identification of the contaminant.

The most robust data analysis systems would not choose between univariate and multivariate data analysis systems, but would use both. As expressed previously, univariate analysis offers a built-in instrument check and balance, providing data on what a particular instrument is seeing, and providing the option to compare it to other similar instrument signals. Multivariate analysis offers a potentially quicker trigger of an alarm condition, and in a well established system, the potential to identify the cause of the alarm. Alarm triggers will vary per system, depending on the complexity of the system, its baseline conditions, and ability to support univariate and/or multivariate analysis.

## Section V. Multivariate Analysis as a Decision Making Tool

A combination of conventional sensors and intelligent software can be the basis of a readily deployable, high performance, low cost and reliable security monitoring system. The types of sensors envisaged are already widely used to measure water chemistry properties, such as specific conductance, pH, and residual chlorine. Indeed, experimentation has shown that toxin concentrations well below LC50 change water chemistry in significant and measurable ways.

The capabilities of the intelligent software should include automatically learning and remembering "normal" patterns of water quality measurements; detecting unprecedented patterns (anomalies) that could indicate an attack; generating alarms; and making recommendations to operators about what to do. Additional capabilities could include automated recognition (classification) of toxin types, and predicting concentrations and fate and transport within the distribution system.

To evaluate the potential of this concept, four threat chemical contaminants and commercial-off-the-shelf water quality sensors were used in combination with intelligent software by Charleston Public Works, Colorado State University (CSU), and Advanced Data Mining, Inc (ADMi). In this study, four credible threat contaminants, sodium arsenate, sodium cyanide, sodium fluoroacetate, and aldicarb were injected into a bench-scale distribution system loop at various concentrations that was pressurized with local finished water to determine on-line instrument response. Figure 2 indicates that the univariate response of sensors to the injected contaminants can sometimes be seen in the collected data by inspection. The horizontal axis is in minutes from data acquisition startup. The vertical line at about 200 minutes gives the time of injection, which is followed by a delay connoting transport time of the chemical to the sensor array.

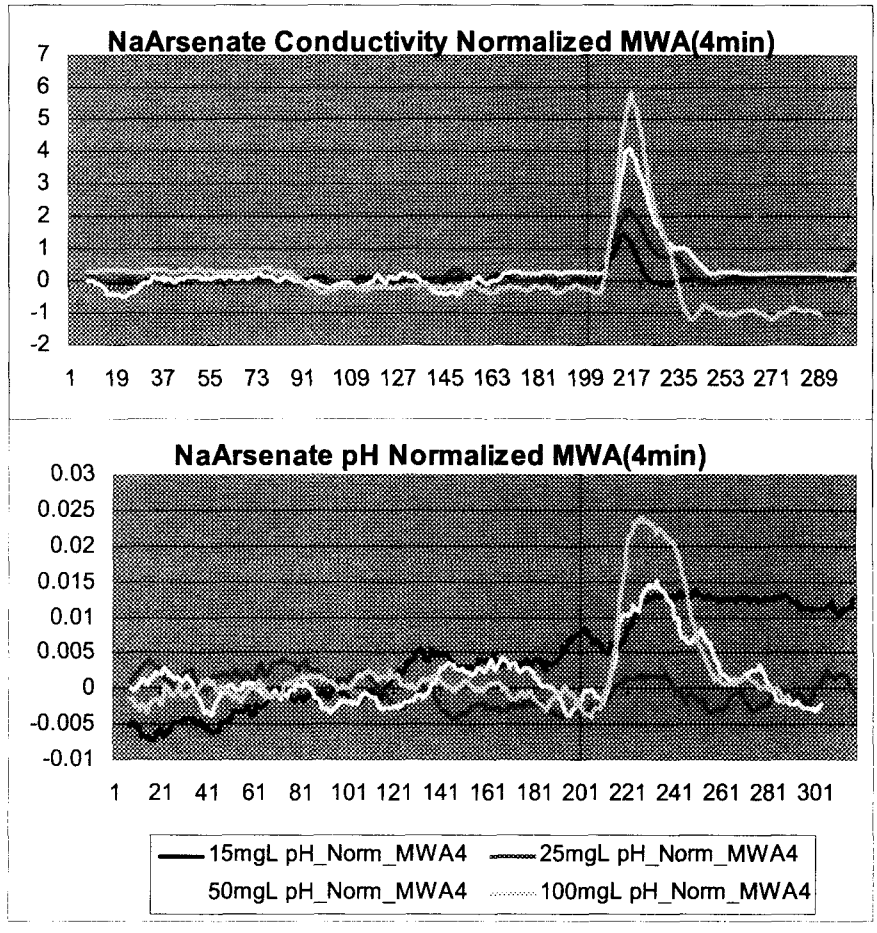



**Figure 2** Univariate response to sensors.

Given that an important part of the security challenge is discriminating an anomalous event in a background of normal variability, techniques that included state vector clustering and artificial neural networks were applied to the data. These techniques were not only able to automatically detect the onset of injection, but could also determine the chemical type. These early results support the soundness of this approach to distribution system security.

**Decision Support System Functional Requirements:** The concept of intelligent computer programs assisting process operators is very appealing because it is broadly recognized that

increasing regulation, security, and process complexity are making it difficult for them to keep all bases covered all of the time. Given the added challenges of continuously assuring security, it is easy to imagine that there might be no other alternatives. Consider the following problems:

- Vigilance – detecting problems in real-time requires around the clock monitoring of many variables.
- Diagnosis Difficulty – can a deliberate attack be differentiated from any one of a number of mundane problems, e.g., sensor failures or a main break? At the onset of a problem, does it matter to operators? Accurate diagnoses might not come until later, yet the goal is to handle every potential threat regardless of cause.
- Data⇒Information⇒Knowledge – data is transformed by the computer into information through inference, pattern matching, or by other means. Knowledge can only be disseminated to operators by explaining these transformations.
- Ambiguity - there will be occasions when multiple courses of action must be recommended because it is unclear which is best.
- Needs that Exceed Human Capabilities

The Decision Support System (DSS) can succeed only through the integration of multiple, advanced computing technologies. They will be arrayed as levels of software components that lie between the water chemistry in the distribution system and ultimately the advisories passed to operators through their SCADA system. These levels are described below.

**Data Collection:** Conventional, commercial SCADA systems comprised of sensors, communications, databases/process historian, and operator-interfaces are generally adequate for the DSS. SCADA also provides data validation (e.g., range checking), data filtering (e.g., moving window averaging), and control of equipment such as pumps and valves. SCADA systems are normally augmented with Laboratory Information Management Systems (LIMS) for storage/retrieval of laboratory data collected for regulatory and process monitoring.

**Diagnosis:** Options for detecting anomalies in water chemistry include Rule-Based Systems (RBS) and Cased-Based Systems (CBS). RBS are comprised of IF-THEN rules to provide real-time reasoning through programmed schedules that loop through rules and poll for new data. A problem with RBS is that they are developed using complex programming languages that require custom implementations for each site. A CBS operates by comparing a collection (vector) of measurements that represent the process' current state to a historical database of previously evaluated states, and determining if the current state is similar to those seen in the past. The CBS contains several components and features:

- A Case Base for storing and retrieving cases that are comprised of state vectors, actions taken, and results.
- Process State Characterization – states can be manually specified by process experts, or automatically discriminated from a historical collection of state vectors.
- Process State Identification – given a new state vector of measurements, the CBS must retrieve similar cases from the Case Base to identify the new process state and determine needed actions. Retrieving similar cases requires a pattern matching methodology such as a classifier.
- Case Addition/Adaptation – new cases representing previously unknown process states and actions can be entered into the Case Base using information provided by process operators. They may be adaptations of known cases.
- Machine Learning - achieved by adding new cases to the Case Base or by modifying existing ones.

**Decision Support:** Decision support occurs by assessing the current process state and determining what needs to be done. When there is a poor match with the Case Base, operators are notified that the process is in an unknown state and directed to start looking for a problem by following a prescribed protocol. A predictive "what if" process model can be used to evaluate scenarios and determine the best way to proceed. Once the problem has been mitigated, a new case can be created and added to the Case Base.

**Action Plans:** Plans are defined as sequences of actions to be taken in the event of a problem of known or unknown origin. Their efficacy will vary with the degree of certainty about a problem's origin. A hydraulics model can be helpful for evaluating distribution system behavior to help create action plans.

**Performance / Deployment Criteria:** The objective of traditional installations of sensors and control has been to avoid problems of a conventional nature and to improve operational efficiency. While it is accepted that a good security system might also be valuable for general

operations, the reverse is not true. Below are a number of reasons why security threats are special.

- Surprise – security threats appear without warning. There is a critical need for the earliest possible detection of a potential problem to give operators the most time to act.
- Velocity – they might evolve quickly. The system must evaluate multiple factors simultaneously to quickly provide guidance on corrective actions.
- Magnitude – they are designed to have a large impact.
- Randomness – they can take on innumerable forms. It is unlikely that there will be a relevant case in the Case Base if a terrorist strikes.

The above imply DSS performance criteria that can be expressed in terms of sensitivity, speed, and reliability. The need for a system that can be quickly and affordably installed in distribution systems of all sizes establishes the following additional criteria.

- Leverage Existing Infrastructure – the system must easily integrate with existing SCADA systems, which can already check individual sensors and poll them at high frequencies.
- Generality – approaches that require detailed, site-specific knowledge of a process' physics are inherently difficult and expensive to develop and maintain. Alternatively, detecting anomalous process states by comparing them to a Case Base of previously characterized state vectors is a generic methodology that is suitable for a wide range of monitoring applications. In addition, general recommendations based on studies for sensor suites and sampling frequencies, which are matched to different processes, could make CBS-based installations straightforward and widespread. Action planning would remain necessarily site specific, though industry guidelines would be helpful.
- Costs - the technical skill level and time to develop the more site-specific conventional process models and expert systems are high because of the mathematics, chemistry, and programming involved. The more generic CBS with recommendations for sensors could be made operational by plant staff or industrial systems integrators.

The National Science Foundation (NSF) has recently awarded a project to Carnegie-Mellon University titled, "Sensors: Placement and Operation of an Environmental Sensor Network to Facilitate Decision Making Regarding Drinking Water Quality and Security," award number 0329549. The outcome of this project may provide valuable information in the future regarding topics in this white paper. A good summary of this effort is available in SIGMOD Record, Vol. 32, No. 4, Dec 2003, available at http://66.102.7.104/search?q=cache:wl6gwV2JT7gJ:www.acm.org/sigmod/record/issues/0312/10.ailamaki03.pdf+Placement+and+Operation+of+an+Environmental+Sensor+Network&hl=en.

In addition, a proprietary algorithm that addresses some of the requirements described in this section has already been developed by the Hach Company, and will be fielded shortly in conjunction with the purchase of their continuous water quality monitoring equipment. It offers the potential to detect and identify contaminants based on continuous monitoring equipment responses. It compares sensor signals to a library of contaminant "fingerprints" that were determined from laboratory contaminant-instrument response studies, allowing it to "recognize" previously determined instrument responses to known contaminants (King, 2004).

## Section VI. Intelligent Software Technologies

The increases in the processing power of computer hardware have been mirrored by advances in algorithms for characterizing, monitoring, and automatically reasoning about complex physical processes. These algorithms can be combined in ways to develop intelligent systems like the DSS. Below are descriptions of the most important algorithms to be employed.

**Chaos Theory and State Space Concepts:** Chaos Theory (Abarbanel, 1996) is a new science that characterizes and models physical systems whose behaviors are highly sensitive to small changes in boundary conditions, such as the injection of a toxin into a water main. "State space reconstruction" is the workhorse of Chaos Theory. It describes how systems change from one state to another in time, and proposes that each new state is derived largely, but not entirely, from previous states.

As shown in Figure 3, each state is characterized by a "vector" of measurements for monitored process variables at each "time step". A vector having n elements (for n variables) is said to be "n-dimensional". The figure on the next page (left) shows that a vector denotes a point in "n-space". Figure 4 shows that as a process changes in time, it leaves a track of points in n-space, which represents a state history. A processes' recent state history can be used to predict near-term future states by curve fitting. The sudden tracking of a process into a previously unpopulated region of n-space could signal a terrorist attack.

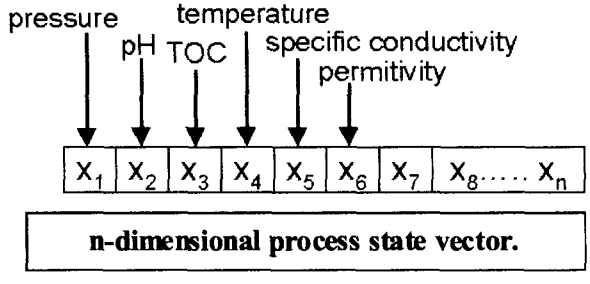
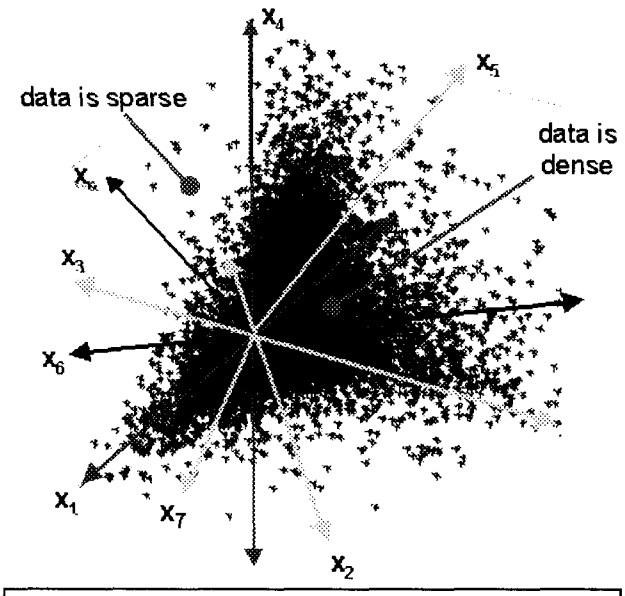
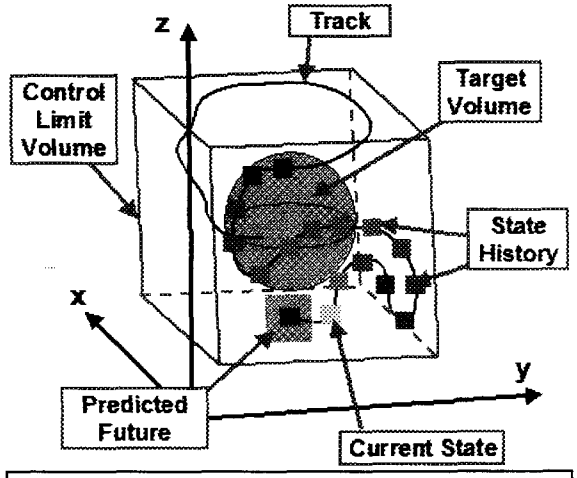



**Figure 3** Water Quality Surrogates as State Vectors.




**Representation of data points, whose coordinates are given by state vectors, in an n-dimensional state space (n-space).**

***Figure 4*** *Data points in n-space.*




**Sequence of process states represented as a track in 4-space (x, y, z, t).** Upper and lower control limits for variables x, y, x can be represented as a box. Near-term future prediction based on near-term past states can be used to predict a future state.

***Figure 5*** *Tracking of process state in 4-space.*

***Machine Learning, Case-Based Reasoning, Clustering and Classification:*** *Machine learning focuses on methods that allow the computer to automatically learn from example cases. "Rule induction" is a methodology that automatically generates "knowledge bases" (KBs) of IF-THEN rules, which can in turn be represented as decision trees. KBs can be made more capable or made to adapt to changing conditions using rule induction. Similarly, Case-Based Reasoning (CBR, a.k.a. reasoning by analogy) solves a current problem by retrieving best matches of previously solved cases from a database. The best matches are then modified according to the specifics of the new problem. Adding cases to or removing them from the CBR database offers a mechanism for incremental or adaptive knowledge development.*

Clustering and classification methods offer an approach to CBR that works well with large amounts of numerical data having imprecision and uncertainty. Clustering (Weiss and Indurkhya, 1998) optimally sub-divides state vectors, which represent process behavior, into groups (a.k.a. classes) according to their relative nearness in n-space. Commonly used clustering methods include k-means and self-organizing maps. Classification is the assigning of a new state vector to the class containing vectors that are most like it. For a linear method, such as a "nearest neighbor classifier", this

means simply the class having the nearest mean value. Non-linear classifiers effectively vary the relative importance (weight) of each state vector element in a way that depends on which class the state vector is compared to. Artificial neural networks (see below) are commonly used as non-linear classifiers.

**Anomaly Detection:** Anomaly detection algorithms compare a new state vector's position in n-space relative to historical vectors that have been previously characterized and stored in a reference database. The new vector is judged to be "normal" or "not normal", with the latter generating an alarm and triggering a call to action. Machine learning is implemented by adding to or modifying vectors in the reference database. A large distribution system would need multiple anomaly detectors to monitor different parts of the system. Different anomaly detection algorithms are described below.

**Convex Hull:** As shown in Figure 6, a convex hull fits a surface to the state vectors in n-space. The surface creates a boundary between "normal" and "not normal" sub-regions. A new state vector can be evaluated for its "inside" / "outside" / "nearness" to the convex hull boundary. Machine learning is achieved by adding new "normal" vectors to refine the hull. Convex hulls have been used for detecting computer network intruders, where the types of assaults made by hackers can be infinitely varied.

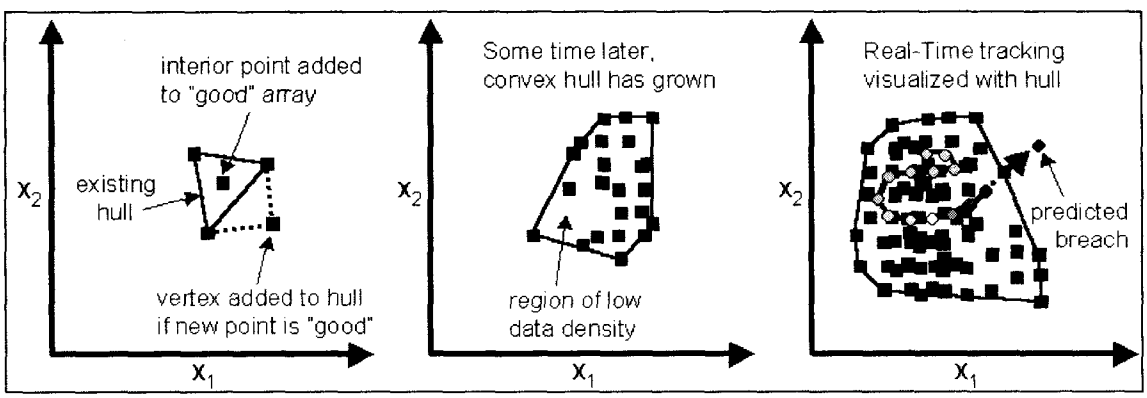



**Figure 6** 2-Space Convex Hull Example.

**Clustering and Classification:** As shown in Figure 7, clustering sub-divides a set of state vectors into classes. The state vectors assigned to them, called their "basis vectors",

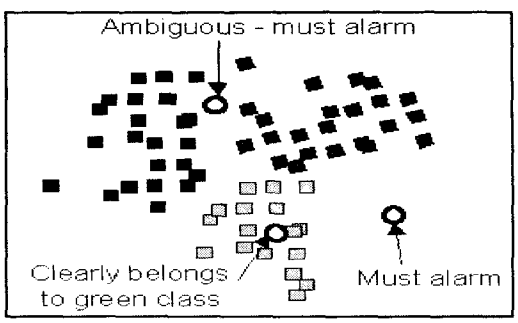



**Figure 7** 2-Space Clustering and Classification Example

effectively define the classes. A new vector is assigned to one class or another using a "classification" algorithm such as "nearest neighbor" or an artificial neural network. The distance between a new vector point and its assigned class' geometric center provides an alarm criterion. Machine learning is achieved by adding new "normal" vectors and re-clustering

**Spectral Pattern Perturbation:** As shown in Figure 8, spectral pattern perturbations are detected by using the power spectra of time series variables to characterize "normal" behavioral patterns. Adding a new state vector to a "standard" pattern will change its spectra by some amount, establishing an alarm criterion. Multiple variables, each with its own standard pattern, can be used and a composite change evaluated. Machine learning is achieved by adding new "normal" measurements to standard spectra data.

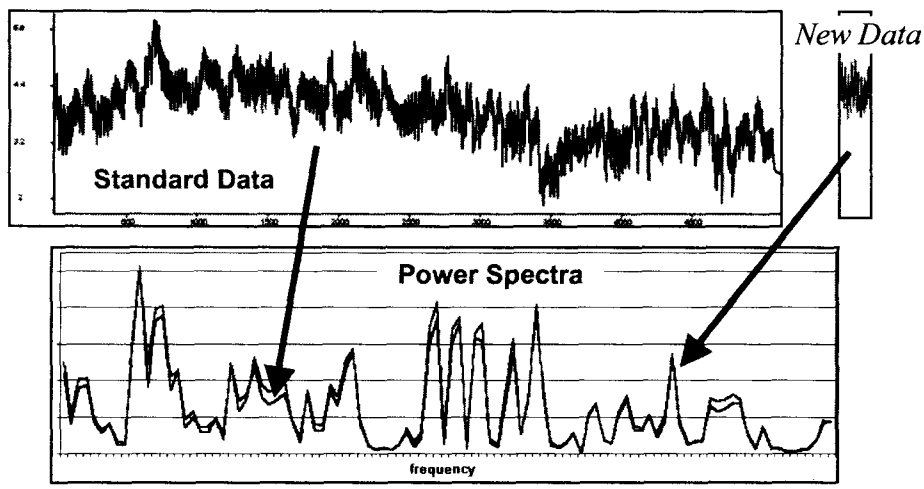



**Figure 8** Spectral Pattern Perturbation Example Using a Single Variable.

**Empirical Models and Artificial Neural Networks:** Artificial Neural Networks (ANNs) are a form of machine learning that has had great success in process industry applications. They involve fitting numerical data with empirical correlation functions (a.k.a. curve fitting). Figure 9 shows data

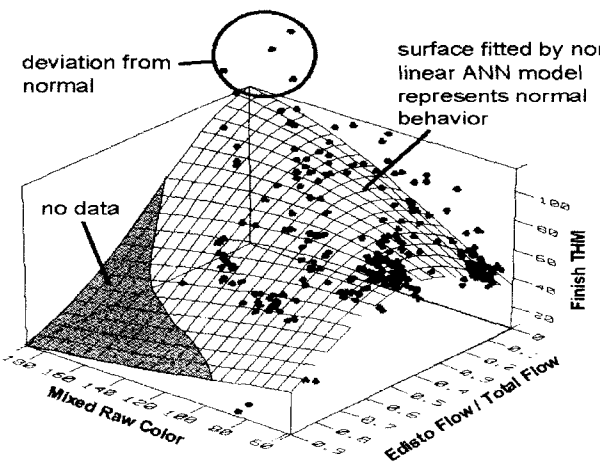



**Figure 9** Process data plotted with ANN response surface.

Points from a water treatment process plotted in 3-space. A surface has been fitted by an ANN model, which can fit behaviorally complex data (Rosenblatt 1958, Rumelhart et al. 1986). The surface is obviously non-linear and matches the process data quite well, though imperfectly. Recognize that the data itself is imperfect (noisy), and that there are other "unshown" process variables at play. Another method having capabilities similar to ANNs are Multivariate Adaptive Regression Splines (Friedman 1991, Dwinnell 2000).

ANNs have seen broad application for prediction models for virtual sensor and advanced process control applications (Jensen, 1994). Virtual sensors, a.k.a. inferential sensors, can be used to predict in real-time values for measurements that are too time consuming or costly to measure continuously, e.g., trihalomethanes. Process models can also be used to determine "what ifs" for evaluating alternative courses of action to achieve process optimization (Devine and Roehl, 2003). Like rule induction and CBR, numerically-based machine learning methods can be made more robust by manipulating the case data from which they are derived. However, they also provide unmatched interrogative performance and synergy with advanced visualization techniques to impart broad and deep process knowledge to users.

The case study that follows will apply the contaminant-instrument response data that has been discussed with data mining techniques to demonstrate the potential to detect and classify threat chemical contaminants in a drinking water distribution system.

## Section VII. Case Study Utilizing Data Mining Techniques to Detect Distribution System Contamination

Preliminary research using the data collected by CSU investigated the effectiveness of a number of methods for detecting and characterizing toxins that might be introduced into a water distribution system. The methods included clustering, classification, and ANNs. The measurements included pH, specific conductivity (SC), chlorine residual, total organic carbon (TOC), and turbidity. Four toxins were tested at various concentrations that were percentages of LC50 (50% mortality). The four toxins were 1080, Aldicarb, NaArsenate, and NaCN[5].

[5] 1080 and Aldicarb are organic compounds, while NaArsenate, and NaCN are inorganics. 1080 (a.k.a. sodium fluoroacetate, monofluoroacetate, fratol, furatol, ratbane, and yasoknock) is a rodenticide that has been previously used in the United States to control gophers, squirrels, coyotes, and prairie dogs, and is presently banned (Eisler, 1995). Interestingly enough, Verschueren (2001) lists fluoroacetic acid as a chemical warfare agent. 1080 is a deadly human poison by ingestion (Sax and Lewis, 1989). Aldicarb is an extremely toxic carbamate insecticide that is still presently in use. It is a cholinesterase inhibitor, causing respiratory failure or cardiac arrest due to central nervous system paralysis, potentially leading to death (Manahan, 1992).

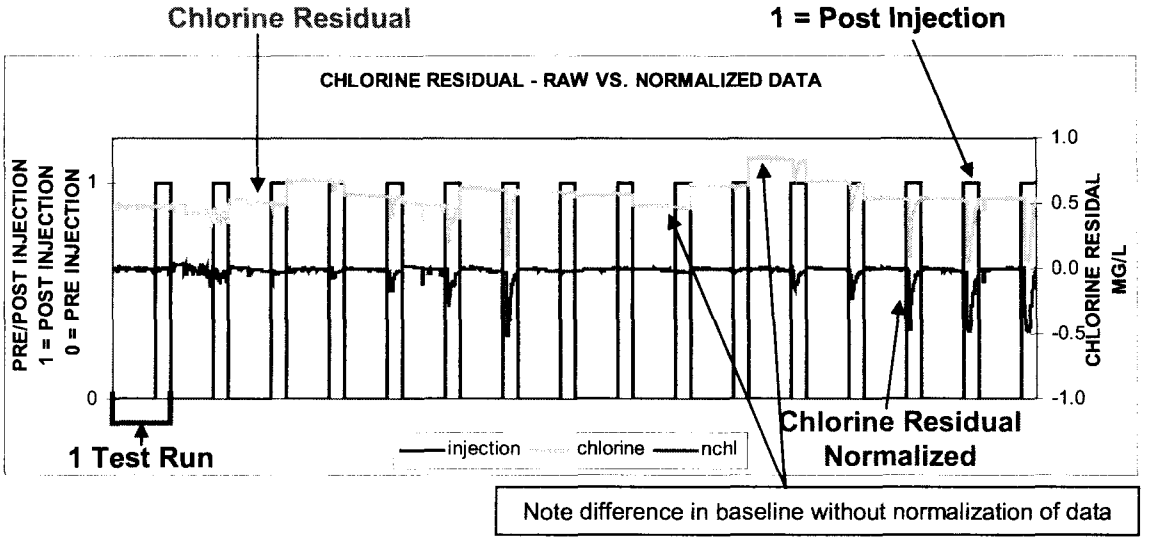



**Figure 10** Comparison of normalized vs. raw chlorine residual time series data.

**Normalization of Data Prior to Analysis.** Figure 10 illustrates the need for normalizing sensor outputs. Shown is the chlorine residual for all 16 experimental runs concatenated together, comprising four toxins at various concentrations. Each run consisted of a 100-minute pre-injection period followed by 35-minutes of post-injection. The duration of chemical injection was four minutes.

CSU's data comprised 16 test runs – 3x 1080 concentrations, 4x Aldicarb, 4x NaArsenate, and 5x NaCN. Due to mixing and a transport delay, water chemistry impacts would peak a few minutes after the onset of injection and then decay exponentially as the system was purged with clean water. Sampling was at 30-second intervals. The figure above shows the output of the chlorine residual sensor as raw data (mg/L) and as normalized data calculated by subtracting an average of the baseline. Normalization allows one to more clearly see how sensor response varies by chemical concentration.

**Clustering Water Chemistry State Vectors Into Classes**

The objective of this first analysis was to determine if clustering could automatically discriminate between pre and post injection data. The water chemistry time series were first organized into state vectors comprised of normalized 1-minute time derivative and 2-minute moving window averages (MWA) for each sensor. The top figure on the next page shows the results of clustering each toxin/concentration dataset into 2 classes. For each toxin, the green line

represents the class to which each vector is assigned by the clustering rountine. Ideally, all pre injection vectors should be assigned a 1 and all post injection vectors assigned a 2. It can be seen that discrimination for 1080 and NaArsenate is poor at all concentrations, but good for Aldicarb and NaCN, especially at higher concentrations.

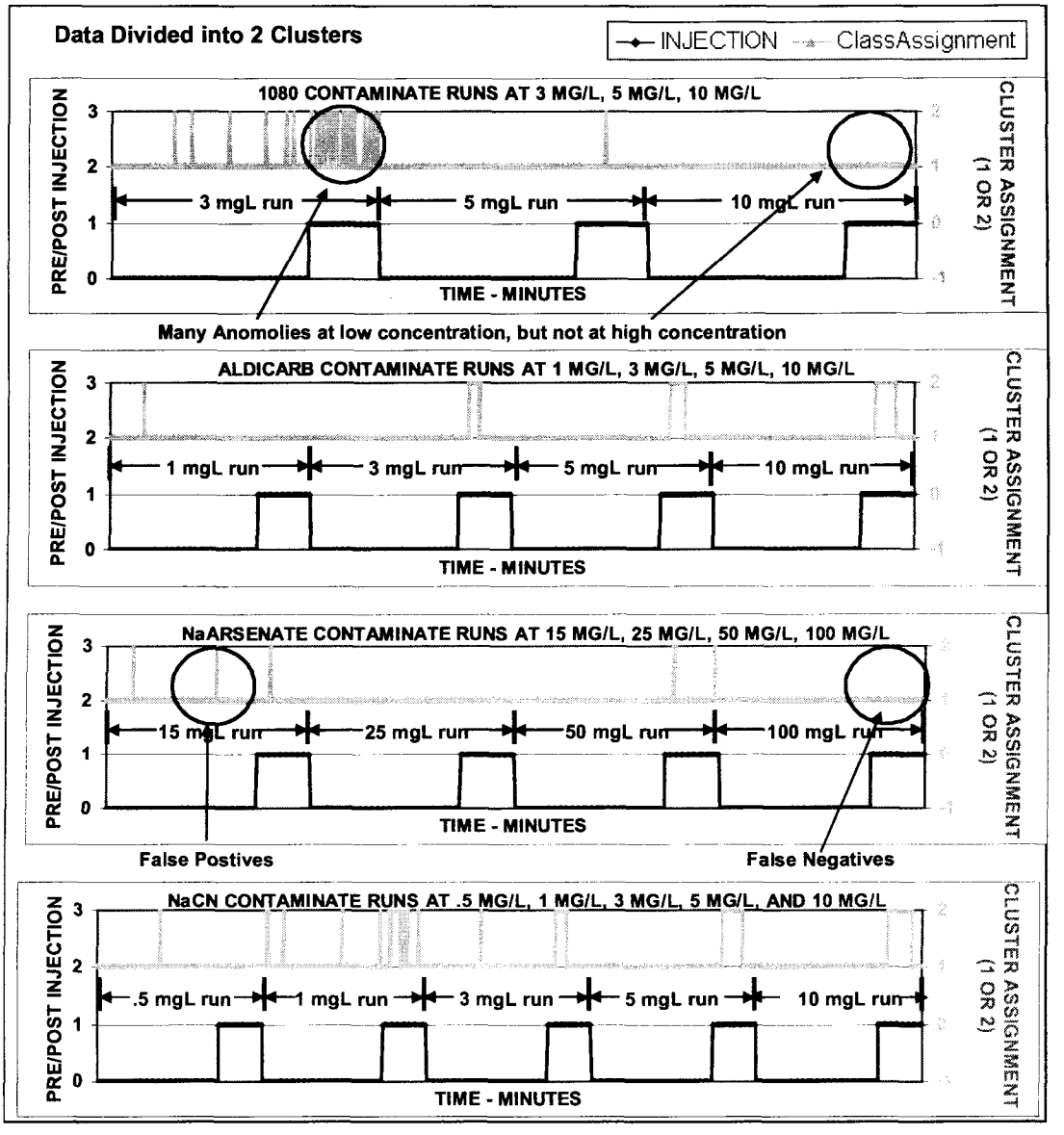



**Figure 11** Data subdivided into two classes (cluster assignment).

A possible explanation is that dividing state space into only two regions is insufficient to discriminate between the number of toxin/concentration permutations. Consider that water chemistry might exhibit different classes of behavior for each of the four chemical types, and yet

a fifth type for the pre injection behavior. Figures 12 and 13 on the next page show that by using a slightly more involved 2-step classification procedure, extremely good discrimination of all toxin/concentration permutations can be achieved. The first step clustered the vectors into 5 classes to provide a greater articulation of water chemistry state space. At first glance, the results shown in the Figure 12 look a bit jumbled; however, closer inspection shows that most of the pre injection vectors belong to classes 1, 2, and 3, and that most of the post injection vectors belong to classes 4 and 5. Figure 13 shows the results from step 2, which combined classes 1, 2, and 3 into a "Normal" class, and classes 4 and 5 were combined into an "Anomaly" class. It is observed that anomalies are discriminated at low concentrations for all toxins (while tolerating a few "false positives"). These results strongly indicate:

1. Post injection behavior is different from pre injection behavior in detectable ways.
2. The water chemistry time series can be classified automatically into pre and post injection behaviors.
3. Each contaminant affected water chemistry differently, therefore, it should be possible to automatically identify an offending toxin type using relative changes in water chemistry state.

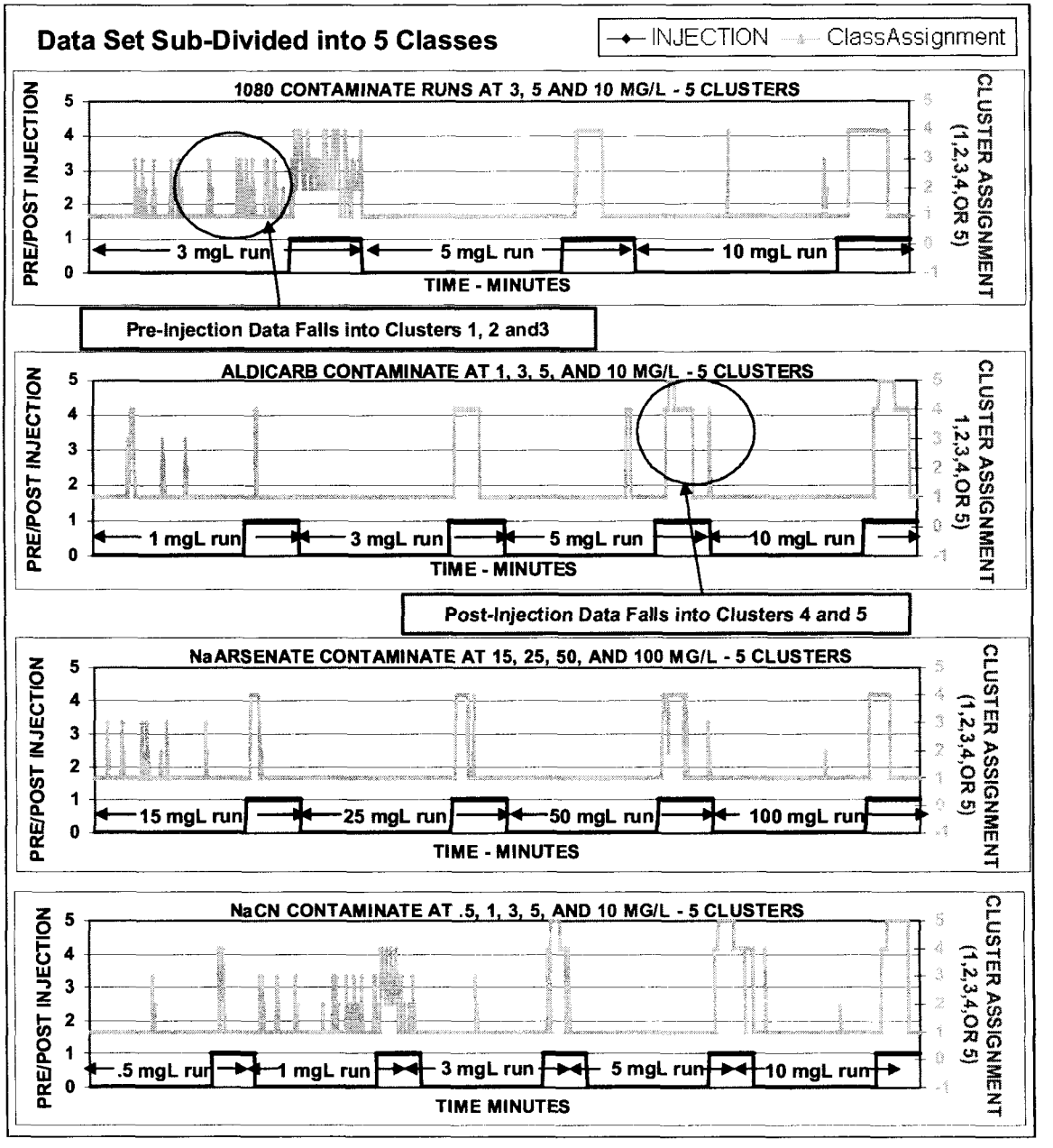



**Figure 12** Data subdivided into five classes (cluster assignment).

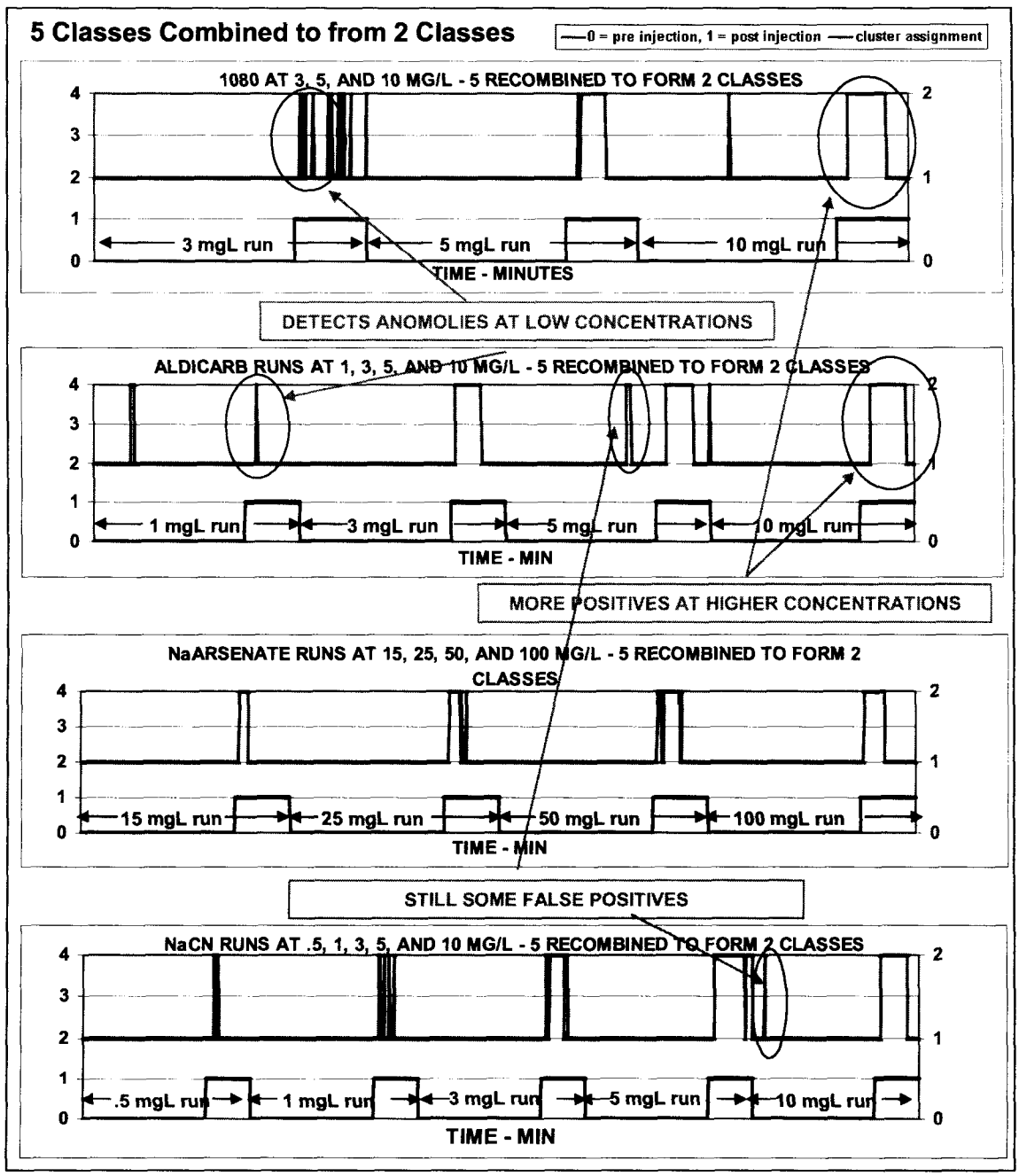



**Figure 13** Five classes combined into two classes.

## ANNs for Anomaly Detection

ANNs are commonly used as non-linear classifiers, and this study was extended to evaluate their use to automatically "infer" an anomalous water chemistry state under (simulated) online conditions. The question to be addressed was what would an ANN-based classifier, trained only

on pre-injection state vectors, do with post injection vectors? It was anticipated that a weak classification output would infer an unknown and therefore anomalous water chemistry state.

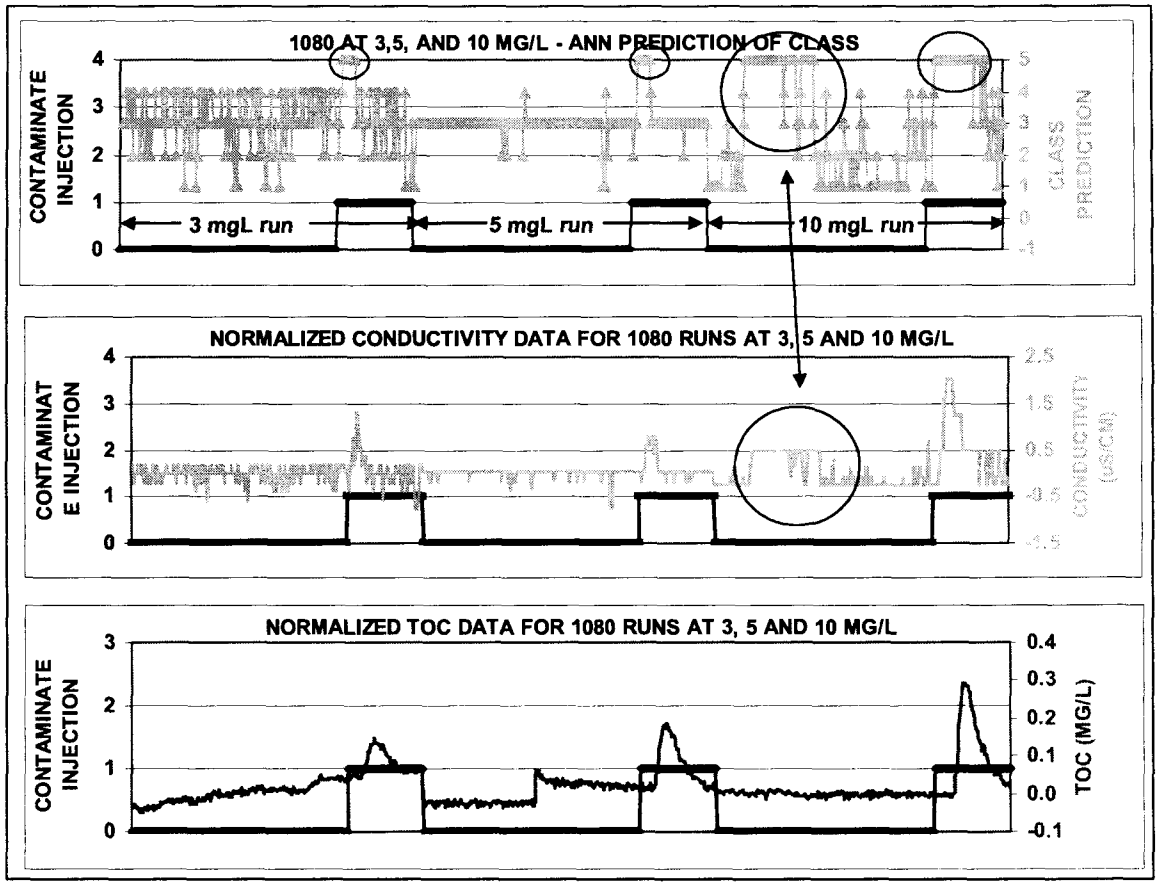



**Figure 14** ANN-predicted class.

All of the pre injection data were combined and clustered into five classes[6] to create training data to be used to develop an ANN-based classification model. Inputs to the model were the state vector elements, and five binary-valued outputs, one for each of the pre injection state vector classes. Each class was identified by an output pattern of four 0's and one 1, e.g., (1,0,0,0,0) and (0,1,0,0,0). These "input/output vector pairs" were used to train the ANN. The figure above shows the results for 1080. Each graph indicates the time of injection for reference. The top graph shows the class predictions made by the ANN, which was determined by associating a class with the output having the largest value. The top graph shows that soon after

injection the ANN "thinks" that the water chemistry state "looks like" the pre injection Class 5[7]. The two lower graphs show sensor data that help explain why. The pre injection SC of the third run exhibits a sustained elevated period, which when the clustering was applied, undoubtedly grouped pre-injection vectors with the elevated SC together into Class 5. It is also seen that the SC is elevated soon after injection in all three runs. Also note that the TOC also is elevated soon after injection, but it does not show any elevated levels in the pre injection data. An interpretation of these findings is that full automation in the construction of vector classes, as provided by the clustering method used here, is a sub-optimal solution. A human in the loop would be able to identify spurious data (once alarmed) or otherwise control the ongoing training/configuration of the detection system. The results for Aldicarb, NaArsenate and NaCN were similar to those of 1080 with respect being sensitive to "spurious" sensor behavior.

**Classifying Contaminant Types Using ANNs**

ANNs are commonly used as non-linear classifiers, making them potentially suitable for identifying offending contaminant types from changes in water chemistry. An ANN model was configured for each chemical type using the "anomalous" post-injection state vectors classified previously. Each model had a single binary output which was set = 1 if the vector corresponded to a toxin of the correct type and a 0 otherwise. The models were trained and their outputs post-processed, such that the model having the highest output value for a given state vector would indicate the contaminant type.

Figure 15 shows that this approach performed very well in classifying the toxin types, and that prediction accuracy improved with higher concentrations. The blue line indicates relative concentration, with 0 being the lowest used, 1 being the second lowest and so on. The red line represents the actual toxin with 1=1080, 2=Aldicarb, 3=NaArsenate, and 4=NaCN. The green line represents the predicted toxin type, determined from the model output having the highest value. The correct toxin type has been identified where the red and green line overlap. These results also point to the possibility of estimating toxin concentration from the relative magnitude of multivariate responses.

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[6] The choice to use 5 classes here is unrelated to the 5 used to cluster the pre+post injection state vectors. For a given problem, the number of clusters is determined by evaluating the inflection point of an error parameter that reaches its maximum when only one cluster is used, and approaches zero as the number of clusters nears the number of vectors.

[7] Class numbering was arbitrary, so that other than being a differentiator from the other classes, the number 5 has no significance.

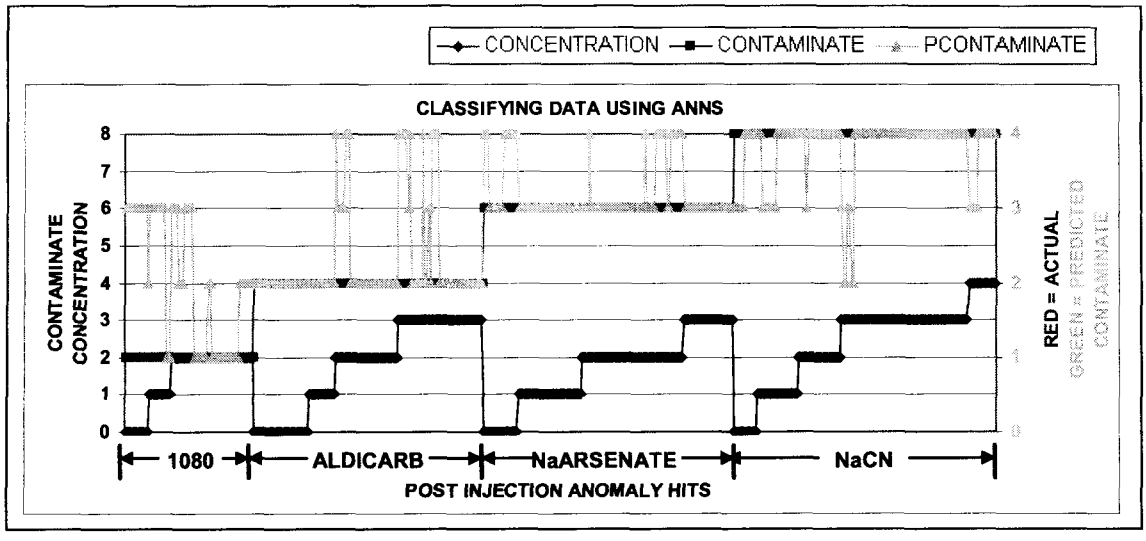


**Figure 15** Using ANNs to classify injected toxin type from water chemistry observations.

This study shows that state space concepts and various algorithms used in combination, such as clustering, classification, and ANNs can discriminate between "normal" water chemistry states and other "anomalous" states brought on by unknown causes. Other approaches have the potential to identify contaminant types and concentrations by pattern matching with known multivariate sensor responses, which can be determined through offline experimentation.

## Section VIII. Summary

The threat to drinking water distribution systems is well established and requires an urgent response to ensure that contamination events are recognized before a public health disaster ensues. To aid in this proactive effort, SCADA systems offer significant capability to transmit data from remote locations, and provide remote control of key resources. In doing so, it must be emphasized that SCADA systems themselves are potentially vulnerable, and that every effort must be made to maximize the effectiveness of SCADA systems while ensuring that they do not add to the vulnerability of a utility. In addition, the capability to receive data from remote locations brings to the surface issues that must be addressed by management such as whether or not to store data at instrument locations, reconciling data, centralized data management, and developing checklists of known, expected alarm conditions.

Having the most effective SCADA systems and monitoring instruments in your distribution system will not prove beneficial if an exhaustive baseline is not established. All changes in water quality parameters and even toxicity indicators will need to be compared to baseline water quality conditions to determine if a contamination event has occurred. This leads to a look at how these instrument responses should be evaluated. Univariate or multivariate analysis are available for determining alarm triggers. Optimally, a utility would use both techniques to gain advantages in reducing false alarms while potentially lowering limits of detection and providing the identity of a contaminant.

This white paper provides a significant amount of background information on pattern recognition techniques such as cluster analysis and artificial neural networks. A case study is provided to demonstrate the application and potential effectiveness of these techniques using credible threat chemical contaminants and continuous monitoring equipment. Research is continuing in the security data analysis area and continued improvement in the ability to detect anomalies at low concentrations with minimal false positives and negatives is expected in the future.

## Acknowledgements

We would like to acknowledge the contributions of the following participants (in addition to the authors) at a workshop held at CSU on April 6th, 2004. Their participation significantly influenced the content of the white paper presented here.

| | |
|---|---|
| Dick Burrows | US Army CHPPM |
| Kevin Gertig | City of Fort Collins Water Utility |
| Karl King | Hach Company |


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# Methodology and Characteristics of Water System Infrastructure Security: Section 5.3 - Models

**Submitted to**

**American Society of Civil Engineers**

**Prepared by**

Kenneth Carlson
David Byer
John Frazey
Department of Civil Engineering
Colorado State University
Fort Collins, Co

**May 1, 2004**

# Section I: Introduction

**Rationale**

There are many reasons why models of flow, chemistry, and other key parameters are gaining importance in the water field. E. Timothy Oppelt, the Director of the National Risk Management Research Laboratory stated that "water utilities are feeling a growing need to understand better the movement and transformations undergone by treated water introduced into their distribution systems" (Rossman, 2000). Real time monitoring has become crucial. William Muszynski, EPA Region 2 Deputy Regional Administrator, stated the importance of such monitoring: "Whether a contaminant enters a water supply system by terrorist action or by accident, it is vital that we have the information to respond quickly. That's why real-time monitoring offers such great promise." (Water Tech Online, 2004). Once this data is obtained, it can be analyzed through a model that will reveal a great deal of additional information, including the areas of contamination. Modeling can also help in determining if the sampling is a false positive.

New technology is making real-time monitoring possible. The EPA is now evaluating technologies that will alert water-system operators to a range of possible threats to human health including deliberate dumping of contaminants, sewage treatment plant failures, chemical spills, harmful algae blooms, and pollutants from stormwater runoff. It is interesting to note that in the past, major events have been relatively rare, and because of this, there have been suggestions to curtail these early warning systems (Grayman and Males, 2002). However, there are new movements to increase the monitoring. For instance, the EPA recently allocated $500K to create a pilot project to provide system operators with real-time information about safety and quality of their water supplies. The technology exists, but it needs to be tested together in a real-world setting (Water Tech Online, 2004).

Modeling can also assist with determining the actual sampling sites. In order to select sample stations in a rational manner, understanding of flows in system is absolutely necessary. Lee and Deininger state that no matter how complex the system is, there are specific pathways for water to get to points (Lee and Deininger, 1992). There are other reasons for the increased interest in water quality modeling. Harding and Walski state that much of impetus for development and application of water quality modeling is coming from the new regulatory framework specifying standards for the quality of water at the point of use, rather than at the point where it enters a water distribution system. In the past, much of the concern was on the water as it left the plant, even though the Safe Drinking Water Act of 1974 clearly specifies that the standards should be met at the tap (Clark, Grayman, and Males, 1988). Two specific regulations have shifted the focus to attainment of standards at the tap—the Surface Water Treatment Rule and the Total Coliform Rule. The Surface Water Treatment Rule requires the utility to maintain a detectable disinfectant residual at representative locations in the system to provide protection against pathogens. The Total Coliform Rule regulates coliform bacteria that are used as surrogates to indicate whether or not breakdown of primary disinfection is occurring (Clark, Rossman, and Wymer, 1995). Additionally, under the SDWAA, the EPA is required to regulate levels of pathogenic microbiologicals in water—specifically Giardia lamblia, enteric viruses, and Legionella (Boulos, Altman, Jarrige, Collevatie, 1994). Modeling is one method to assist evaluating the water at the tap.

The final major reason for the use modeling is to provide information regarding security of the system for intentional or accidental contamination. Information regarding the system will be crucial during an attack, especially for smaller communities, because even though the probability of a terrorist attack is a low, experts agree that it is not a matter of if, but when (Waeckerle, 2000). The same experts state that local communities must be ready to be self-sufficient for at least 24 hours because state and federal resources may not be available during that period (Waeckerle, 2000). Any information that will assist during this time will be extremely valuable.

Allmann (2003) conducted modeling work to determine how the distribution system would respond to such an attack. He found that the flow direction in the system must be known, which illustrates the

significance of the hydraulic information that would be needed for a sophisticated and highly effective attack. He also found that the flow pattern determined the contaminant spread. The patterns were surprisingly conducive to transporting contaminants from one neighborhood to another through most of the system. Allman's work will be discussed more in-depth later in this paper.

Haestad Press gives the following example of a scenario in which the use of a model would be valuable. A call comes in from the police with information concerning a possible water contamination. The location, chemical, time, and duration are known. The first action is to notify the public. The second action is to determine how to flush the contaminant, i.e., which hydrants to open and for how long. Flushing can drastically change the way water moves throughout the system. Trial-and-error for the flushing program would be long and risky. The best and easiest method is to use a model to analyze the flushing. Obviously a properly calibrated model would be required for such analysis and that model must be ready for immediate use (Haestad Press, 2003). These examples represent a few scenarios where flow models can be a powerful tool in water security analysis, both before an attack and the response afterwards.

**Examples of model applications**

Past modeling has been conducted on a variety of contaminants, including VOCs, inorganic chemicals, and microbes, as well as disinfectant decay (Haestad Press, 2003). Models have been completed in forensic studies, also called hindcasting, to identify responsible parties in litigation. Many of these have been completed, but few have been published because of legal issues (Haested Press, 2003). Some examples of modeling are discussed below.

The EPA used water modeling to study a salmonella outbreak in Gideon, MO. Gideon had 1104 residents, and it was estimated that up to 44% (over 600) of the town's residents were infected with diarrhea, and seven nursing home residents died. Using EPANET, it was concluded that bird droppings in large municipal tank were most likely the source of contamination (Rossman, Clark, and Grayman, 1996). By the time it was recognized as a water outbreak, none of the routine surveillance samples yielded positive samples. This illustrated the difficulty of tracking and identifying the course of contamination in drinking water systems (Clark and Deininger, 2001). Epidemiology studies showed that no similar food source was shared, but they all drank the same water (Clark, Geldreich, Fox, et al, 1996). It was concluded that the outbreak resulted from bird contamination in a municipal water storage tank. There was also a sudden drop in temperature on November 9, 1993, causing a turnover of water in the tank. This likely caused contaminated water to mix with the clean water (Clark, et al, 1996).

Other similar studies have been completed. The EPA modeled the water system in Cabool, MO, where an E. coli serotype O157:H7 outbreak occurred. The outbreak involved 243 cases and 6 deaths. It was attributed to two water main breaks (Geldreich, 1996). One of the first modeling examples found in the literature was completed at the North Penn Water Authority. This study, conducted by the EPA and North Penn Water Authority, used a series of field monitoring and systems to study contaminant movement within the system (Clark, Grayman, and Males, 1988). The "Solver" component of EPA's Water Supply Simulation Model (WSSM) was applied to the steady-state hydraulic solution using the known concentrations in the water sources. The actual pathways of water flow and trace analysis was conducted. The major finding of the study was the importance of adequate modeling of the system matching the actual system, i.e., model calibration. Additionally, the study showed that water can change in quality before reaching the user, based on chemical or biological transformations or due to a loss of system integrity. Once calibrated, the steady-state predictive model was found to be a reasonable first step to characterize the system (Clark, Grayman, and Males, 1988).

Another study, completed in Cheshire, CT, was done mainly for tank and system operation and design. The study found that tank operations can have a major impact on drinking water—long residence time in tanks implies that chlorine residual can be very low or zero for the discharge. The chlorine residuals, based on the assumptions, will vary widely depending on the location of the sampling point and operating scenarios, with the ranges being from 0 to 2 mg/L. These residuals varied throughout the day; however, they did note that changing the tanks operations did not solve the problem. Additionally,

although it was very difficult to characterize the water in the system, the authors did find that field data showed what the model predicted, thus models can be very useful (Clark, Grayman, Males, Mar/Apr 1993).

Another study, conducted with the South Central Connecticut Regional Water Authority, used a contaminant propagation model that demonstrated long residence times in one of the service areas. The result of the study showed the potential difficulties in maintaining chlorine residuals. A follow-up study verified that maintaining a chlorine residual is difficult and demonstrated that a first order decay model associated with modeling chlorine is inadequate (Clark, Grayman, Goodrich, Nov/Dec 1994).

Forensic models are done to show what occurred in the past. These are not discussed in detail here for two reasons. First, not many of these have been published due to legal issues (Haested Press, 2003). And second, the focus of this paper is to help avoid such a scenario, that is, where contamination has already occurred and studies must be conducted to verify the spread.

One of the most famous cases of forensic modeling occurred in Woburn, MA. A model there was used to substantiate the contamination that occurred many years before (Murphy, 1991; Harr, 1995). This contamination was in the book and movie "A Civil Action". The model done was for groundwater contamination requiring years of historical data (Haestad Press, 2003). Another similar study was conducted for in Dover Township, NJ, where models were developed there for the time period from 1962 to 1996 to determine the path of water (ATSDR, 2001; Maslia, et al, 2000).

Another forensic study was completed in Phoenix and Scottsdale, AZ, as part of litigation over contamination of wells first detected in the fall of 1981 (Walski and Harding, 1997a, 1997b). The primary contaminant was trichloroethylene (TCE) (Harding and Walski, no date). The analysis was done using a modified version of EPANET (Rossman, et al, 1994) using data sets assembled on a yearly basis (Harding and Walski, no date). The objective was to reconstruct the spatial and temporal patterns of contamination in the water distribution systems over a study period that covered more than 20 years (Harding and Walski, no date). The results of the study showed that concentrations can fluctuate widely at specific locations both hourly and seasonally, due to pumping changes based on varying demands (Harding and Walski, 2000).

**Objectives**

The objectives for this paper include:

- Provide guidance to water utilities of all sizes as to the use of models for water security related issues
    - Include required data inputs, outputs, decision points, site specific information required, and risk assessment techniques
- Provide database of all available distribution system hydraulic models
- Provide case studies of how water models have been used for water security
- Provide guidance on model use for detection capabilities including possible response

## Section 2: Existing Flow and Chemistry Models

### Description of models.

Models have evolved tremendously to meet water system requirements. The first models worked from output from steady-state hydraulic models (Wood, 1980). In the 1980s, increasingly sophisticated codes were developed, which included stand-alone water quality models (Males, et. al., 1985; Clark, et. al., 1984). In the late 1980s, the first models able to simulate time-varying conditions were developed (Grayman, et. al., 1988; Clark, et. al., 1986). Most of these were able to use the extended-period simulation (EPS) approach (Harding and Walski, no date). These types of models do not simulate the inertial effects due to rapid changes in velocity; however, they do simulate flow reversal, the reactivity of constituents, and track conditions in tanks (Harding and Walski, no date). Fully dynamic models and models that account for dispersion have been developed (Axworthy and Karney, 1996; Islam and Chaudry, 1998). For the last decade, the attention was focused on algorithms for use in modeling the water quality in pipe systems (Boulos, Altman, Jarrige, Collevatie, 1994). EPS models are currently the most advanced technique that is widely deployed for practical applications (Harding and Walski, no date). Based on this, modeling water quality in water distribution systems has become a widely accepted tool in support of water supply planning, operations and research (Harding and Walski, no date).

Models can be used in a wide range of situations. Even when it is not possible to accurately model behavior of a chemical or a microbe, models can provide a picture of how water moves throughout the distribution system and from this information, it can be determined which portions of the system are exposed to water from particular sources, tanks, or pipe breaks (Haested Press, 2003).

One of the emerging abilities of models is to help utilities understand how the system will respond due to either accidental or intentional contamination (Haested Press, 2003). ESP models can be extremely effective in examining consequences of "what if" scenarios. Specifically, as applied to water system security, models have been used to examine three different time frames. First, they have been used as planning tools to assess vulnerabilities of the systems for various events. Second, they are used as a real-time tool during actual events for assistance in formulating responses. Third, they have been used for investigating events that occurred in the past (Haested Press, 2003). These three uses have also been defined as planning/design, operations, and forensics.

There are of course limitations to using models. Flow patterns in a water distribution system can be highly variable and these flows can have a significant impact on the way contaminants are dispersed in a network, thus it is difficult to predict where a parcel of water will be at a given time (Clark and Deininger, 2001). However, if a model is calibrated properly, these limitations can be minimized.

**Steady-state vs. EPS**

Hydraulic models can evaluate two different times: steady-state (system is not changing) or extended period simulation (many different steady-state models run together). The steady-state analysis computes the state of the system by assuming the hydraulic demands and boundary conditions do not change. These computations include flows, pressures, pump operating valves, positions of valves, etc. The information typically obtained from such a model includes pressures and equilibrium flows (Haested Press, 2003). Steady-state models can be a reasonable first step to characterize the distribution of water quality in multi-source systems, but are less dynamic in terms of operation (Clark, Grayman, and Males, 1988). It is basically a snapshot in time, used to determine the operating behavior of the system under static conditions. Steady-state models can be useful though, determining the short-term effect of fire flows or average demand conditions within the system (Haested Press, 2003) as well as modeling flow-tracing for contaminant movement, flow paths, and travel times through the network (Clark, Rossman, and Wymer, 1995).

Because water systems are rarely in a steady-state, these types of models are very limited. It is like looking at a blurred photograph of a moving object. Because of this, they are typically building blocks for other types of simulations or done to analyze specific worst-case conditions such as fire

demand, peak demands, and other system component failures that do not have a large impact by time (Haested Press, 2003).

Dynamic water-quality models are used to simulate movement and transport of substances in water under time-varying conditions (Clark, Rossman, and Wymer, 1995). They can be very effective for contaminant propagation studies. When combined with a flow-tracing algorithm, they have proven to be very effective in modeling contaminant propagation in the drinking-water distribution system (Clark, Grayman, Males, Mar/Apr 1993). These also model changes in water tank levels, valve settings, storage tanks and pumps going on and off-line, flow reversal, and rapid demand changes (Boulos, Altman, Jarrige, Collevatie, 1994). For these reasons, dynamic models have largely replaced steady-state models for water systems because they provide a better representation of the time-variant behavior of contaminants in distribution networks, particularly that arising from flow reversal in pipes.
Dynamic models involve a sequence of steady-state solutions linked by an integration scheme for the differential equation describing the storage tank dynamics. Each such time-dependent change in system boundary conditions refers to a hydraulic event and duration called a hydraulic time step, usually 1 hour (Boulos, Altman, Jarrige, Collevatie, 1994). The time period for these models has generally been limited to periods of a day or a few days; however, longer time periods can also be completed. Longer time periods, up to weeks, months, or a year, can be completed with only minimal changes to the model codes.

The data requirements for these models are much greater than for steady-state models. This data includes water use patterns, more detailed tank information, and operational rules for pumps and valves. Additional information required includes start time, duration, and the hydraulic time step (Haestad Methods, 2002).

**Analysis Algorithms: Water Quality.**

The water quality portions of many water quality models (H2OMAP, WaterCAD, PipelineNet, WADISO SA, Mike NET, Pipe 2000, etc.) are based on the conservation of mass with incorporation of reaction kinetics as calculated in EPANET. The basic equations used in these models are described below (Rossman et al., 1993 and Rossman and Boulos, 1996). The programs are based on the fact that a dissolved substance will travel in the pipe with the same velocity as the fluid in the pipe and at the same time it will react with its concentration either increasing or decaying. In most pipe systems, there is little longitudinal dispersion, i.e., there is no intermixing of mass between adjacent parcels of water that are traveling down the pipe. Advective transport in the pipe is represented by the following equation (Rossman, 2000):

$$\frac{\partial C_i}{\partial t} = -u_i \frac{\partial C_i}{\partial x} + r(C_i)$$

where:

- $C_i$ = concentration (mass/volume) in pipe i as a function of distance x and time t
- $u_i$ = flow velocity (length/time) in pipe I
- $r$ = rate of reaction (mass/volume/time) as a function of concentration.

Where two or more pipes meet, the incoming flow is assumed to be mixed completely and instantaneously. This allows the substance concentration to be calculated through a flow-weighted sum of the concentrations from the in-flowing pipes by the following equation (Rossman, 2000).

$$C_{i|x=0} = \frac{\sum_{j \in I_i} Q_j C_{j|x=L_j} + Q_{k,ext} C_{k,ext}}{\sum_{j \in I_i} Q_j + Q_{k,ext}}$$

where:

- i = link with flow leaving node k,
- $I_k$ = set of links with flow into k,
- $L_j$ = length of link j,
- $Q_j$ = flow (volume/time) in link j,
- $Q_{k,ext}$ = external source flow entering the network at node k,
- $C_{k,ext}$ = concentration of the external flow entering at node k.
- The notation $C_{i|x=0}$ represents the concentration at the start of link i, while $C_{i|x=L}$ is the concentration at the end of the link.

The easiest method to deal with storage facilities is to assume the contents are completely mixed. It is reasonable to make this assumption for many tanks that operate under fill-and-draw conditions assuming that there is enough momentum flux imparted to the inflow (Rossman and Grayman, 1999). When these are assumed, the concentration throughout the tank is a blend of the current contents and the entering water. However, at the same time, the internal concentration may be constantly changing because of reactions. Storage facilities can be represented by the following equation (Rossman, 2000):

$$\frac{\partial(V_s C_s)}{\partial t} = \sum_{i \in I_s} Q_i C_{i|x=L_i} - \sum_{j \in O_s} Q_j C_s + r(C_s)$$

where:

- $V_s$ = volume in storage at time t,
- $C_s$ = concentration within the storage facility,
- $I_s$ = set of links providing flow into the facility,
- $O_s$ = set of links withdrawing flow from the facility.

**Analysis Algorithms**

There are two basic methods used for solving the model equations. These are the Eulerian and Lagrangian approaches (Haested Press, 2003). The Eulerian approach is best described as an observer located at a fixed location watching the water as it flows by (Haested Press, 2003). This method was originally developed for water quality modeling in distribution systems (Grayman, Clark, Males, 1988) and was later formalized and named the Discrete Volume Method (Rossman, Boulos, and Altman, 1993).

The Lagrangian method is a hybrid of the Eulerian Discrete Volume Method (DVM) of Rossman et al. (1993) and the Lagrangian Event-Driven Method (EDM) of Boulos et al. (1995). It is described as the observer moves with the flow rather than watching it. Rather than having a fixed grid, the parcels of water are tracked through the pipe. Each parcel of water has a homogeneous concentration and is tracked through the pipe. New parcels are added when the water quality changes due to changes in source quality or when the parcels are combined at the junctions (Haested Press, 2003). This method was developed by Liou and Kroon (1987) and Hard, Meader, and Chiang (1986), and is commonly used in water models today.

For the programs, the time steps are much shorter than the hydraulic time. This is done to accommodate the short travel times that can occur within the pipe (Haestad Methods, 2002; Rossman, 2002). The method tracks the size and concentration of non-overlapping water segments that fill each link in the network. Throughout time, the upstream segment in a link increases in size as water enters. At the same time, there is an equal loss in size of the most downstream segment. The sizes of those in between remain the same. The contents of the segments are subjected to reactions and an accounting for total mass and flow volume entering nodes, as well as the contributions from external sources. The water positions are updated and new node concentrations are then calculated (Rossman, 2000).

**Database of all available distribution system hydraulic models.**

There are numerous models available, each with unique abilities in regards to not only hydraulic capacities but also applications in water security. These models are summarized in Table 1. A more in-depth description of these water models is provided in the Appendix. Each of the water models has some similarities. These are discussed below.

**Similarities**

The programs perform similar functions. Hydraulically, they all perform the same type of analysis: flow and velocity of water in pipes, pressure and head at nodes, height of water in tanks, discharge flow and pressures from pumps. They all perform steady-state and extended period simulation analysis. For water quality simulations, all perform age, trace analysis, and constituent analysis. Most use the same three common friction equations (Hazen-Williams, Darcy-Weisbach, or Manning's methods). Additionally, the programs have similar capabilities regarding modeling water quality. Each can perform water age, tracing, and constituent analysis. Additionally, they model constituents in the same manner: n-th order kinetics to model reactions in the bulk flow and zero or first order kinetics to model reactions at the pipe wall. Wall reaction rate coefficients can be correlated to pipe roughness and the global reaction rates can be modified on a pipe-by-pipe basis. The constituents can grow or decay up to a limiting concentration. Also, they can perform four different models of tanks. In regards to water quality, the three major types of analyses include age, trace, and constituent. These are explained in more depth below.

Water age is a function that calculates the age of the water in the network, computed at any node. Most of the models compute this characteristic based on EPANET calculations. This calculation is performed under constant hydaulic conditions and is a simple, non-specific measure of the overall quality of delivered water. It tracks the percent of water over time that reaches any node in the network and that had its origin at a specifically sited node. These can be any nodes in the network. The information required for age analysis is pipe velocity and flow rate and therefore a reaction coefficient is not required (Haestad Methods, 2002).

The trace function determines the fraction of water that originates from a specified node over time, again with most models performing this calculation based on EPANET calculations. EPANET treats the source node as a constant source of non-reacting constituent, entering the network at the node with a concentration of 100 (Rossman, 2000). The analysis can be useful for analyzing systems with two or more raw water sources, thus showing how the water is blended over time (Rossman, 2000). This analysis can only be performed using the EPS method (Haestad Methods, 2002) and the only information required is pipe velocity and flow rate.

**Table 1** Summary of available distribution system hydraulic models.

| Software | Water Quality Analysis | Security Specific |
|---|---|---|
| BRANCH 3.0 / LOOP 4.0 | None | None |
| CROSS (WaterPac®) | Information not available | Information not available |
| EPANET (Version 2.0) | Water age, trace analysis, and constituent analysis. Constituent analysis various types of reaction coefficients to be input into the model. | Information not available |
| $H_2OMAP$/ $H_2ONET$ | The program can conduct water age, trace, and constituent analysis. Constituent analysis various types of reaction coefficients to be input into the model. | Event/consequence management, vulnerability assessment, tracking contaminants to the originating sources, computation of purge volumes, event isolation, and customer report notification generation. |
| Helix delta-Q (Version 2.28) | Information not available | Includes "what-if" scenarios which allows closing pipes to view network effect. |
| InfoWater™ Protector | Same general capabilities as $H_2OMAP$/ $H_2ONET$ | Models propagation and concentration of contaminants in system; assess effects of water treatment on the contaminant; evaluates potential impact of unforeseen facility breakdown. Locate areas of contamination and calculates population at risk. Identifies valves to close to isolate a contamination event. Tracks contaminants to the originating supply source, computes purging volume, flushing strategies, result on fire-fighting capabilities, and prepares data for eventual prosecution. |
| MIKE NET 2002 | Water age, travel time, and constituent source tracking can also be performed. Tracks movement and fate of water quality constituents. Allows different reaction coefficients. | Allows "what if" scenarios, allowing user-selected changes in network configurations, demand loading conditions, and changes in physical system characteristics. Can run several different scenarios on the same network. |
| optiDesigner (Version 1) | Information not available | New update including stochastic behavior of the system and a method to determine the source of contamination. No release date has been set. |
| PIPE2000/KYPIPE (Version 2) | Automatic aging of pipes (roughness) and many other capabilities. | Information not available |
| PipelineNet | Water age, trace analysis, and constituent analysis. Constituent analysis various types of reaction coefficients to be input into the model. | Model flow and concentration of a biological or chemical agent within a city or municipal water system. Assesses effects of water treatment on the agent. Models flow and concentration of agent through the system and calculates population at risk. |
| Pipenet™ | The program has "What-if" scenarios, but is advertised for broken or blocked pipes. | Information not available |
| STANET® (Version 7.3) | Stationary mixing/tracking of contents (heating value, water quality, water age). | None |
| WADISO SA (Version 4) | Water age, trace, and constituent analysis. Allows different reaction coefficients. Constituent analysis various types of reaction coefficients to be input into the model | Information not available |
| WaterCAD | Water age, trace, and constituent analysis. Allows different reaction coefficients. Constituent analysis various types of reaction coefficients to be input into the model | Includes scenario for selection of valves for contamination isolation and developing flushing strategies. Simulates failure of critical water sources and identification of customers who will be impacted by the event. Predicts influence of these events and assesses possible impacts of correction actions. Prioritizes physical security improvements using component criticality and water system safety. |

A constituent is defined as any substance that the growth or decay can be adequately described through bulk and wall reaction coefficients (Haestad Methods, 2002). This type of analysis determines the concentration of the constituent at all nodes and links in the system. The constituent can be anything from chlorine to fluoride to an unwanted contaminant. This analysis will determine the concentration of the constituent at all nodes and links in the system (Haestad Methods, 2002). The source of the constituent can be from the main treatment works, well head or satellite facility, or unwanted contaminant intrusion and either conservative or reactive species can be modeled.

This analysis can only be performed using the EPS. The following must be input into the model:

- Initial Constituent: the initial concentration of the constituent at the beginning of the analysis.
- Bulk Reaction: reaction rate used to model reactions of the constituent within the bulk flow.
- Wall Reaction: reaction rate constant for the material reacting along the pipe wall.

As can be seen, this analysis may require two reaction coefficients: the bulk and pipe wall. An additional reaction coefficient for tanks is described below. Once entered into WaterCAD, this reaction information is stored in the constituent library .

The constituent analysis is based on the principles of conservation of mass and reaction kinetics. There are three processes used to conduct this calculation: (H2OMAP User Guide, text):

1. Advection in pipes. This is based on that fact that the constituent will travel down the pipe with the same average velocity as the fluid carrying it. While traveling, the constituent will react, either growing or decaying. Longitudinal dispersion is usually not an important transport mechanism under most operating conditions meaning there is no intermixing of mass between adjacent parcels of water traveling down a pipe.
2. Mixing at Junctions. The mixing is assumed to be complete and instantaneous.
3. Mixing at Tanks. There are several different types of mixing in tanks. These different types of mixing are discussed under tank mixing.

**Mode of Entry for Contaminant**

Another similarity between the models is the mode of entry for the contaminant. The models allow any node in the system to serve as the source for a chemical constituent. Each modeling program allows several different methods to introduce the contaminant into the system. These are explained below (Haestad Methods, 2002; H2OMAP User Guide, text; Rossman, 2000). :

- Concentration. This method fixes the concentration of any external inflow entering the system at a node. An example would be a reservoir or a negative demand located at a junction.
- Flow Paced Booster. This method adds a fixed concentration to the flow resulting from the mixing of all inflow to the node from other points in the network.
- Setpoint booster: This fixes the concentration of any flow leaving the node. This can be used as long as the concentration resulting from all inflow to the node is below the setpoint.
- Mass booster: This is used to add a fixed mass flow to the flow entering the node from other points in the network.

The best method to use for contaminant entry is discussed later.

**Tank mixing**

Tank mixing is another item that impacts the way a contaminant acts. Again, most models that complete this calculation use the EPANET method which include three options for tank mixing: complete mixing, two-compartment mixing, first in/first out plug flow, and last in/first out plug flow. These are described more in detail below.

- Completely Mixed. This assumes that all water entering the tank is completely and instantaneously mixed with the water already in the tank. This is a reasonable assumptions for many tanks operating under fill-and-draw conditions providing sufficient momentum flux imparted to inflow.
- Two Compartment. This assumes that the tank storage is divided into two completely mixed compartments, both of which are assumed to be completely mixed. Inflow and outflow are assumed to take place in the first compartment. The second compartment receives over-flow from the first, and this overflow is completely mixed. The inlet and outlets of the tanks are in the first compartment. As new water enters, it completely mixes with the first compartment. Overflow is sent to the second compartment. When water leaves the first compartment, it receives an equivalent amount of water from the second compartment. The second compartment can have dead zones.
- First In/First Out Plug Flow model (FIFO). This model assumes there is no mixing of water during the time it is in the tank. Water parcels are effectively stacked on one another, moving through the tank in a segregated fashion where the first parcel to enter is the first parcel to leave. This is most appropriate for baffled tanks that operate with simultaneous inflow and outflow (Rossman, 2000).
- Last In/First Out Plug Flow model (LIFO). This model assumes that no water mixing occurs in the tank. Water parcels still stack up one on top of another, and the last parcel to enter is the first to leave from the bottom of the tank. This is most appropriate for tall, narrow standpipes that have an inlet/outlet pipe at the bottom and low momentum inflow (Rossman, 2002).

**Chemistry modeling**

The water models use the EPANET calculation methods for modeling reactions. The EPANET method can model bulk and wall reactions, in regards to decay or growth. The bulk reactions used by these programs include: simple first-order decay, first-order saturation growth, two-component second order decay, Michealis-Menton Decay kinetics, or zero-order growth (Rossman, 2000).

There are two different types of reactions: bulk and wall. These are discussed separately. Figure 1 shows the differences in these reactions (Rossman, 2000).

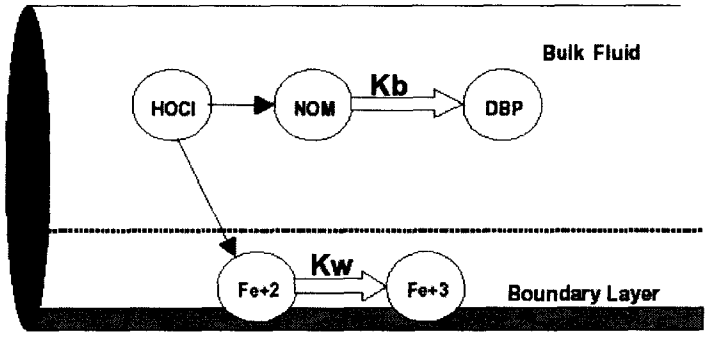



**Figure 1** Pipe and wall reactions.

Each reaction can be an important consideration. Some estimates are that up to 34% of the reactions occur in the wall phase with 17% occurring in the bulk phase. The remaining 49% occur in tanks (H2OMAP user text).

Bulk Flow Reactions.

The programs model reactions in the bulk flow with n-th order kinetics. The instantaneous rate of reaction (R in mass/volume/time) is assumed to be concentration-dependent according to

$$R = K_b C^n$$

Where:

- $K_b$ = a bulk reaction rate coefficient. $K_b$ has units of concentration raised to the (1-n) power divided by time. This is positive for growth reactions and negative for decay reactions.
- C = reactant concentration (mass/volume)
- n = reaction order.

There are other special case equations, described below. These equations are based on three parameters used to characterize bulk rates ($K_b$, $C_L$, and n). Table 2 summaries the parameters and gives examples of a constituent that each would model.

**Table 2** Summary of model parameters and example.

| Model | Parameters | Examples |
|---|---|---|
| First-Order Decay | $C_L = 0$, $K_b < 0$, n = 1 | Chlorine |
| First-Order Saturation Growth | $C_L > 0$, $K_b > 0$, n = 1 | Trihalomethanes |
| Zero-Order Kinetics | $C_L = 0$, $K_b <> 0$, n = 0 | Water Age |
| No Reaction | $C_L = 0$, $K_b = 0$ | Fluoride Tracer |

The special case equations are discussed below. Again, all three programs are capable of calculating these.

- Simple First-Order Decay. ($C_L = 0$, $K_b < 0$, n = 1)

$$R = K_b C$$

This can be used for the decay of many different substances, including chlorine.

- First-Order Saturation Growth. ($C_L > 0$, $K_b > 0$, n = 1)

$$R = K_b (C_L - C)$$

This is can adequately model the growth of disinfection by-products where the ultimate formation is limited by the amount of reactive precursor there is in the water.

- Two-Component, Second Order Decay. ($C_L \neq 0$, $K_b < 0$, n = 2)

$$R = K_b C (C - C_L)$$

This equation assumes that substance A will react with B in some unknown ratio, which will produce product P. Based on the reaction, the rate that A disappears is proportional to the product of A and B remaining. For this model, $C_L$ can be either positive or negative and this value depends on whether either A or B is in excess, respectively. Some have had success in applying this model to chlorine decay data not conforming to simple first-order models (Clark, 1998).

- Michaelis-Menton Decay Kinetics. ($C_L > 0$, $K_b < 0$, n < 0)

$$R = \frac{K_b C}{C_L - C}$$

The programs will use the Michaelis-Menton Decay Kinetics when a negative reaction order *n* is specified, shown above for a decay reaction, but this is only a special case. The above is for decay reactions, but for growth the denominator becomes $C_L + C$. This equation is used frequently to describe enzyme-catalyzed reactions and microbial growth. Mathematically, it produces first order behavior at low concentrations and zero-order behavior at higher

concentrations. For decay reactions, $C_L$ must be set at a higher value than the initial concentration present (Rossman, 2000).

This equation was applied by Koechling to model chlorine decay in a number of different waters. It was found that $K_b$ and $C_L$ could be related to the organic content of the water and that its ultraviolet absorbance is as follows.

$$K_b = -0.32UVA^{1.365}\frac{(100UVA)}{DOC}$$

$$C_L = 4.98UVA - 1.91DOC$$

where:

- UVA = ultraviolet absorbance at 254 nm (1/cm)
- DOC = dissolved organic carbon concentration (mg/L).
- Note that these expressions apply only for values of $K_b$ and $C_L$ used with Michaelis-Menton kinetics.

- Zero-order Growth. ($C_L = 0$, $K_b = 1$, $n = 0$)

  $R = 1.0$

  This is a special case that can be used to model the water age. For each unit of time, the concentration, or age, increases by one unit. There is a relationship between the bulk rate constant at one temperature (T1) related to another temperature (T2). This is often expressed using the van't Hoff – Arrehnius equation of the form:

  $$K_{b2} = K_{b1}\theta^{(T2-T1)}$$

  where: $\theta$ is a constant.

Use of the equations discussed above is predicated on some knowledge of the reaction coefficients. If the reaction coefficients are unknown, they will need to be measured in the lab or estimated with empirical relationships.

Substantial water quality changes can occur at or near the pipe wall interface. Wall reactions can be complicated, as it depends on temperature as well as pipe material and age. As metal pipes age, their roughness tends to increase with encrustation and tuberculation of corrosion products on accumulating on the pipe walls. This in turn produces a lower Hazen-Williams C-factor or a higher Darcy-Weisbach roughness coefficient that results in greater frictional head loss through the pipe. Dissolved substances are transported to the pipe wall and react with materials such as the biofilm or corrosion products (e.g. iron oxides) on or near the wall. Several variables will influence this reaction. One of these is the area available for the reaction, which is simply the surface area per unit volume. Another variable is the rate of mass transfer between the fluid and the wall. The factor is represented by a mass transfer coefficient. The value of this mass transfer coefficient depends on the reactive substance's molecular diffusivity as well as the Reynolds number of the flow. The wall reaction rate can be considered to be dependent on the concentration in the bulk flow by using an expression of the form:

$$R = (A/V)K_w C^n$$

Where:

- $K_w$ = a wall reaction rate coefficient

- (A/V) = the surface area per unit volume within a pipe (equal to 4 divided by the pipe diameter).

Both of the programs (H2O MAP and EPA Net) limit the choice of wall reaction order to either 0 or 1, so the units of $K_w$ are either mass/area/time or length/time, respectively. The $K_w$ value must be supplied by the modeler. The first-order $K_w$ values can have a wide range, anywhere form 0 to 5 ft/day. The value should be adjusted to account for any mass transfer limitations in the moving reactants and products occurring between the wall and bulk flow. Both programs do this automatically based on the substance's given molecular diffusivity and on the Reynolds number of the flow.

Both programs can make the pipe $K_w$ a function of the roughness coefficient. Note that WaterCAD does not have these calculations listed in the manual. The equations are listed below:

| **Headloss Formula** | **Wall Reaction Formula** |
|---|---|
| Hazen-Williams | $K_W = F / C$ |
| Darcy-Weisbach | $K_W = -F / \log (e/d)$ |
| Chezy-Manning | $K_W = F\ n$ |

Where $C$ = Hazen-Williams C-factor, $e$ = Darcy-Weisbach roughness, $d$ = pipe diameter, $n$ = Manning roughness coefficient, and $F$ = wall reaction - pipe roughness coefficient. The value for F must be developed from site-specific field measurements. It will have a different meaning depending on which head loss equation is chosen. This method requires only F to allow wall reaction coefficients to vary within the network.

Pipe wall reactions can also be expressed by using the following set of equations. Note that all three programs use these.

- First order rate.

$$r = \frac{2k_w k_f C}{R(k_w + k_f)}$$

where:
- $k_w$ = wall reaction rate constant (length/time),
- $k_f$ = mass transfer coefficient (length/time),
- R = pipe radius.

This would be representative in situations where chlorine is the limiting reactant. This might occur with reactions that involve complex organic compounds, or those found in exocellular enzymes and metabollic products produced by biofilm on the pipe wall (MWH Soft, 2004).

- Zero order kinetic reaction.

For this equation, the rate cannot exceed the mass transfer rate, thus the equation becomes:

$$r = MIN(k_w, k_f C)(2/R)$$

where $k_w$ now has units of mass/area/time.

The mass transfer rates are normally expressed by the Sherwood number, which is a dimensionless number ($Sh$):

$$k_f = Sh\frac{D}{d}$$

where:

- $D$ = the molecular diffusivity of the species being transported (length$_2$/time)
- $d$ = pipe diameter.

When the flow is fully developed laminar, the average Sherwood number through the pipe is expressed by the following:

$$Sh = 3.65 + \frac{0.0668(d/L)\,\mathrm{Re}\,Sc}{1 + 0.04\left[(d/L)\,\mathrm{Re}\,Sc\right]^{2/3}}$$

where:

- $Re$ = Reynolds number
- $Sc$ = Schmidt number (kinematic viscosity of water divided by the diffusivity of the chemical)

When the flow is turbulent, the following empirical correlation is used (Notter and Sleicher, 1971):

$$Sh = 0.0149\,\mathrm{Re}^{0.88}\,Sc^{1/3}$$

where all the values are the same as for the above equations.

MWH states that the zero-order model would be representative when chlorine immediately oxidizes some reductant (i.e., a ferrous compound) and the rate is then dependent on how quickly the reductant is made by the pipe. Based on this, this mechanism would apply mostly to corrosion-induced reactions (MWH Soft, 2004).

Estimating reaction coefficients.

Unlike bulk reaction rates, wall reaction rates cannot be directly measured—they must be back-fitted against calibration data collected from field studies. This involves trial and error to determine the coefficient values that will replicate the same results that match the field data best. The type of pipe will have a large impact on this coefficient. There is not any expected wall demands for disinfectants for plastic and relatively new lined iron pipes (Rossman, 2000).

### Specific Water Quality Models

There are numerous models that have been developed for some aspect of water quality. These range from spill monitoring to drinking water quality in the distribution system. Some specific models are described below and a more in-depth database is provided for models specifically applicable to water distribution security in Appendix I.

Monte Carlo simulation

The Monte Carlo simulation is a well-known technique for analyzing complex physical systems where probabilistic behavior is important, such as rivers for an early warning system (EWS) designs, monitoring locations, sampling frequency, and responses where these spill events would impact drinking water sources (Haestad Press, 2003). These are widely used in modeling probabilistic systems in water resources and other scientific fields where the events are represented as probabilistic occurrences (Grayman and Males, 2002).

## Matrices model

Another type of model used is the matrix method as applied by Lee and Deininger (1992). If the entire network were to be covered, every node would have to be sampled, which is not possible. The matrix model is based on the logic that when one water tap is sampled, only the water at that tap is known

but it can be assumed that the nearest node is also known. If water quality at node i is known, and if node i has a demand of $D_i$, and D is the total demand, then the fraction $D_i/D$ is known. The authors also applied this to upstream nodes. That is, if all water from the sampled node came from an upstream node, then water quality of this upstream node would also be known. Model calculations are completed to show how much of the demand can be assumed to be safe. This can be applied to make decisions based on the amount of water supply through each node.

The method develops a matrix from the knowledge of the system which is then used to determine where to sample. In order for a node to be termed "covered", at least 50% of the water passing through the node should have been sampled. This concept was applied to Flint, MI, a medium-sized city. Using this method, total demand coverage was increased from 18.5 to 54%. They concluded that this method, combined with pathway analysis, coverage matrices, and integer programming provide first step towards rational algorithm for locating monitoring stations.

DWQM

In the early to mid 1980s, the Drinking Water Research Division of the EPA identified major elements involved in water-quality modeling. This resulted in development of a dynamic water-quality model (DWQM) (Clark and Coyle 1990). The early version of this applied to small drinking water system, such as the North Penn Water Authority in Lansdale, PA (Clark, Grayman, Goodrich, Nov/Dec 1994).

CFD: Mixing in tanks

Computational fluid dynamics (CFD) models use mathematical equations to simulate flow patterns, heat transfer, and chemical reactions. These provide a much more accurate representation of the mixing processes occurring in a tank (Haested Press, 2003). There are several commercial packages available, but these take significant experience to develop practical applications. The model run times take a long period of time (hours, days, or even weeks) for complex situations. Despite these time commitments, the use CFD modeling has grown significantly over the last few years.

**Uses of Models.**

There are several distinct uses for models in security applications. To be useful, the model must be calibrated for a wide range of alternative scenarios and be ready to apply rapidly in the EPS mode. The model must be set-up in an automated mode so that operation is represented by a series of logical controls established for the current operating procedures. The authors state that such an evaluation is possible, including the required data, but that only limited demonstrations of this type of operation have been accomplished so far. The obvious key to this is that the model must be ready immediately because there would not be time to establish the model in an emergency. Security applications of distribution system hydraulic models include:

1. Detector placement. Models can be used to help determine the optimum placement of monitors. As discussed in the literature review, there are different approaches for determining where models should be located with the distribution system. Modeling is another technique to aid in this important task. Whether strictly modeling is used or another method, modeling is a method to verify the effectiveness of the placement methodology.

2. Pre-event response scenarios. Extensive modeling could be conducted before an event occurs to facilitate response planning. Various scenarios can be input into a model and then run to determine the extent of the contamination and to develop and test response plans that will minimize any impacts. There are many variables that could impact this use, but using professional judgment for these variables will be an important factor to obtain the best type of responses. The response plan will be analyzed much quicker in the model.

3. Design/upgrade of water systems. Once the model is run and the possible contamination areas are highlighted, the next step will be to identify the weak points in the water system. There are two aspects to this use. First, flow patterns through neighborhoods can be seen in the model. System design modifications may be able to minimize these flow patterns, thus preventing flow from re-entering the major distribution lines and spreading to other areas. Second, optimal system design will include methods to isolate and flush the contaminants. After a response, the optimal solution will be to isolate the contaminant and then conduct a proper flush, all the time ensuring the contaminant water is handled properly. No water system will be perfect in regards to isolating and flushing the contaminant without further impact to additional users; however, evaluation of the system through this method will allow utilities to pinpoint areas that need improvement.

4. Identifying location of contamination. During an actual contamination event, a model could be used to determine the location. When there has been a confirmed response, the model could be run with the data available to determine the input location of the contaminant. If the model is operated properly, this could be done relatively easily once with a minimal amount of operating information.

5. Confirmation of positive event. One positive alarm from a monitoring may not necessarily indicate contamination. There could be numerous causes that would result in a false positive and therefore a reasonable approach for confirming a positive alarm must be developed. It would be unreasonable for a utility to immediately react as though the system was being sabotaged on only one reading; however, due diligence must be practiced to ensure a proper response is initiated to limit the number of casualties. Once a positive is detected, there would be a mobilization to verify the field monitors with other monitors. At the same time, another verification could be done with the model. This would be done through predicting where the contamination, if truly in the system, would travel to next and the appropriate reading that would be expected at that point. Once the water reaches that point and the monitor responds in the model-predicted manner, the second response has been found. Depending on how the utility decides to respond (i.e., whether two or three positives are required prior to initiating a response), the response can be initiated.

   Note: in this scenario, the reaction equations will become important. If the constituent is assumed not to decay, then there may be a substantial overestimation of the level of constituent. This may lead to the conclusions that there was not a contamination event even though there was one.

Some examples of these uses of hydraulic models can be found in the literature. Understanding these uses and their application is important to optimizing model use as applied to security issues. These uses are explored further in the following case studies.

## Section 3: Case Studies

Three case studies are provided as examples of the use of hydraulic models in a distribution system security context.

**Case Study I.**

Allmann (2003) completed a study for modeling and detecting chemicals in a water distribution system. H2OMap$^{TM}$ was used to model one pressure zone of a water system in a primarily low-density residential area covering approximately 4 square miles with an average demand of 3.9 mgd. The model was not calibrated, but did represent normal hydraulics in the area. He used small steps—15 seconds for the high flow scenario (hydrant pumping) and 1 minute for the others. The pipe throughout the system was assumed to be PVC because it is non-reactive with most chemicals, thus was a conservative (worst case) choice. Because of this choice, pipe wall

reactions were not considered. Also, the worst-case temperature was chosen (5 °C), which is the typical temperature for many systems in winter or early spring and would reduce the amount of chemical decay. Alkalinity and pH were chosen to be 40 mg/L and 7.9, respectively. These values are typical for the type of water system he modeled.
The chemicals modeled were parathion, sodium monofluoroacetate (Compound 1080), and cyanide, and were chosen based on availability, lethality, potency, and persistence. Decay rates were determined as much as possible from the literature. Contaminant injection began at midnight. Both toxic and fatal doses for the contaminants were determined and converted to the applied concentration necessary to achieve this delivery assuming 0.5 L water consumption by a 60 kg person. These applied concentrations were adjusted for low solubility (parathion) and the taste and odor threshold (cyanide). The maximum amount of cyanide and 1080 assumed to be obtainable was 1000 pounds.

## *Scenarios*

There were three different methods for introducing the contamination into the water system. Table 3 lists the parameters for the contamination scenarios. Strategic locations within the system were chosen for contaminant injection. Figure 2 shows where these contaminants were injected into the distribution system. Using the same feed rate at each location was not practical based on the water flow in each area. Contours were completed to show the level of contamination throughout the system. Figure 3 shows these contours.

**Table 3** Parameters for metered contamination scenario

| **Parameters for Metered Contamination Scenario** | | | | | |
|---|---|---|---|---|---|
| Contaminant | Toxic Goal | Target Concentration (mg/L) | | Feed Conditions (g/L) | |
| Parathion | Max solubility | 24 | at min hourly flow | 1260 | pure product |
| 1080 | $LD_{50}$ | 240 | at max hourly flow | 1000 | dissolved |
| Cyanide | $LDL_o$ | 171 | at max hourly flow | 370 | dissolved |

Based on this, the total quantity of contaminant injected at each location was determined by the flow rate. The areas with the highest flows thus had the largest impacts on the system. The spread was then modeled and recorded after 3, 6, 12 and 24 hours of injection. The contamination was quantified according to the proportion of the system demand affected. The three different scenarios were evaluated for the worst-case contaminant injection conditions described above.

Scenario 1.

The first scenario involved continuous covert backpressure feed into the system, using a standard ¾-inch diameter service connection with a small pump, operating at flows of 0.01 gpm or less. This delivered smaller quantities of a pure, highly concentrated contaminant just above system pressure. This method would give the saboteurs an advantage because of the delay caused by the time needed to displace the water in the service connection pipe. This could amount to hours before the contaminant reaches the distribution system, depending on the feed rate and length of the service connection. This could allow the perpetrators to flee before any ill effect occurs. This method was selected as the feed method of greatest concern.

Scenario 2.

The second scenario was similar to the first, except it used a larger pump, rated at 35 gpm at 155 psi, thus creating high flows of a dilute dissolved substance under high pressure. This high flow of a diluted contaminant would require capability for a large quantity of stored water because the backflow through the service connection will not allow for any water to be supplied to the building. This scenario would require mixing of the contaminant, which could be harmful to the saboteurs. The high pressure could also cause leaks in the building and detectable increases in pressures and flows within the system. The additional water pumped into the system would increase pipe velocity and speed contaminant spread. If the additional volume causes the upstream flow to reverse, a second direction for contaminant spread within the system could be opened.

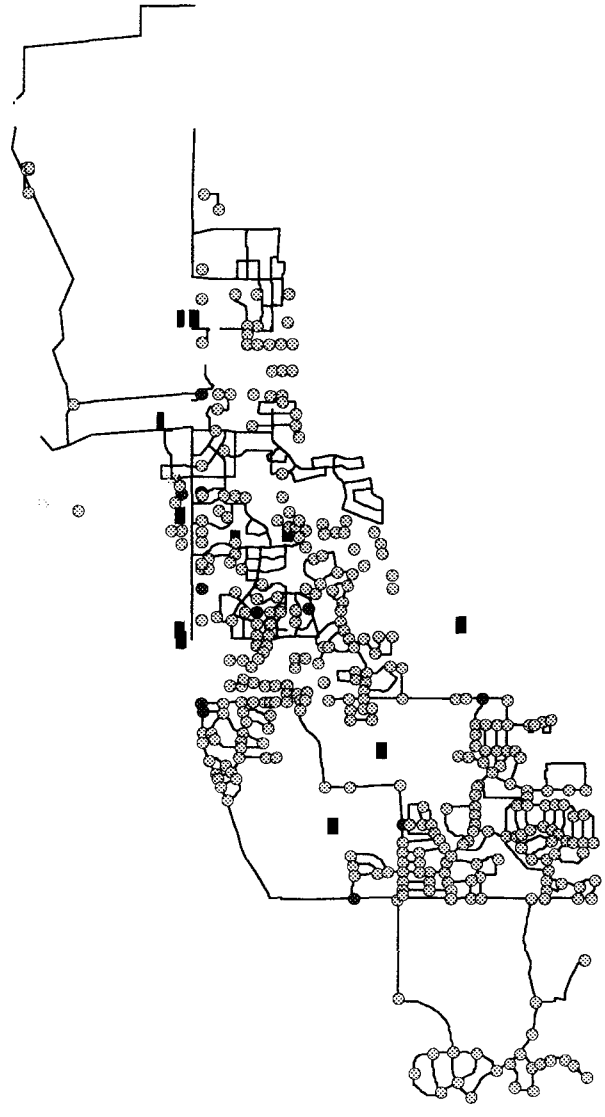


**Figure 2** Points of injection for modeled contamination.

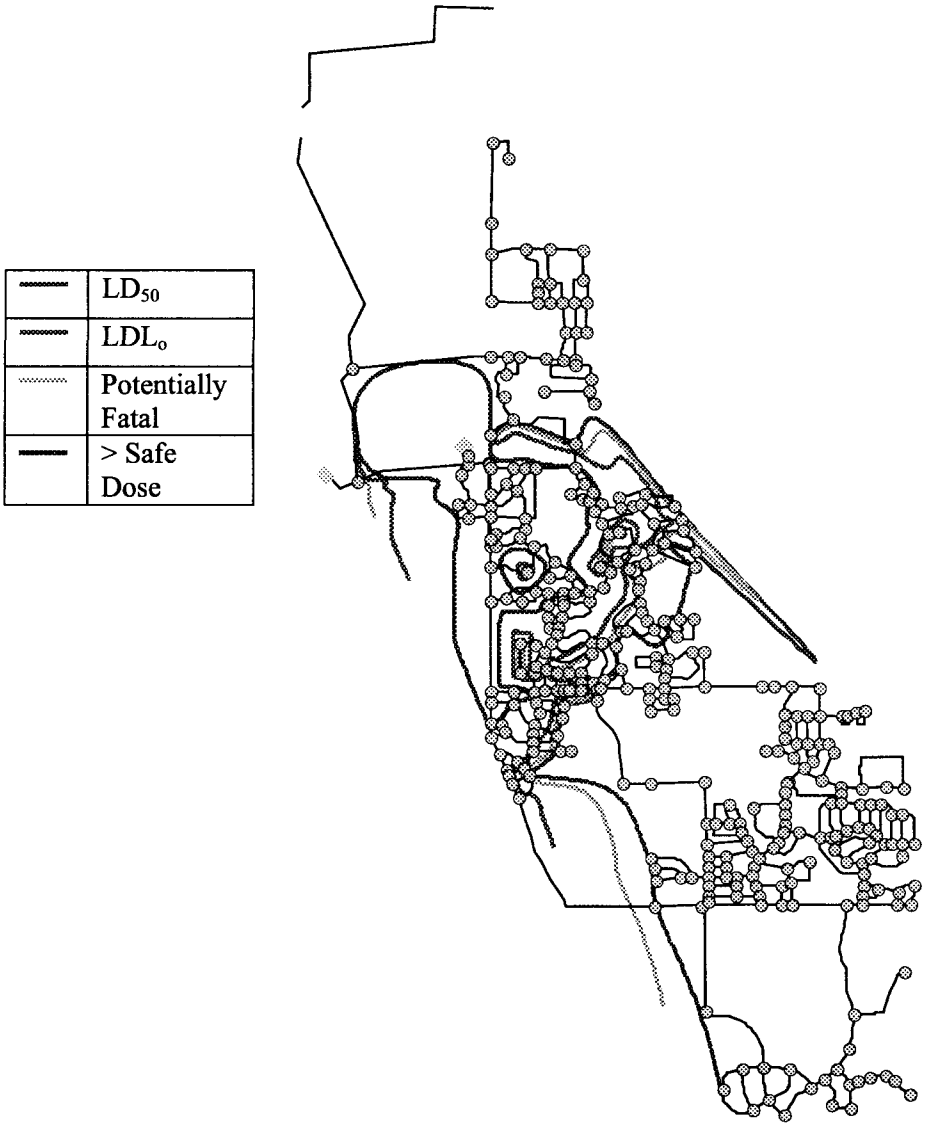



**Figure 3** Spread of 1080 contamination from location 1 after 3 hours.

Scenario 3.

The third scenario included a tank truck with a built-in pump that would unload contaminated cargo through a backpressure into a fire hydrant in just a few minutes. The rates for this were at 750 gpm or greater. This has the same limitations as the high flow scenario as well as the volume that can be transported including the visibility and noise of the truck and tank. The primary problem with this scenario is the necessary speed of the attack. Because the contaminant is introduced into a flowing stream of water, the volume affected is the product of the flow rates and the length of injection. If the time is limited to several minutes, then even at high flows such as in large mains, the volume of water impacted is in the thousands of gallons. The impact of this is limited because only 1 to 2% of drinking water is actually consumed, thus dispersion of the slug of water is not considered significant. Mixing can also produce larger quantities of water more dilutely contaminated. If the model is highly looped, the multiple paths allow the slug to mix with unaffected water resulting in multiple slugs passing through many locations in the system, which can still produce potentially toxic water albeit diluted.

Worst-case scenario.

After evaluation of these scenarios, it was determined that the low-volume, pure product metering approach was the most dangerous, which was then selected for further study. This scenario was then applied to several different locations in the system to determine the impacts on the system as well as possible detection scenarios. For this study, it was assumed that the objective of the actions would be to obtain the maximum toxicity with minimum indication of contamination.

Contaminant Detection

An important aspect of the case study was detection. Detection of the parameters was based on a significant change in a standard drinking water quality parameter, defined as a variation greater than $3\sigma$ from the mean baseline value. These variations were established using five parameters measured with real-time instrumentation over a six-day period. The parameters were turbidity, chlorine, total organic carbon (TOC), pH and conductivity. The primary detection for the organics was TOC. Detection limits for parathion, and 1080 were calculated based on their carbon content. Cyanide is inorganic; however, bench tests showed that TOC can be used to detect it. pH also offered an effective detection method for cyanide due to the acid-base reactions that occur with this compound. Another detection method for cyanide was conductivity since the TDS concentrations would be elevated (Snoeyink and Jenkins, 1980). Based on these detection methods, all of the chemicals can be detected at concentrations below those that would be necessary to cause a significant acute hazard to human health.

## ***Placement of Detectors***

The model was used to evaluate the placement of detectors throughout the system. The contour lines from Figure 3 were uses to show the expected transport of contamination. This information was then used to find common paths of contamination, which were then evaluated for detector sites. Several different criteria were used to site the detectors—size of the upstream area that could be monitored at the location, detectability of contamination occurring in this area, and the timeliness of detection. The amount that could be detected was greatly impacted by mixing. From these variables, four areas were selected for detectors. Table 4 shows the time at which contamination was detected at the detectors from the various points of origin. The first point of detection is in bold.

It was found that the contaminant in the lower parts of the system was significantly more difficult to detect because it did not spread quickly. These areas had low flow rates and velocities. Based on the flows in these lower areas, there would be a lower threat in these areas. This showed that it was not possible to detect the contamination in all areas of the system. Because of this, the detection efforts should be risk based.

System Upgrades

The analysis showed that flow patterns and pipe bifurcation play important roles in contaminant propagation. Those areas in the middle of a neighborhood did not present as large of a hazard as those directly upstream of the neighborhood while those areas with branches immediately downstream had a large impact. The analysis showed that water passed through neighborhoods in sheets, with downstream mains acting as major receiving lines. This means the contamination will pass from one neighborhood to another, eventually hitting another main, then transported further downstream. The contaminant will be diluted, but still make it downstream. The spread of contaminant in the smaller lines was virtually the same as the larger ones; however, the greatest danger is still on major supply lines. If decay is minimal,

**Table 4** Time of detection by origin of contamination and detector location.

| Contaminant Origin | Detector Location | | | |
|---|---|---|---|---|
| | #1 J430 | #2 J378 | #3 J632 | #4 J540 |
| 1 | **2:50** | 3:42 | 8:42 | 2:58 |
| 2 | 3:08 | 2:40 | 9:34 | **1:54** |
| 3 | ND | ND | 9:20 | **1:28** |
| 4 | ND | ND | * | **1:14** |
| 5 | ND | ND | ** | ND |
| 6 | 2:22 | **1:52** | 9:30 | *** |
| 7 | **1:00** | 3:16 | 7:26 | ND |
| 8 | ND | ND | **3:42** | ND |
| 9 | ND | ND | **6:10** | ND |
| 10 | **4:46** | 9:04 | 20:34 | ND |
| 11 | ND | **2:00** | 10:20 | **** |

Time from injection to detection given as hours:minutes
ND = not detected
*Approximately 40% of the detection limit at 16:10
**Approximately one-half the detection limit at 10:20
***Approximately one-half the detection limit at 5:30
****Approximately one-half the detection limit at 5:00

lethal concentrations can be reached far downstream, representing the greatest potential danger from contamination. The flow direction must be known if a sophisticated and highly effective attack is to be achieved, but the overall results show that that large-scale contamination of a drinking water system can be accomplished through backflow into major network water supply lines. In addition, points of attack outside the major supply lines can also produce large-scale contamination but at lesser concentrations.

Randomly selected points for contamination can impact large areas depending on pipe velocities, flow patterns, and other factors. In order to be successful, detailed system knowledge would be

required. Gross contamination of the system would be easy, but also detectable. Mass casualties would be avoided, but there would be fear created.

Finally, the risk posed by a contaminant it is usually proportional to the ability to detect it because the risk is represented by the spread of a contaminant. The greater the spread, the more likely a contaminant will hit a detector. Mobile contamination that presents a large risk to a large part of the system can be detected and this must be the focus of a monitoring system. A loose grid detection system will only detect after a significant portion of the system has been contaminated. Only a highly dense detector system will allow both detection and response in a timely manner to ensure control of the contamination.

Application and use of model

This case study demonstrates several important aspects of modeling. Through the use of the model, detector placement was evaluated. This was done using flow propagation information in the model. If another detection methodology is chosen and used, it can also be tested using modeling to determine its effectiveness. The scenario also showed how contamination location can be identified. This was done through the use of contour lines. The scenario also showed that flow patterns and pipe bifurcation play an important role in contamination. This information can then be used to upgrade the system as needed.

**Case Study II.**

A project was completed by Bahadur, et al.,(2003) using PipelineNet for a case study of the East Bay Municipal Utility District (EBMUD) in Oakland, California. The case study addressed the following issues: location of monitors in the system, timing and frequency of monitoring, and monitoring techniques and water quality parameters. The study evaluated 13% of the 122 pressure zones in that distribution system using a fully calibrated EPS model. The study area considered all pipes with diameter equal to or greater than 2 inches. The model run included 17,997 pipes (748 miles), 16 different pressure zones, and 16,878 junctions. The model was calibrated by adjusting model parameters until acceptable values were obtained. This was accomplished by comparing the SCADA data to the simulated water tanks over a 24-hour period (Bahadur, et al, 2003). There were three additional tools developed for PipelineNet:

- Consequence Assessment Tool. Provides quick identification and quantification of the areas at risk from contamination, including population, infrastructure, and resources. This tool calculates the population at risk, taps contaminated, total pipe (in miles) contaminated, number of hospitals and beds, and the number of schools and students within the area.
- Isolation Tool. This allows the modeler to change the status of any pipe in the system, i.e., open or close each pipe, to control the flow of water.
- Spatial Database Display Tool. This tool is used for determination of optimal placement of extraction and monitoring devices. It can also be used to predict where the contaminant will go (Bahadur, et al, 2003).

## Detection

Sampling locations were based on protection of critical populations and high vulnerability areas based on a proper response. The timing and frequency of sampling was based on performing routine screening while providing development of a suitable response to the incident. The last aspect included determination of parameters to track as well as interpretation of the data.

One basic question that is hard to answer is how many samples should be analyzed. For contamination, this needs to be defined based on the flow of the contaminant in the system at different times, thus professional judgment must be used. The answer must be based on an objective approach that

is dependent on several factors including the desired statistical power and confidence level in the final decision as well as the variability of the environmental attribute of interest.

The case study developed a hierarchal selection process for monitoring locations, based on model inputs, outputs, and GIS layers. This included evaluating all elements of the water system initially, which was then reduced based on water utility priorities. These priorities included nodes physically accessible, high priority areas based on flow, velocity, pressure and water quality, and proximity to critical areas, such as schools and hospital. There was a three-step process used to rank the sites.

- Step 1: Prioritization of sources. Not all nodes are available for sampling, so all those inaccessible or unavailable were eliminated. These included nodes not physically inaccessible; junctions of two pipes with different diameters or materials; nodes of dead end pipes; nodes near crosses, tees, or other such items; nodes on transmission pipes, and nodes with backflow-preventers. These nodes were then considered not available for sampling.
- Step 2: Distribution System Response. The hydraulic and water quality results from the model determine the distribution system response. The authors used the model to evaluate four sets of parameters (flow, velocity, pressure, concentration). After evaluation of these, a numerical value was assigned to each pipe, with a range from 1 to 10 (10 being a high level of concern. Each of the parameters were assigned a value, which can be determined or overridden by the user. Guidance is provided in the program for the number system.
- Step 3: Critical Facilities and Population Density. This step involved user selection of critical areas. For this value, those pipes in or near critical areas were assigned a value of high concern.

Pipelinenet has a ranking tool for the EPS simulations done which can serve as a starting point for monitoring location selection. There are different methods for the user to allocate scores based on the system parameters. These are discussed below:

- Natural Breaks: This identifies the break points between different classes of parameters using a statistical formula called Jenk's optimization. This method minimizes the sum of the variance within each of the parameter classes, which can be complex. It basically finds groups or patterns within the data.
- Equal Interval: This method divides the range of parameters into sub-ranges that are equal in size. Then the features are further classified based on those sub-ranges.
- Quantile: This classification method involves classifying the parameters into the same number of classes with the same number of features. These quantiles are best suited for linearly distributed data, other data that does not have disproportionate numbers of features that have similar values.

The user can select any of these three options for any parameter. The values used were only guidance—the user can override any value that is output from the three options. The scores ranged from 1 to 10, for velocity, pressure, and flow. Thus, each pipe could receive a score up to 30, but scoring could be changed. These values were then displayed in the model. Once in the model, overlay of critical facilities can be done to further eliminate sites. Figure 4 shows the pipes with high scores and also critical infrastructure (hospitals and schools).

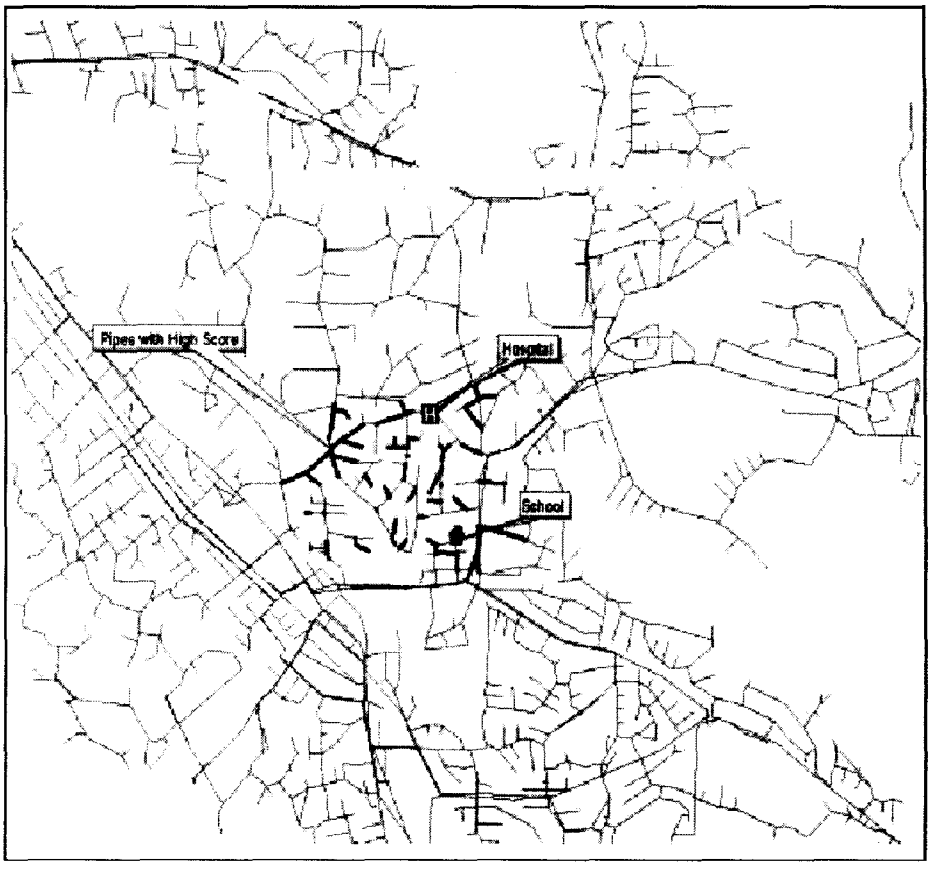



**Figure 4** PipelineNet system showing high score areas with critical infrastructure

The case study concluded with the evaluation of consequences, by showing the spread of the contamination from the source, showing the critical facilities and population affected.

Application and use of model.

This case study demonstrated how models can be used to select sites for detector placement. The authors established a hierarchal process to choose the sites and demonstrated this in the model. This process ranked the nodes based on hydraulic parameters based on scores for each. The model used throughout the process to identify the areas where monitors should be placed. It not only assisted in the selection, but it also was a very useful method to present these decisions as well.

## Case Study III.

The next case study is an example of a post-scenario analysis, or after an attack. Both constituent and trace analyses were conducted using H2OMAP. As discussed above, there are three different water quality analyses in the models (trace, age, and constituent). Both the trace and constituent analyses can be used for the post-scenario analysis, and were done here. For these analyses, H2OMap$^{TM}$ was used. The headloss equation was the Hazen-Williams, the accuracy was 0.001, and the water quality tolerance was 0.01. The duration was 24 hours and the hydraulic, pattern, and quality time steps were set at 1 minute. The clock start time was set at 00:00:00 (midnight), i.e., the contaminant was introduced at midnight. The contaminant modeled was sodium fluoroacetate (1080). 1,000 pounds of the contaminant was pumped into the system at a specified node (number 342) using a low flow pump.

The purpose of this scenario was to show how the model can be used for post-scenario analyses. This case study was generated to show two specific uses of the model—to show how the location of the contaminant would be identified and how to confirm a positive event. There would obviously be information constraints in a real world scenario, i.e., the actual site, contaminant, contaminant level, pump rate, and various other hydraulic data, would not be known. The purpose of this case study was to show how an existing model can help determine if the event actually occurred and where the contaminant is. In a real world situation, a utility would input any information available into the model. If required, the user could assume a contaminant identity (e.g. cyanide) until more information is obtained.

Constituent Analysis.

The first post-scenario analysis conducted was constituent analysis. From experiments conducted at Colorado State University, 1080 can be detected at levels of 3 mg/L using normally measured water quality parameters. The model was then used to estimate the flow areas of the contaminant.

Figures 5 – 12 were generated from the model run. Each of these figures show two key pieces of information in their contour lines. The yellow line is the $LD_{50}$ line (240 mg/L), as calculated by Allmann (2003). The red line is the point in the system where the contaminant would be 3 mg/L or greater, the detectable level according to the experiments. The figures depict the contaminant travel at times of 1, 3, 6, and 12 hours. Each time increment has two distinct figures—one of the entire distribution system and one that is zoomed in at the site that contamination was entered.

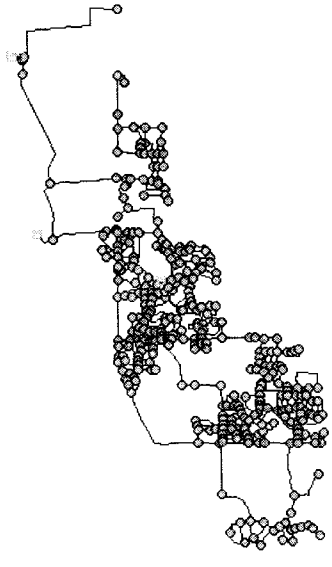


**Figure 5** Contaminant travel after 1 hour, full view.

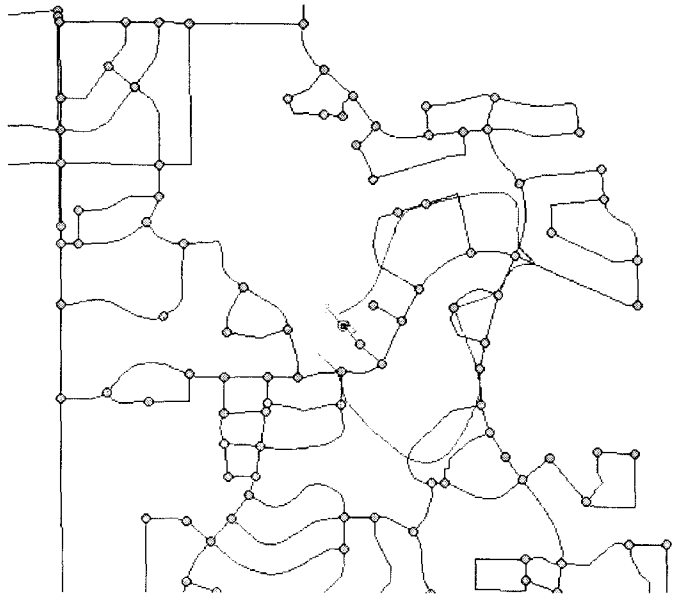


**Figure 6** Contaminant travel after 1 hour, close view.

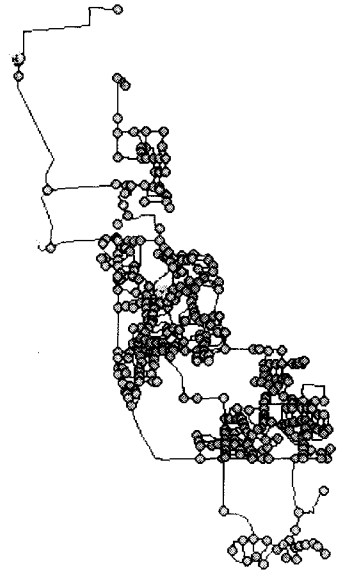


**Figure 7** Contaminant travel after 3 hours, full view.

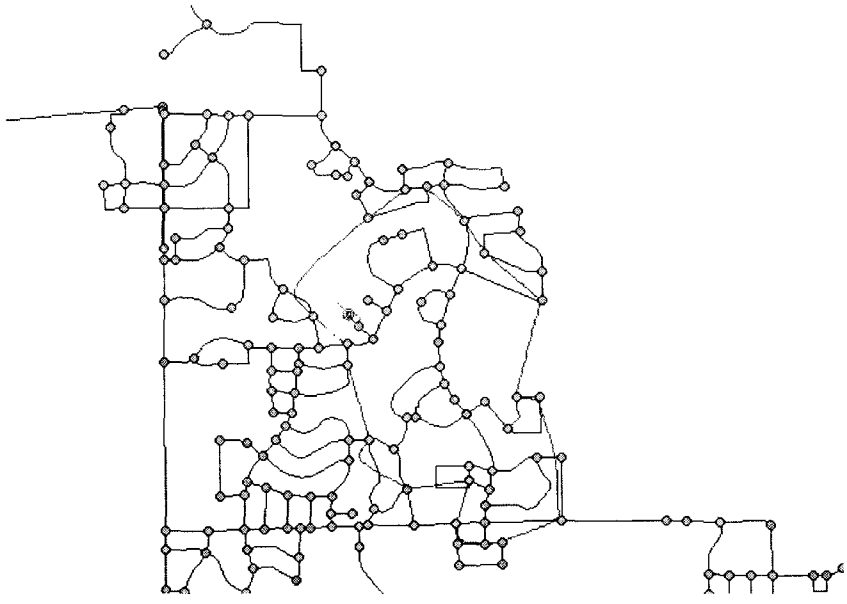


**Figure 8** Contaminant travel after 3 hours, close view.

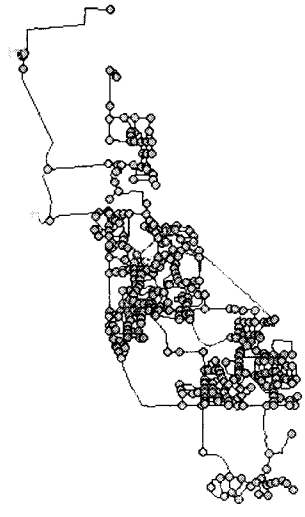


**Figure 9** Contaminant travel after 6 hours, full view.

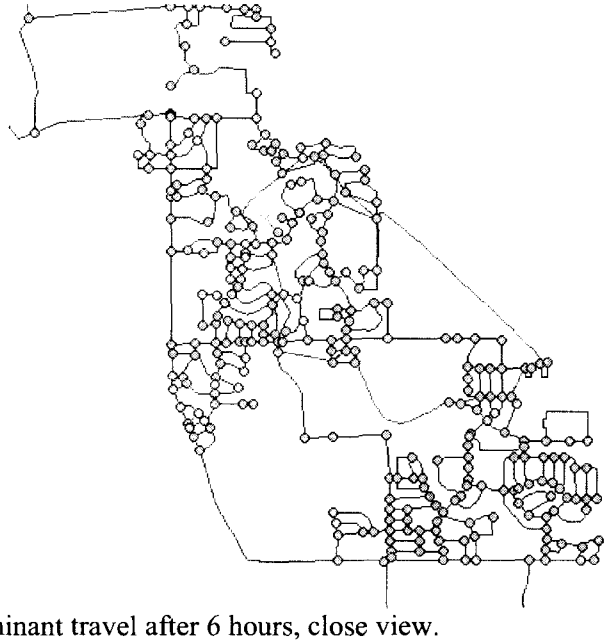


**Figure 10** Contaminant travel after 6 hours, close view.

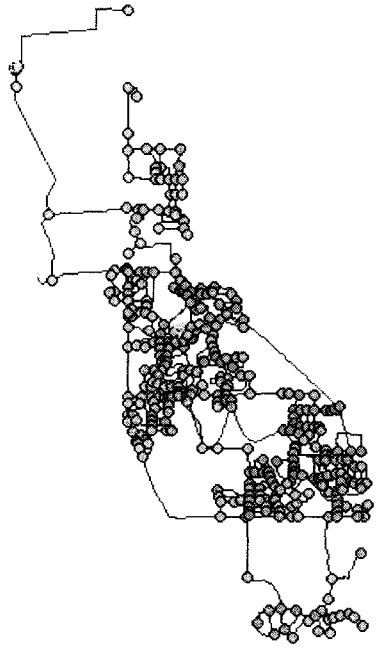


**Figure 11** Contaminant travel after 12 hours, full view.

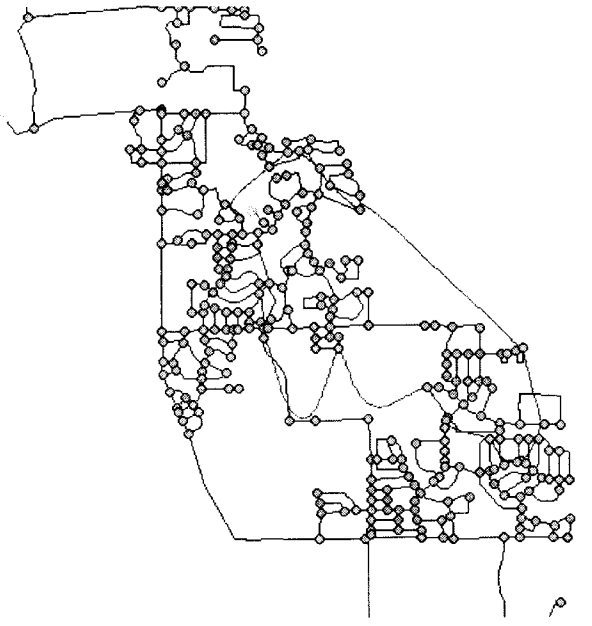


**Figure 12** Contaminant travel after 12 hours, close view.

Trace Analysis:

The next analysis completed was a source trace analysis for node 342, the node where the contaminant was entered. The same model was used with the same data. This analysis can be used to determine what other nodes were impacted by the contaminant. The contaminant was injected at node 342, which was then used as the trace node. These numbers will change significantly based on hydraulic factors of the system, including the demand patterns. The time of 0800 hours was arbitrarily chosen to present for this case study. Note that only those nodes impacted by the contaminant are listed.

Table 5 shows the nodes that were impacted by the water from the trace node, which is represented as a percentage. Again, this information would be useful because the amount of water impacted by the contaminant is shown.

**Table 5** Trace analysis of contaminated node.

| Node | % 342 |
|---|---|
| 343 | 100 |
| 342 | 100 |
| 344 | 100 |
| 346 | 100 |
| 348 | 100 |
| 347 | 100 |
| 345 | 100 |
| 446 | 80 |
| 448 | 63 |
| 451 | 63 |
| 445 | 63 |

| Node | % 342 |
|---|---|
| 432 | 62 |
| 433 | 62 |
| 431 | 62 |
| 602 | 62 |
| 452 | 61 |
| 456 | 60 |
| 601 | 60 |
| 600 | 59 |
| 603 | 57 |
| 555 | 55 |
| 551 | 51 |

| Node | % 342 |
|---|---|
| 614 | 42 |
| 615 | 42 |
| 623 | 41 |
| 624 | 40 |
| 631 | 39 |
| 611 | 28 |
| 378 | 23 |
| 373 | 23 |
| 550 | 19 |
| 388 | 16 |
| 552 | 13 |

| Node | % 342 |
|---|---|
| 454 | 62 |
| 442 | 62 |
| 444 | 62 |
| 450 | 62 |
| 455 | 62 |
| 443 | 62 |
| 441 | 62 |
| 440 | 62 |
| 435 | 62 |
| 430 | 62 |
| 434 | 62 |

| Node | % 342 |
|---|---|
| 607 | 49 |
| 604 | 48 |
| 612 | 48 |
| 606 | 48 |
| 447 | 48 |
| 453 | 48 |
| 613 | 47 |
| 605 | 46 |
| 630 | 44 |
| 610 | 44 |
| 620 | 42 |

| Node | % 342 |
|---|---|
| 556 | 10 |
| 632 | 10 |
| 634 | 6 |
| 387 | 3 |
| 377 | 3 |
| 541 | 0 |
| 542 | 0 |
| 516 | 0 |
| 386 | 0 |
| 553 | 0 |
| 543 | 0 |

Application and use of model

This case study demonstrates several key aspects of model application after a contamination event has occurred. The first main aspect is confirmation of a positive event. Obviously drastic actions would not be taken at the first positive, but confirmation must begin. A model would be a powerful tool for confirmation because it can show where the contaminant would be expected to travel. This can show when it would reach another monitor or allow workers to go and take samples in the field. The second major aspect is identifying the location of contamination. The source node can designated. This source node does not need to be the actual source and could be the area where the contaminant was first detected. Other nodes throughout the system that were impacted by the contamination can then be identified for further action.

## Section 3: Guidance for Use of Flow/Chemistry Models

Haestad Press provides a water security example of modeling. In that example, a call is received with information given about the location, chemical, time, and duration. The first step is public notification. After notification, the contaminant must be flushed and treated accordingly. Flushing can drastically change the way water moves throughout the system. Trial and error would take too long to determine the appropriate flushing, thus a model would be necessary to determine the proper flushing (Haestad Press, 2003).

In a real world scenario, much of the above information would not be available. If monitors are in the system, there may only be a positive response at one of the detectors. Therefore, a lot of information will be lacking. The use of models will help in the preparation for an incident, including proper instrument siting, confirmation of positive results, and then formulation and evaluation of responses. After an attack has been conducted, it is too late to develop a model to help in response. Therefore, it is crucial that the model be developed prior to a contamination event.

The guidance presented in this paper is broken into four distinct categories: general model development, security applications pre-scenario analysis, security applications post-scenario analysis, and detector placement. Each of these are presented and discussed below.

### General Model Development

The security-specific guidance in this section is largely based on the assumption that the system model has already been completed and just needs applied in a water security manner. The time to get a model running is largely dependent on the condition and status of the existing model, but even if the model is in good operating condition, there can still be a major time investment. Some estimates are that if the model and GIS data is in good status, it can be operational in a short time frame of three to six months, but this could be longer if the model is not fully developed (Bahadur, et al, 2003). The guidance

discussed in this section is directed at developing a hydraulic model in preparation for security applications. A flow chart outlining the guidance for general model development is shown in Figure 13.

Determine Model and Model Size

One of the first steps is to choose the actual model and the size, both of which are important decisions. Each model has it strengths and weaknesses and these must be considered prior to model selection. Once that decision is made, the next decision is the size of model required. The size of model can greatly affect the price, so the size required is one that must be carefully determined to ensure the proper capabilities are achieved while minimizing the price.

Create Model

The next step, if not already completed, is data entry, or creating the basic model of the hydraulic system. The actual model creation is beyond the scope of this paper. This step will include data entry of the initial system parameters.

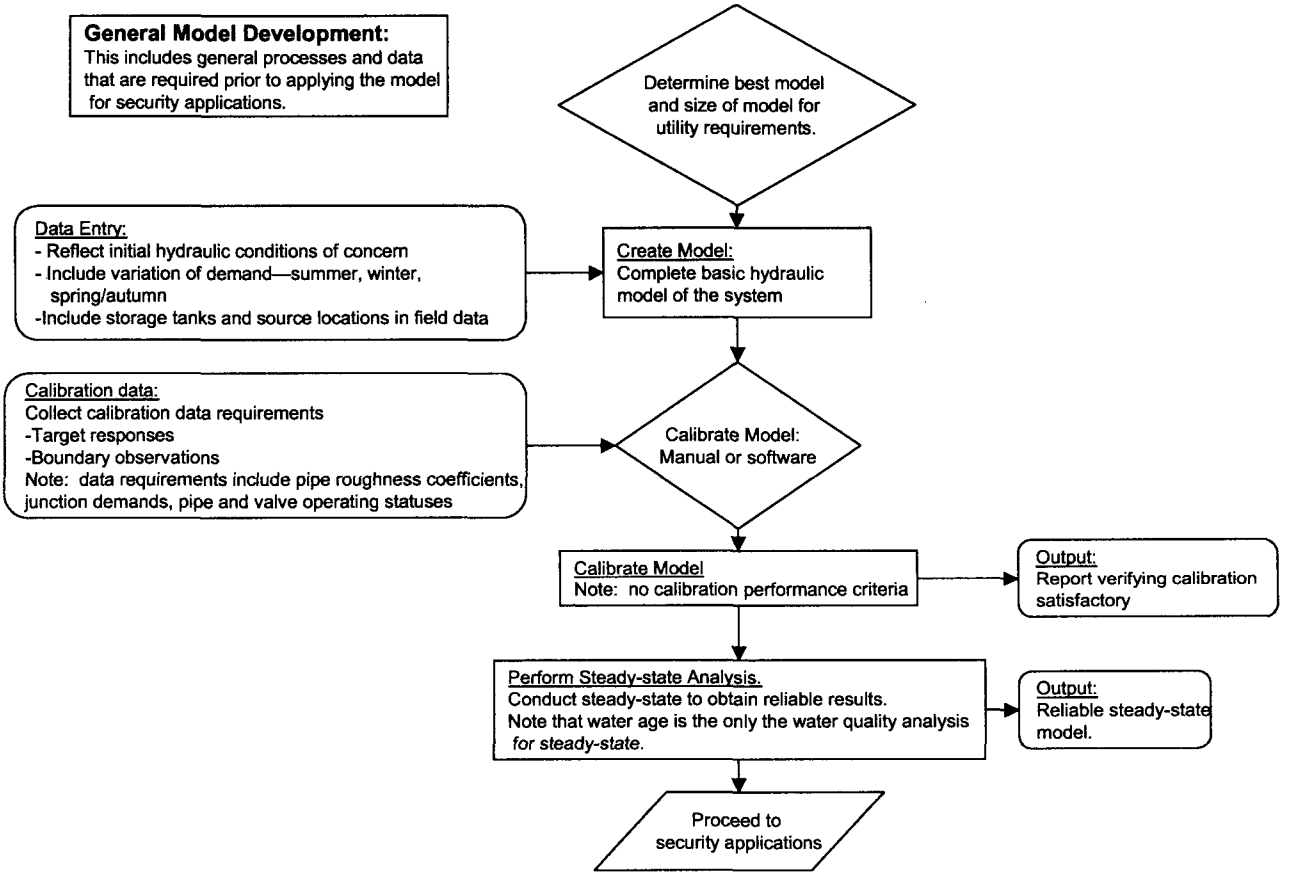



**Figure 13** Flow chart for general model development.

Data Entry

There is a large amount of data that must be entered into the model. The model must reflect the initial hydraulic conditions of concern. It is impossible to model all conditions, but carefully selecting appropriate conditions will provide insight into most of the possible situations as opposed to just a few extreme days. The model must include a variety of demands, and not just the worst case such as a

summer day. The model should include typical summer, winter, and spring/autumn days. When collecting the initial field data, it is recommended that storage tanks and source locations be included in the measurements (Rossman, 2000).

Calibrate Model

Calibration is the process of adjusting the model so that the predicted flows and pressures match actual observed field data to an acceptable level. This must be done to ensure the model is being used correctly and simulating the flow patterns properly, or to ensure it predicts the system properly (Haestad Methods, 2002). Calibration involves adjusting model characteristics and parameters so that the output matches the field data to an acceptable level (WaterCAD, 2004). In short, calibration makes the model credible. Without that credibility, the most complex and theoretically sound model that could be developed would not be effective in helping plan a sound system. A well calibrated model will not only result in more accurate water quality simulations but will also greatly assist in locating optimal sampling and satellite treatment locations and in making sound and cost-effective water quality management decisions (MWH Soft, 2004). Overall, calibration is essential to increase the knowledge and understanding of the system. There is no calibration performance criteria in the U.S. and there is no industry consensus about the acceptable threshold match although AWWA does have calibration guidelines (AWWA, 1999).

There are many parameters that must be considered for calibration. The data required can be broken down into two main categories: target responses and corresponding boundary observations. The target responses are junction pressure and pipe discharges. The boundary observations are such items as tank levels, valve settings, pump statuses and speeds. Calibration typically consists of measuring the required parameters at different times of the day at different sites. These should correspond to different demand loadings and boundary conditions. Based on time and labor constraints, only a small percentage of representative sample measurements can be gathered (Haestad Methods, 2002). Calibration can be done either manually or through relatively new calibration software.

Manual calibration.

Manual calibration is basically a trail-and-error process, which can become very tedious. It includes adjusting model inputs using only basic engineering judgment. This requires using all time-disjoint field data to ensure the model simulated the actual physical systems under all conditions (MWH Soft, 2004; Haestad Methods, 2002). The manual method requires the modeler to estimate the model parameters, run the model to obtain values, and then compare to the field data. Then the model values are changed. This is an iterative process that is repeated until the desired results are obtained. The process can be very time consuming, especially for larger systems (WaterCAD, 2004; MWH Soft, 2004).

Calibration software.

There are numerous models with water calibration software. These use genetic algorithms that allow the model to test millions of solutions and then identifies the best solution. For instance, WaterCAD has a program called "Darwin Calibrator", which uses Fast Messy Genetic Algorithm (fmGA) to calibrate the model in steady state, multi-steady state, or EPS modes. This program allows manual changes if required (WaterCAD, 2004). MWH Soft Inc. offers $H_2OMAP$ WQ Calibrator and $H_2ONET$ Calibrator® extension for calibration, which use the Object-Oriented Messy Genetic Algorithms technology with advanced Elitist and Global Search Control strategies in a true high-performance GIS environment. The calibrator works to minimize the difference between site-specific measurements (or residual concentration data) and the model concentration predictions (MWH Soft, 2004). EPANET has calibration reports, which tell how well the simulated results match the actual field measurements. These pages include:

- Statistics Page: Lists error statistics between those simulated and observed values at each location measured. The program will find values through interpolation if a measured value was completed at a time in-between the simulation's reporting time intervals.

- Correlation Plot Page: Shows a scatter plot consisting of the observed and simulated values for the measurements at each location in the network with each location assigned a different color in the plot.
- Mean Comparisons Page: Bar chart comparing the mean observed and mean simulated values for the calibration parameters for measurements at the each location they were taken.

The major disadvantage with these calibration software packages is the cost.

## Steady State vs. EPS

There are certain water quality analyses that can be completed in the model. These will be discussed later, but those that are most useful can only be completed using EPS analysis. However, it is highly recommended that the model be examined under steady-state situations prior to using the EPS model. The will make it easier to complete the EPS analysis (Haested Press, 2003).

Once the model has been completed and run satisfactorily, the model is ready to be applied to a specific water security issue.

### Security Applications—Pre-scenario analysis

Once a satisfactory model has been developed and run, security specific applications can be developed. This section describes analyses that would be completed before a contamination event occurs. A flow chart for conducting the pre-scenario analysis is shown in Figure 14.

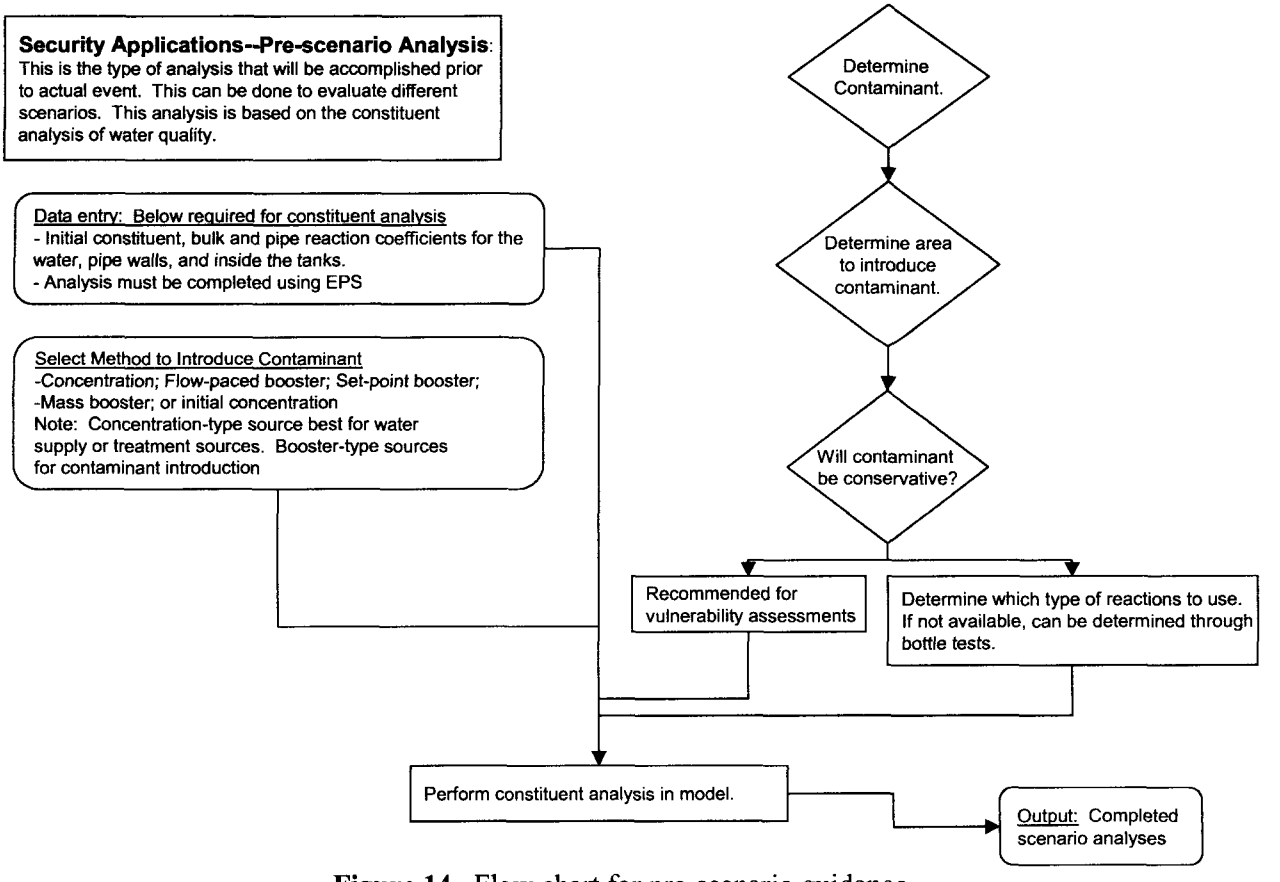



**Figure 14** Flow chart for pre-scenario guidance.

There are three distinct types of water quality analyses that can be conducted (water age, trace analysis, and constituent analysis) and each requires different types of information. The constituent analysis would be the scenario most appropriate for water security because it allows direct input of a contaminant. Trace analysis can be useful if the source of the contaminant is determined because this will show other areas impacted by the contaminant. Water age analysis can be useful to show how long the contaminant will be in the system, but is not the recommended analysis method. Water age can be performed using steady-state analysis, so it can be one of the first analyses performed. Each analysis requires different data input as explained below:

- Age. Requires pipe velocity and flow rate. No reaction rate coefficients are required.
- Trace. Requires pipe velocity and flow rate. No reaction rate coefficients are required. This analysis can only be performed using EPS.
- Constituent. Requires the greatest amount of information: initial constituent, bulk and pipe reaction coefficients for the water, and interaction between the water and pipe walls as well as tank reactions. If the contaminant is assumed to be conservative, these parameters will be zero. This analysis can only be completed using EPS (Haestad Methods, 2002).

Determine contaminant to use

The first step in water security modeling is to determine the contaminant to model. The actual selection goes beyond the scope of this paper, but will be briefly discussed. An ideal agent that would be used by a saboteur would be readily available and not easily detected by monitoring equipment. The physical appearance would have no odor, color, or taste. Dosage and health effects must also be considered. The agent must also be chemically and physically stable in the water as well as tolerant to chlorine (Haested Press, 2003).

There are many different methods available that have rated the effectiveness of contaminants. One such method is by Deininger and Meier (2000), who developed an equation to rank contaminants based on a factor of relative effectiveness. This is but one example of an equation to select a contaminant, but gives a general idea of selection criteria. R, is based on lethality and solubility, using the following equation:

$$R = \textit{solubility in water (in mg/L)/(1000 x lethal dose (in mg/human))}$$

There are many different factors that can be used to select a contaminant. The contaminants range from those that cannot be easily detected and can be detected quite readily. It would probably be best to select an agent that is detectable for the first scenario because this would show where it could be detected. However, there are numerous contaminants that can be selected and the reader is referred to other white papers for determination of contaminants to model.

The contaminant is represented in the system by describing its transformation characteristics and how it was introduced into the system. The items that must be input include the time and the amount of contaminant that was placed into the system. Most models provide several alternatives to input this information.

## ***Determine area to introduce contaminant***

Once the contaminant is determined, the location in the system where it will be injected into the system must be determined. This could be any node in the system, so the possibilities are many. The actual location could be chosen from a vulnerability assessment conducted. It is recommended that many different sites be selected and evaluated. The sites should be from places throughout the system and also different types of nodes (i.e., large mains, small mains, inside buildings, etc.). One purpose of this analysis is to determine possible scenarios, so the more nodes chosen and evaluated the better. By

choosing a wide range of nodes, certain sites that are more vulnerable may become obvious. Guidance on the selection of nodes can be evaluated through the case studies in this paper. That is, the nodes that others have chosen are nodes that may present higher risks. Another consideration are nodes around high value targets, such as hospitals and schools. These areas may present ideal targets for saboteurs.

## Determine Reaction Coefficients

The next step is to determine if the contaminant will be conservative or reactive. Reaction coefficients are normally treated as conservative or simple first-order kinetic (Boulos, Altman, Jarrige, Collevatie, 1994; Haestad Press, 2003), but are usually assumed to be conservative for security studies (Haestad Press, 2003). If there are not conservative, the reaction coefficients can be entered through various decay methods. Coefficients may be found for some contaminants in the literature.

## Determining Reaction Coefficients if Unknown

If there is a need to determine the actual reaction coefficient for a specific chemical, it can be determined through bottle tests (Rossman, 2000). These cannot be used for wall reactions because they cannot be directly measured—they must be back-fitted against calibration data collected from field studies. This will involve trial and error but provide the best match to field data. The type of pipe has a large impact on this coefficient. Rossman does note, however, that there is not a large wall demand expected for plastic and relatively new lined iron pipes (Rossman, 2000).

The reaction coefficients depend on the type of pipe in the system. For example, unlined cast-iron pipes have higher chlorine consumption than polyvinyl chloride (PVC). Also, larger-diameter cast-iron pipes have lower consumption than smaller-diameter pipe (Clark, Rossman, and Wymer, 1995). The water can have an impact also—water high in humic and organic material that is transported in the network can lead to pipes with a high disinfectant demand (Clark, Rossman, and Wymer, 1995). Biofilm on iron pipes are much more resistant to free chlorine than biofilms on galvanized, PVC, or copper pipe surfaces, which is probably because free chlorine reacts more ferrous iron to produce insoluble ferric hydroxide (Lu, Biswas, and Clark, March 1995). These are just a few examples of the complexities that make estimating of pipe wall reactions difficult.

As shown, there are several different methods that the reactions coefficients can be estimated and represented in the model. The default for water security is conservative, that is, no decay. Most of the available literature also states that this is the preferred method. However, there can be potential problems with this in some aspects of modeling, specifically verifying a positive sample. If it is assumed that no decay occurs and if in fact there is decay, then the readings at down stream meters may be lower than anticipated. This may mean that the detectors will not read the expected values, and the conclusion could be made that there was not contamination in the system. This could be overcome by simple awareness, but this is still a consideration that the modeler must be aware.

## Introduction of Contaminants

After the above decisions are made, the method for contaminant entry must be determined. There are several methods that contaminants can be entered into the system. These methods can be applied to anything from pipe breaks to intentional or accidental contamination (Haested Press, 2003, Rossman, and H2OMAP). These methods are discussed below.

- Concentration: Fixes the concentration of any flow that enters the network at a node. Would be used for flow reservoir or a negative demand (a source) placed on junction.
- Flow-paced booster: Adds a fixed concentration to the flow. This results after mixing of all inflow to the node from other points throughout the network.
- Set-point booster: Fixes the concentration of any flow leaving the node. This can be used as long as the concentration resulting from all inflow to the node is below the set-point.

- Mass booster: Acts by adding a fixed mass flow to the flow entering the node from other points in the network.
- Initial concentration: Sets concentrations in tanks, changing over time due to the influences of either decay or dilution during fill cycle (Haested Press, 2003)

The EPANET and H2OMAP manuals state that the concentration-type source is best used for nodes that represent source water supplies or treatment works, such as reservoirs or nodes assigned a negative demand. They also state that the booster-type source is best used to model direct tracer injection, introduction of additional disinfectant, or to model contaminant intrusion (Rossman, 2000, H2OMAP user guide). Based on this, the booster-type source is recommended for contaminant introduction.

The contaminant information that must be input is discussed below. Note that these were taken from H2OMAP, but the other water quality simulations will require the same type of information (H2OMAP User Guide from computer).

- Trace node. Used for trace analysis. The one node that acts as the origin for the tracing procedure must be specified.
- Chemical name and mass unit (usually mg/L). Self-explanatory.
- Global bulk. This value is the rate at which the chemical will grow or decay due to reactions in bulk flow of water
- Global wall. This is the rate at which the chemical will decay due to reactions with the pipe walls.
- Global pipe bulk reaction order. This value will be zero-order, first-order, second-order, etc.
- Global pipe wall reaction order. Unlike the term above, this will be either zero-order or first-order
- Global tank reaction order. This will be either zero or first-order.
- Limiting potential. This term is used to specify a limiting concentration that a chemical can either grow or decay
- Roughness correlation coefficient. This term relates to the wall reaction rate constant that is dependent upon headloss equation being used.

There are several other parameters that must be input for water quality models. These include relative diffusivity and quality tolerance.

- Relative diffusivity: This is the ratio of the molecular diffusivity of the modeled chemical to that value for chlorine at 20 deg C, which is 0.00112 sq ft/day. This value is used in the following manner: if the chemical diffuse twice as fast as chlorine, 2 will be used, if it is half as fast, then 0.5. This applies only for mass transfer for pipe wall reactions. If no effects, then it should be set to zero (Rossman, 2000).
- Quality tolerance. This parameter is the smallest change that will create a new water parcel in the pipe. A normal value would be 0.01 if the chemical is measured in mg/L. The value of this parameter could be the detection limit of the procedure to measure the chemical as well as including a factor of safety also. If the value is too large, the accuracy of the simulation will suffer. If the value it too small, it will impact computational efficiency. Selection of this criteria may require trial and error (Rossman, 2000).

## Simulation Duration

The simulation duration must be entered, which is usually some multiple of 24 hours because it is the most recognizable pattern for demand and operation. For emergencies, it may be better to model just a short time in the future in order to make predictions on immediate changes in tank level and system pressures. Other applications may require several days in order for certain parameters to stabilize. The hydraulic time step is normally assumed one-hour, unless other reasons dictate need for different time step (Haested Press, 2003).

The variables that must be entered are listed below, with typical values included:

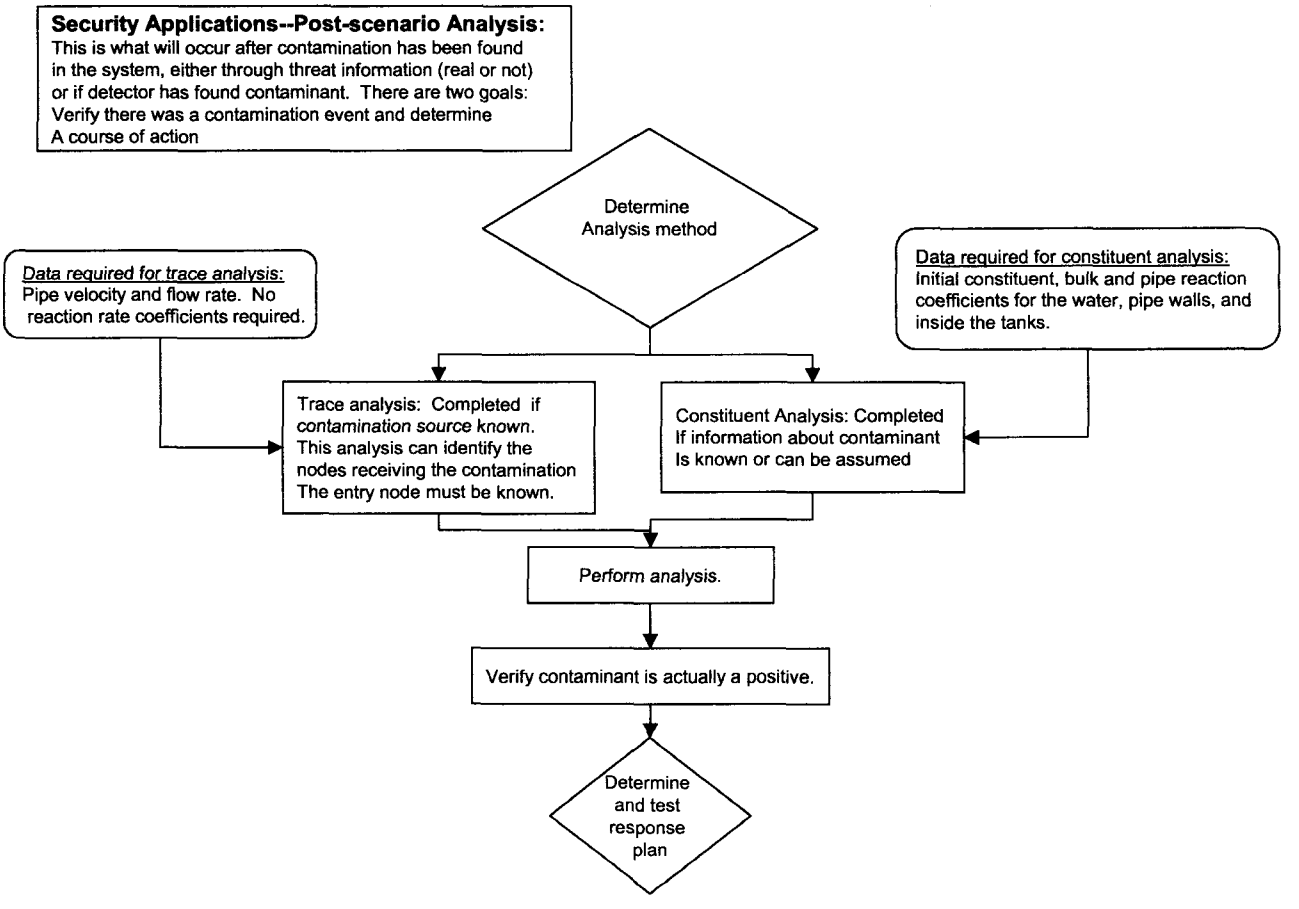
- Total Duration: Total time of simulation in hours. 0 means single period (steady-state).

- Hydraulic Time Step: Time between re-computation of hydraulics. Default is usually 1 hour. Quality Time Step: Time between routing of water quality constituent. Default is usually 5 minutes.
- Pattern Time Step: Time used with all time patterns. Default is normally 1 hour.
- Pattern Start Time: Hours that all time patterns being. Value of 2 means that the simulation beings with the time patterns at their second hour. The default is 0.
- Reporting Time Step: Interval between times that results are reported. Default is 1 hour.
- Report Start Time: Time that computed results begin to be reported. Default is 0.
- Starting Time of Day: Clock time that simulation begins. Default is midnight.

Once these decisions are made and the data entered, the model can be run for numerous scenarios. This data can be changed relatively easily so that different nodes and chemicals can be evaluated. There will be a certain amount of engineering judgment that must be used to determine the locations for contaminant entry. Overall, the more scenarios that can be run, the better.

**Security Applications—Post-scenario analysis**

This section will describe analyses that can be completed after an event has occurred. There could be various scenarios that could trigger this: a received threat, saboteur caught contaminating the system, or a positive response in the system from a monitor. There are two major goals with this analysis: verify a contamination event occurred and then determine and evaluate a course of action. A flow chart for conducting the post-scenario analysis is shown in Figure 15.



**F igure 15** Guidance for post-scenario analysis.

## Determine Analysis Method

The first step is to determine the analysis method. There are two methods that can be useful in this situation—trace and constituent analysis.

- Trace analysis: Trace analysis would be useful if the contamination source is known, i.e., the threat is known or the saboteur was caught. This analysis could then be used to determine where the water went throughout the system and determining the other nodes that are impacted. This method can also determine how much of the water at each node is impacted by the contaminant, e.g., the percent of that node that contains contaminant. The strength of this analysis is that it would be able to identify those users impacted. It may have limited use though because the actual node the contaminant entered must be known, which likely will not be the case. This would require the same data entry as stated above.
- Constituent Analysis: This type of analysis would be completed if information about the contaminant is known or can be assumed. This would occur if a monitor detected the contaminant in the system. This would provide more useful information in this situation than the trace analysis, but it would also require a lot of information that must be assumed. This analysis will also provide information on those customers affected (through contour lines). Again, this would require the same data as stated above.

## Verify Contamination Event

There must be some type of method to verify that the contamination was actually an event and not a false positive. If the event is a false positive and it is reacted to as a true event, a tremendous amount of resources can be wasted. However, if it is a true event, there could be many lives put at risk if it is not responded to quickly. Based on this, verification is a crucial step in the entire process. Modeling can play an important role in verifying the contamination event. If there is a positive alarm at some point in the system, that data can be entered into the model from that point. The data, again, may be very limited, but if there is a positive in the system, then some basic information will be known. For example, if there is a positive for conductivity, then some type of contaminant can be assumed and then modeled.

Once the known information is input to the model, predictions about the contaminant travel can be made through the contour lines. This will show the utility where the contaminant is going and at what concentrations. This will indicate at what point the contamination will hit another monitor and at the expected concentration. Once the water does reach the monitor, verification is given if it is a positive at that monitor. The utility would not have to wait until the flow hits another monitor—the model can show where a verification sample can be taken and responders then sent there to collect samples. Through these uses, the model can help in the verification. These are important steps that will help optimize uses of resources and maximize response.

## Determine and Test Response Plan

Once it is determined that there was a positive in the system, a response plan can be developed. The first response would be to notify the affected consumers, which will be shown through the model. The nest step would then be to formulate a response, such as flushing and/or treatment strategy. The actual response design is beyond the scope of this paper, but once developed, it can be tested in the model. If it is satisfactory, then it can be applied. If it is not satisfactory, then another response plan must be developed and tested. This will likely be an iterative process to some extent, but time will of course be limited.

### Detector Placement

The final use of models for security related applications is detector placement within the system. There are several major decision steps in this process as shown in Figure 16.

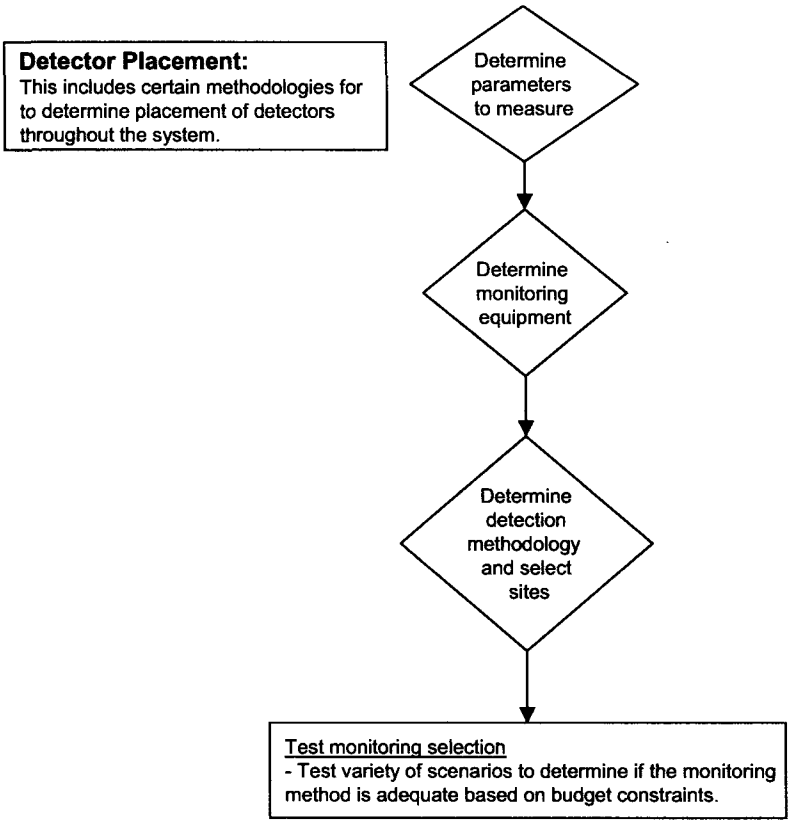



**Figure 16** Guidance for detector placement.

## Determine Parameters to Measure

The first decision point is the type of parameters to measure. This coincides closely to the monitoring equipment that will be chosen; however, this is a distinct decision. For instance, normally measured parameters can be chosen (turbidity, conductivity, chlorine, etc.). Obviously other parameters can be measured also, but at additional capital and operating costs. These issues are discussed in other papers.

## Determine Monitoring Equipment

The next step is the actual monitoring equipment, which will be based on the parameters to measure. There is a wide range of online monitoring equipment available (AwwaRF, 2002), and each of these can be broken down into several distinct categories.

- Conventional sensors. Those monitors in this group are relatively inexpensive, widely available, and easily used. These do not provide a lot of information useful for identifying the presence of most contaminants. Those instruments in this category include DO, pH, conductivity, temperature, and turbidity.
- Advanced sensors. These monitors are more expensive, require greater expertise and maintenance, but are more effective at identifying the agent. This category includes gas chromatographs and spectrophotometers

- Bio-monitoring. This category has been in place for almost 20 years, but is still an emerging technology.

There are other emerging technologies that include electronic noses, DNA chips, flow cytometry, immuno-magnetic separation techniques, and online bacteria monitors. Other monitoring sensors are available, but go beyond the scope of this paper.

## Determine Detection Methodology and Selection of Sites

The next item to be considered is the actual sites to place the monitors. There are several methodologies presented in the literature for determining where to place monitors and some of these are discussed below. Models can play an important role in the site selection as well as evaluating the monitoring sites afterwards. Each water system has unique features; therefore, the monitoring should be based on each individual system. Bahadur, et al, (2003) developed an approach for monitoring site selection based on three tasks.

- Task 1 – Determine appropriate location of monitoring points in the system. These were based on protection of critical populations such as hospitals, monitoring water quality at high vulnerability areas, and still enabling a proper response.
- Task 2 – Determine appropriate timing and frequency of monitoring. This was based on the intent to perform routine screening of system water quality and the intent to develop a suitable response to a suspected or known contamination incident in the network, which would be isolation or decontamination.
- Task 3 – Determine monitoring and water quality parameters to be measured. These should include determining parameters to measure, how to interpret the data, and then how to identify the procedures, monitoring, and methods to determine water quality changes (Bahadur, et al, 2003).

Using this approach, the authors found that optimal location of monitoring states is complex and dependent of many interlinked parameters (Bahadur, et al, 2003).

Allman (2003) used a different method to place the detectors. Through his analysis, he found that there are common paths that the contaminants will travel. He found that the water moved in sheets through the neighborhood and not around them through the distribution lines. There were common paths for the transport of these contaminants, and these then became areas for detectors. The ability of the contaminant to spread is based on pipe velocity, pipe flows, and pipe bifurcation, all of which are input into models. Areas with high flow rates posed a much higher risk to the overall system. Also areas with several branches occurring immediately upstream had a large impact on dispersal of contaminant. It was these flow patterns that determined the contaminant; therefore, knowledge of these flow patterns are crucial for determining the contaminant spread.

The common paths were used to determine their suitability as detection sites. The criteria for detection site selection included the size of the upstream area that could be monitored at the location, the detectability of contamination occurring in this area, and the timeliness of detection. The results showed that certain areas were difficult to detect. The detectability was greatly impacted by mixing, which could reduce the concentration to below the detection limit. This means that locations where large quantities of water are mixed are not suitable for detectors. There were four locations selected to examine the performance of a theoretical system of detectors at these locations. The selection of those sites showed that contamination in the lower parts of the system was significantly more difficult to detect because the contamination did not move and spread quickly based on the low flow rates and velocities. The same characteristics that make the chemicals difficult to detect (low flow rates and velocities), also present a low health risk. The greater the spread of the contaminant, the more likely it will hit a detector. Based on this, the methodology of detection site selection must be based on health risk.

Kessler, et al. (1998) found that the minimum number of monitoring stations decreases in exponential manner as level of service decreases and that an equal number of stations does not necessarily provide a unique level of service. They included three conceptual steps for planning a detection system:

Step 1. Establish relationship between the number of monitoring units and the level of service, which will include trade-offs between cost and health risk.
Step 2. Select minimum number of monitors, which is set by the decision maker. This will involve budget limitations and health risks.
Step 3. Allocate the minimum number of monitoring stations based on vulnerability considerations

Another paper presents other design methods for detecting contamination, which provides useful information even though it was based on accidental contamination. The methodology allows capturing accidental intrusion of contamination within given level of service and is aimed at identifying the best monitoring locations. The method was developed to find the optimal layout of detection system to capture any accidental contaminant entry within a pre-specified level of service. The detection system was based on the following concepts (Kessler, Ostfeld, and Sinai, 1998):

1. The level of service of the detection system is measured by the consumed volume of contaminated water prior to detection (i.e., detection before certain volume of water is consumed)
2. Pollution due to external intrusion is propagated by immediate flow pattern and flow patterns that follow. Because the contaminant can enter at any location, the propagation is possible by infinite number of flow combinations.
3. Domain of detection for a particular node includes all nodes that are subject to contamination following an accidental pollution at that node.

The authors then established a methodology for establishment of a detection network, broken into five steps (Kessler, Ostfeld, and Sinai, 1998):

Step 1: Conduct a hydraulic stimulation covering average demand cycle, such as one day or week.
Step 2: Construct auxiliary network, which includes a set of nodes and directed arcs.
Step 3: Determine shortest paths of water and find the minimum travel time between the nodes.
Step 4: Develop a pollution matrix, which is made to represent the domains of detection and coverage of each node of the network
Step 5: Determine the minimum covering set, which includes minimum number of columns (or stations) that cover all the rows (possible sources of pollution). Following this, the initial cost is determined.

There are just a few examples of different methodologies that can be used for site selection. Each of these should be considered for the individual systems and then the actual sites determined based on the hydraulics of the system.

### Test Monitoring Stations Selection

After the selection sites are determined, they should be tested in the model with different scenarios. This will show the strengths and weaknesses of the selection sites and how they can be changed. This type of analysis would follow the same type of analysis presented above.

## Section 6: Summary

The objectives of this paper were to provide guidance to water utilities for using models for security purposes including:

- a database of current models used
- case studies of the use of models
- guidance on model use for detection capabilities including possible response

A comprehensive database is included that will serve as a starting point for utilities to select a model. There are many models available, and selecting the proper model is crucial. It is also important to understand how these models operate and therefore the equations and algorithms are presented and discussed.

Models can play an important role in water security. There are five possible uses of models for security related purposes including:

- detector placement
- pre-event response scenarios
- design/upgrade of water systems identification of the location of the contamination
- confirmation of a positive result

The three case studies demonstrate how models can be used for these water security applications.

Finally, guidance for using these models was presented. This guidance was broken into four parts: general modeling, pre-scenario analysis, post-scenario analysis, and detector placement. Flow charts were also presented that will allow utilities of all sizes to begin to apply models to water security applications.

Water utilities are under pressure to determine the operating conditions of their systems. Models have been used to characterize the flow and quality of water in distribution systems. Now, as utilities focus on water security, the models can be an important tool for this application. If models exist already for the system, the security applications can be developed rather easily. These analyses, if done properly, can help utilities increase their security, prepare for an event, and respond accordingly if an event should occur.

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|---|---|
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| Ed Roehl | Advanced Data Mining Inc., Greenville, SC |


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# APPENDIX II

Database of Water System Software Currently Available

# BRANCH 3.0 / LOOP 4.0

| Developed by the University of North Carolina | Download from:<br>Environmental Management<br>105, Hanuman Industrial Estate<br>42, G.D. Ambekar Road, Wadala<br>Mumbai - 400 031<br>India<br>Tel : 91 22 24168217 / 2413 9125<br>Fax : 91 22 2413 9125<br>Internet: http://www.emcentre.com/ |
|---|---|

**General Description:** **BRANCH 3.0** and **LOOP 4.0** are programs that were developed by the University of North Carolina and financed by the World Bank for simulation, design, and optimization of branched water distribution networks. The programs are free and are in the public domain. The program runs in MS DOS, but its user-friendly data entry editor, on-line help and a report generation routine provide a MS Windows like experience. The program is widely used across the world today by students, researchers, municipal engineers and professionals.

**BRANCH 3.0** is used to design pressurized, branched (tree-type, non-looped) water distribution networks by choosing from among a set of candidate diameters for each pipeline so that the total cost of the network is minimized subject to meeting certain design constraints. Both construction costs and the design constraints can be expressed as linear, mathematical statements. The network is characterized by links (individual pipes) connected by nodes, which are points of flow input, outflow or pipe junctions. This version of the software can handle up to 125 pipes. BRANCH 3.0 formulates the linear programming model for the least cost design, solves the model and outputs the design as well as corresponding hydraulic information. Data required include description of network elements such as pipe lengths, friction coefficients, nodal demands and ground elevations, data describing the geometry of the network, the candidate diameters and their unit costs, and system constraints (minimum pressures, minimum and maximum gradients). Outputs include optimal lengths and diameters of pipes in each link, total network costs and hydraulic information.

**LOOP 4.0** simulates the hydraulic characteristics of a pressurized, looped (closed circuit) water distribution network. The network is characterized by pipes and nodes (points of inputs/demand or pipe junctions). Data required are the description of the elements of the network such as pipe lengths, diameters, friction coefficients, nodal demands and ground elevation, and data describing the geometry of the network. The program outputs include flows and velocities in the links and pressures at the nodes. It does not accommodate inline booster pumps or pressure reducing valves. This version handles up to 1,000 pipes and can simulate up to 10 nodes with known hydraulic grade lines (e.g., storage reservoirs). It will accept any looped, partially looped / branched or completely branched network. LOOP's normal use is to simulate the hydraulic response of a network to a single or multiple input with at least one known hydraulic gradient line elevation. It also contains a sub-program for generating a cost summary once a final design is completed

**GIS:** Information not available.
**CAD:** Information not available.
**Model Size:** BRANCH: 125 pipes, 126 nodes, 30 diameters / LOOP: 1000 pipes, 750 nodes, 20 reservoirs, 20 booster pumps, 20 PRVs, 20 check valves, 30 diameters
**OS:** MS DOS
**Head-loss Equations:** Hazen-William, Darcy-Weisbach
**SCADA Link:** Information not available.
**Presentations:** Tabular, ASCII file, Printing, Graphic (LOOP). Its user-friendly data entry editor, on-line help and a report generation routine provide a MS Windows like experience.
**ArcSDE/Geodatabase Compatibility:** Information not available.
Scenarios: **Information not available.**
**Security Specific:** none
**Calibration:** Information not available.

**Water Quality Analysis:** none

**Price:** Free – Public Domain
**Support:** On-line help

## CROSS (WaterPac®)


| | |
|---|---|
| Rehm Software GmbH<br>Großtobeler Strasse 41<br>8276 Berg / Ravensburg | Telephone: +49 751 560200<br>Fax: ++49 751 5602099<br>E-mail: info@rehm.de<br>Internet: http://www.rehm.de/ |


**General Description:** CROSS is a hydraulic calculation for water supply pipes. The program package CROSS can be applied to carry out hydraulic calculations for both ring distribution systems and arterial distribution systems for the water-supply. Following elements can be considered in the program: hydrants, slide valves, reflux valves, spring feedings, transit shafts, pass elevated tanks, water towers and flow regulators. The water is fed in the pipes through centrifugal pumps, piston pumps and elevated tanks. Different pressure zones can be taken into account in the calculations through pressure regulators, pressure boostings as well as pressure reducing valves. In addition, the program can construct a site plan, if coordinates are available.

The results of the hydraulic calculation are provided to the following programs for further processing:
CROSSDESIGN: Graphical planning system for water supply pipes
CROSSPLOT: Drawing longitudinal sections of the pipe lines
CROSSPLAN: Drawing pipe-line plans for the water supply
WERTWASER: Property assessment for water supply pipe-lines

**GIS:** Information not available.
**CAD:** AutoCAD from R2000 or AutoCAD Map from R4 is required to use CROSSDESIGN
**Model Size:** Maximum 3 operating states can be considered with maximal: 10,000 pipes or nodes, 60 supply areas, and 13 different pipe elements (each 30). Up to 5 pipes may be connected to a node. If more inflows should be available, the other inflows can be included by inserting fictitious nodes behind the current node.
**OS:** Microsoft® Windows™ (Me, XP, 2000, NT4.0)
**Head-loss Equations:** The hydraulic calculations are performed according to the formula of Prandtl-Colebrook and the resistance formula of Darcy.
**SCADA Link:** Information not available.
**Presentations:** Following can be printed on screen, printer, or in an ASCII-file for three operating states: node list, pipe list, elevated tank list, pump list, pressure change list, statistic list, and site plan.
**ArcSDE/Geodatabase Compatibility:** Information not available.
Scenarios: **Information not available.**
**Security Specific:** Information not available.
**Calibration:** Information not available.

**Water Quality Analysis:** Information not available.

**Price:** Information not available.
**Support:** On-line help, FAQ, demo CD

# EPANET (Version 2.0)

| | |
|---|---|
| U.S. Environmental Protection Agency<br>Ariel Rios Building<br>1200 Pennsylvania Avenue, N.W.<br>Washington, DC 20460 | Telephone: (202) 272-0167<br>Internet: www.epa.gov |

**General Description:** Program developed by the Water Supply and Water Resources Division (formerly the Drinking Water Research Division) of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory. Specifically developed to help utilities maintain and improve the quality of water delivered to consumers through their distribution systems. Program contains a Windows user interface that provides a visual network editor that simplifies the process of building and editing the network. EPANET was specifically developed to help water utilities maintain and improve the quality of water delivered to consumers through their distribution systems. It can be used to design sampling programs, study disinfectant loss and by-product formation, and conduct consumer exposure assessments. It can assist in evaluating alternative strategies for improving water quality such as altering source utilization within multi-source systems, modifying pumping and tank filling/emptying schedules to reduce water age, utilizing booster disinfection stations at key locations to maintain target residuals, and planning a cost-effective program of targeted pipe cleaning and replacement.

**GIS:** EPANET does not have any direct linkages to external GIS.
**CAD:** EPANET does not have any direct linkages to external CAD.
**Model Size:** No limitations on size. Handles systems of any size
**OS:** Microsoft® Windows™ (95/98/NT)
**Head-loss Equations:** Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas
**SCADA Link:** Information not available.
**Presentations:** Various data reporting and visualization tools are used to assist in interpreting the results of a network analysis. These include graphical views (time series plots, profile plots, contour plots, etc.), tabular views, and special reports (energy usage, reaction, and calibration reports).
**ArcSDE/Geodatabase Compatibility:** Information not available.
Scenarios: **Information not available.**
**Security Specific:** Information not available.
**Calibration:** Includes calibration report, which shows how well the simulated results match the measurements taken from the modeled system. This includes three separate reports—statistics page, correlation plot page, and mean comparisons page. The statistics page lists various errors between those simulated and observed values at each location. The correlation plot is a scatter plot of the observed and simulated values, with each location having a different color. The plot should have a 45-degree angle line. The mean comparisons page is a bar chart that compares the mean observed and mean simulated values for the calibration parameters at each location they were taken.
**Programmer's Toolkit:** Computational engine can be changed through the dynamic link library (DLL). This allows program to be modified to meet specific needs of modeler. The functions can be incorporated into 32-bit Windows applications written in C/C++, Delphi Pascal, Visual Basic, or any other language that can call functions within a Windows DLL. The toolkit has over 50 functions that can be used to open a network description file, read and modify various network design and operating parameters, run multiple extended period simulations accessing results as they are generated or saving them to file, and write selected results to file in a user-specified format. Can be useful for developing specialized applications (optimization or automated calibration models) that require running many network analyses as selected input parameters are iteratively modified. Windows Help File that explains how to uses these.
**Reports:** Numerous data reporting and visualization tools included. Can view results in different formats: color-coded network maps, data tables, time series graphs, and contour plots. Includes graphical views (time series plots, profile plots, contour plots, etc.), tabular views, and special reports (energy usage, reaction, and calibration reports). Animation is also available when a node or link viewing parameter is a computed value.

**Water Quality Analysis:** EPANET's water quality analyzer can model the movement of a non-reactive tracer material through the network over time; model the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) with time; model the age of water throughout a network; track the percent of flow from a given node reaching all other nodes over time; model reactions both in the bulk flow and at the pipe wall; allow growth or decay reactions to proceed up to a limiting concentration; employ global reaction rate coefficients that can be modified on a pipe-by-pipe basis; allow for time-varying concentration or mass

| |
|---|
| inputs at any location in the network, and model storage tanks as being either complete mix, plug flow, or two-compartment reactors. |
| **Price:** Free -- public domain.<br>**Support:** None. The University of Guelph has established an EPANET Users Listserve, which allows subscribers to ask questions and exchange information. |

# $H_2OMAP/H_2ONET$

| | |
|---|---|
| MWH Soft<br>300 North Lake Avenue, Suite 1200<br>Pasadena, CA 91101 | Sales: 626-568-6868<br>Support: 626-568-6869<br>Fax: 626-568-6870<br>Internet: http://www.mwhsoft.com/ |

**General Description:** $H_2OMAP$ can analyze entire system through either steady-state or extended period simulations. It includes minor head losses. It has a unique open-architecture framework that makes it easy to manage and distribute geospatial data and exchange modeling information with other applications.

$H_2ONET$ Analyzer a powerful and complete water distribution modeling, analysis, and design software. It performs fast, reliable, and comprehensive hydraulic and dynamic water quality modeling, energy management, real-time simulation and control, fire flow analysis, unidirectional flushing, and with automated on-line SCADA interface. The program can also be effectively used to analyze pressurized sewer collection systems. $H_2ONET$ Analyzer can build and maintain "custom" modeling database; perform comprehensive dynamic water quality simulations, and analyze the entire system or any selected portions

**GIS:** Provides powerful and practical stand-alone GIS-based program.

**CAD:** Integrate with AutoCAD 2002 (Version 3.5 or 4.x) or with AutoCAD 2004/2005 (Version 5.x). Based on AutoCAD graphics, $H_2OMAP$ optimizes on-line data integration and bi-directional information exchange for complete network model creation and maintenance, eliminating time-consuming translations and ensuring data integrity and reliability.

**Model Size:** No limit in unlimited version (largest client has 40,000 pipes).

**OS:** Microsoft® Windows™ (95, 98, NT, 2000, Me)

**Head-loss Equations:** Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas

**SCADA Link:** SCADA interface included. Monitor water tank levels, pump status and speed, valve status and settings, and demands. Alarms can also be incorporated. It can compare pressures and flows from all modeled items.

**Presentations:** Array of tools, to include color-coded maps, graphs, profiles, tabular reports that can be customized, and animation.

**ArcSDE/Geodatabase Compatibility:** Fully supports ArcSDE 8.1, ArcSDE versioning and ArcSDE Direct Connect Support. These allow management of geographic information in one of four databases: IBM DB2, Informix, Microsoft SQL Server, and Oracle.

**Scenarios:** $H_2OMAP$ has a tree-type scenario manager—each change cascades through all the projects. This allows an array of alternatives to be modeled for one single model. This allows different models to be compared instantly. Data can be inherited through the different scenarios. The inheritance can be from parent to child or vice versa.

**Security Specific:** $H_2OMAP$ also has various advanced water security tools which include event/consequence management, vulnerability assessment, tracking contaminants to the originating sources, computation of purge volumes, event isolation, and customer report notification generation.

**Calibration:** Calibration is available also through the use of genetic algorithm. This can include multiple scenarios calibration and complete EPS calibration

**Water Quality Analysis:** The program can conduct water age, trace, and constituent analysis. It tracks the movement and fate of water quality constituents as it grows or decays up to a limiting concentration. The constituent can be conservative or reactive. It analyzes kinetic reactions both in the bulk flow and at the pipe wall. Incorporates n-th order kinetics to model reactions in bulk flow. Uses zero order or first order kinetics to model reactions at pipe wall. Accounts for mass transfer limitations when modeling pipe wall reactions. The global reaction rate coefficient can be modified on a pipe-by-pipe basis. Wall reaction rate coefficients can be correlated to pipe roughness. Models storage tanks as complete mix, plug flow, or 2-compartment reactors.

**Price:** See charts below for pricing.

**Support:** 1st year free then $800/yr ($1,000/yr for platinum plan); toll free phone support; On-line help; Free upgrades, software and engineering support. Continuing education workshops offered.

| Number of Links | 100 | 250 | 500 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | --- | 10000 | Unlimited |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2OMAP$ Water 4.5 | $1,000 | $1,500 | $2,000 | $4,000 | $5,000 | $6,000 | $7,000 | $8,000 | $9,000 | ... | $13,000 | $14,000 |
| Gold MSP | $800 | $800 | $800 | $800 | $800 | $800 | $800 | $1000 | $1000 | --- | $1000 | $1000 |
| $H_2OMAP$ Water Suite 4.5 | n/a | n/a | n/a | $5,000 | $6,000 | $7,000 | $8,000 | $9,000 | $10,000 | ... | $14,000 | $15,000 |
| Extensions: | | | | | | | | | | | | |
| Platinum MSP | n/a | n/a | n/a | $1,000 | $1,000 | $1,000 | $1,000 | $2,000 | $2,000 | ... | $2,000 | $2,000 |

Extensions: Schedules, Calibrator®, Advisor®, Tracer®, Skeletonizer, Designer, WQ Calibrator---look these up.
All prices shown are in US dollars and apply to both local and network installations. For certain international countries, local taxes may apply. Free Software Maintenance applies for the first subscription period. Receive a 10% discount for the 2nd subscription period with purchase of two (2) consecutive years of Annual Subscription Program (MSP) - Call for details. Receive a 15% discount for the 2nd and 3rd subscription periods with purchase of three (3) consecutive years of Annual Subscription Program (MSP) - call for details.

| Number of Links | 100 | 250 | 500 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | --- | 10000 | Unlimited |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2ONET$ Analyzer 5.1/4.7 | $1000 | $1500 | $2000 | $4000 | $5000 | $6000 | $7000 | $8000 | $9000 | --- | $13000 | $14000 |
| Gold MSP | $800 | $800 | $800 | $800 | $800 | $800 | $800 | $1000 | $1000 | --- | $1000 | $1000 |
| $H_2ONET$ Suite 5.1/4.7 | n/a | n/a | n/a | $5,000 | $6,000 | $7,000 | $8,000 | $9,000 | $10,000 | ... | $14,000 | $15,000 |
| Extensions: | | | | | | | | | | | | |
| Platinum MSP | n/a | n/a | n/a | $1,000 | $1,000 | $1,000 | $1,000 | $2,000 | $2,000 | ... | $2,000 | $2,000 |

Extensions: Schedules, Calibrator®, Advisor®, Tracer®, Skeletonizer, Designer, WQ Calibrator---look these up.
All prices shown are in US dollars and apply to both local and network installations. For certain international countries, local taxes may apply. Free Software Maintenance applies for the first subscription period. Receive a 10% discount for the 2nd subscription period with purchase of two (2) consecutive years of Annual Subscription Program (MSP) - Call for details. Receive a 15% discount for the 2nd and 3rd subscription periods with purchase of three (3) consecutive years of Annual Subscription Program (MSP) - call for details.

# Helix delta-Q (Version 2.28)


| | |
|---|---|
| Helix Technologies Pty Ltd | Telephone: +61 8 9275 0635 |
| PO Box 610 | Fax: +61 8 9275 0615 |
| Morley, WA 6943 | Sales and Support: helix@vianet.net.au |
| Australia | Internet: http://www.helixtech.com.au/ |


**General Description:** **delta-Q** is a powerful tool for engineers and equipment suppliers to quickly and easily design and optimize pipe networks for compressible and incompressible fluids. It can calculate friction losses and pressure drop in pipes and fittings for Liquids, Slurries and Gasses. Model complex process flow pipe networks and solve for unknown flow rates and node pressures at the press of a button.

The program considers pumps, tanks, junctions, nozzles (sprinklers) and any fittings such as bends, valves, tee's, etc. It can calculate friction losses and pressure drop in pipes and fittings for liquids, slurries and gasses. It models complex process flow pipe networks and solves for unknown flow rates and node pressures at the press of a button. delta-Q has database files for liquids, slurries, gasses, pipes, pipe fittings and pumps. Data from the database files can be pasted by clicking on an element in the network diagram.

The program was developed in 1991. A powerful new network analysis engine was added in 1998 that utilized linear theory and Newton Raphson methods. A CAD DXF file generator was added in 1999 for creating large drawings of complex networks. Some features of the actual version are: wuick and easy to use and very powerful network analysis engine; drag and drop network components onto the screen for quick and easy network creation; add individual fittings to pipes using the fitting database or enter an estimate of the total K value; calculate fitting losses using the standard K value method or the Kf method, which compensates for fluid viscosity and turbulence; display the network calculation results such as pipe flows, velocity, head loss, node pressure and many others on the network diagram; network reports' display and print the network pipe and node data as well as calculation results; click on a pipe to view the system curve with the network duty point shown.

**GIS:** Information not available.
**CAD:** Information not available.
**Model Size:** Unlimited number of pumps, tanks, junctions, sprinklers, pipes and fittings and valves, etc.
**OS:** Microsoft® Windows™ (NT, Win 95 or 98)
**Head-loss Equations:** Colebrook, White, Hazen-William, Darcy, Linear Theory and Newton Raphson Network Analysis engine. Orifice plate calculator included and also Settling Slurry, Bingham Plastics and Compressible Fluid (Isothermal and Modified Darcy method)
**SCADA Link:** Information not available.
**Presentations:** The network diagram and system head curves can be printed and Design Reports are produced simply in a compact table format which can be printed or pasted into MS Excel™, Lotus 1-2-3™ or any other Windows compatible spreadsheet or word processor. The network solution can be viewed in graph form.
This allows user to check for minimum or maximum values at a glance. Export data to Excel and create a CAD DXF file drawing of the network at the click of a button. This documents the complete design, on an easy to read format drawing up to A0 in size.
**ArcSDE/Geodatabase Compatibility:** Information not available.
Scenarios: **Information not available.**
**Security Specific:** Model 'what-if' scenarios - closes off certain pipes and views the effects on the network.
**Calibration:** Information not available.

**Water Quality Analysis:** Information not available.

**Price:** See chart below for pricing.
**Support:** The program is supplied with a fully integrated context sensitive help system. Formulae and calculation methods are detailed in the manual and help file. Help-online, annual support contract offered, web page downloads, after sales service provided via the internet and e-mail.

| Description | Version | Price Au$ Excl GST | Price Au$ Incl. GST |
|---|---|---|---|
| Helix **delta-Q Pipe Networks** Program for Liquids, Slurries & Gases | 2.0 | $1,850 | $2,035 |
| Helix **delta-Q PumpManager** Program | 1.0 | $950 | $1045 |
| Annual Software Support Contract | 15% of Price | | |
| Shipping to within Australia | - | $20 | $22 |
| Shipping to outside Australia | - | $68 | $68 |

All Prices exclude GST. From 1 July 2000 Australian customers must allow an additional 10% for GST. Shipments to outside Australia are exempt from GST.

All prices are listed in Australian Dollars and are subject to change at any time. *One Australian dollar is approximately equal to 73 US cents.* The actual rate of exchange ruling at time of order should be checked by the purchaser. Please enclose payment for the total amount. Payments must be in Australian Dollars, with cheques drawn on an Australian Bank, or send international postal money orders in Australian Dollars. VISA, Amex and MasterCard Credit Card payments will be accepted provided all details are submitted correctly. Company Purchase orders are accepted subject to conditions.

## InfoWater™ Protector

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|---|---|
| MWH Soft<br>300 North Lake Avenue, Suite 1200<br>Pasadena, CA 91101 | Sales: 626-568-6868<br>Support: 626-568-6869<br>Fax: 626-568-6870<br>Internet: http://www.mwhsoft.com/ |

**General Description:** InfoWater™ is a fully GIS-integrated water distribution modeling and management software application. Built atop ArcGIS™ using the latest Microsoft .NET and ESRI ArcObjects component technologies, InfoWater™ seamlessly integrates advanced water network modeling and optimization functionality with the latest generation of ArcGIS™. InfoWater™ capitalizes on the intelligence and versatility of the geodatabase architecture to deliver unparalleled levels of geospatial analysis, infrastructure management and business planning. Its unique interoperable geospatial framework enables world-record performance, scalability, reliability, functionality and flexibility - all within the powerful ArcGIS™ environment.

InfoWater Protector represents the state-of-the-art in water security planning, force protection, and vulnerability assessment. Includes expanded power and flexibility in estimating the consequences of a terrorist attack or a crisis event on the drinking water supply infrastructure as well as formulating and evaluating sound emergency response, recovery, remediation and operations plans, and security upgrades.

**GIS:** Fully automate GIS data exchange with ESRI data sources -- pick any GIS attributes automatically without mapping any fields. InfoWater™ extends the core features of ArcGIS™, providing a comprehensive geospatial environment for complete network model construction, graphical editing, network simulation, results presentation, map generation, and enterprise-wide data sharing and exchange. It also adds rich discipline-specific functionality to ArcGIS™ designed to streamline and facilitate all aspects of the water distribution modeling workflow.

**CAD:** The Network Review/Fix Tool is a comprehensive network drawing examination and correction application for use in constructing reliable, credible working models ready for analysis. It offers users complete functionality to quickly identify and automatically correct any network topology problems (e.g., disconnected nodes) and data flaws (e.g., duplicated pipes or nodes) that may arise from digitizing a model or building it using pre-existing GIS and CAD datasets.

**Model Size:** No limit on the size (unlimited link version).

**OS:** Microsoft® Windows™ (95, 98, NT, 2000, Me)

**Head-loss Equations:** Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas

**SCADA Link:** Provides on-line SCADA interface with alarms.

**Presentations:** InfoWater™ easily makes colorful, fully dimensional visualizations. Generates beautiful, accurate, and smooth contours for any variable, including elevation, pressure, hydraulic grade line, demand, water age, chlorine concentration, and more, directly on the map, overlay contours on single drawing.

**ArcSDE/Geodatabase Compatibility:** Information not available.

**Scenarios:** Includes comprehensive tree-type scenario manager. Every change made cascades through the entire set of projects in an easy-to-use, tree-like structure, allowing the modeler to switch between scenarios, compare input data, merge models, and compare results instantly. Reverse (child to parent) inheritance is also fully supported.

**Security Specific:** InfoWater Protector allows the user to model the propagation and concentration of naturally disseminated, accidentally released, or intentionally introduced contaminants and chemical constituents throughout water distribution systems; assess the effects of water treatment on the contaminant; and evaluate the potential impact of unforeseen facility breakdown (e.g., significant structural damage and/or operational disruption). Enables the user to locate areas within the system affected by contamination; calculate population at risk and report customer notification information; and identify the appropriate valves to close to isolate a contamination event. Helps track contaminants to originating source(s); compute required purging water volume; develop efficient flushing strategies; determine the resulting impact on fire-fighting capabilities; and prepare data for eventual prosecution.

**Calibration:** Performs online calibration.

**Water Quality Analysis:** Same as for $H_2OMAP/H_2ONET$

**Price:** See chart below for pricing.

**Support:** Information not available.

| InfoWater | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Licenses | | | | | | | | | | | | | | |
| No. of Links | 100 | 250 | 500 | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 | Unlimited |
| Price | $1,000 | $1,500 | $2,000 | $4,000 | $5,000 | $6,000 | $7,000 | $8,000 | $9,000 | $10,000 | $11,000 | $12,000 | $13,000 | $14,000 |
| InfoWater Suite | | | | | | | | | | | | | | |
| No. of Licenses | n/a | n/a | n/a | | | | | | | | | | | |
| No. of Links | 100 | 250 | 500 | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 | Unlimited |
| Price | n/a | n/a | n/a | $5,000 | $6,000 | $7,000 | $8,000 | $9,000 | $10,000 | $11,000 | $12,000 | $13,000 | $14,000 | $15,000 |

For additional information or to place order call (626) 568-6868 or 568-6869

# MIKE NET 2002

| | |
|---|---|
| BOSS International<br>Corporate Headquarters<br>6300 University Avenue<br>Madison, WI 53562-3486 | Sales: 800-488-4775<br>Tech Support: 608-258-9910 or support@bossintl.com<br>Fax: 608-258-9943<br>Internet: http://www.bossintl.com/ |

**General Description:** MIKE NET can analyze an entire water distribution system, or selected portions, under steady state or extended period simulations, with water quality analysis if needed. Network models can be quickly developed, using a variety of different means. Network components can be read-in directly from an ArcInfo®, ArcFM®, ArcView®, or MapInfo® GIS, or can be interactively created using a mouse by simply pointing and clicking. Graphical symbols are used to represent network elements such as pipes, junction nodes, pumps, control valves, tanks, and reservoirs. MIKE NET allows the user, at any time, to interactively add, insert, delete, or move any network component, automatically updating the modeling database. Selecting and moving a node automatically moves all connected pipes, valves, and pumps. In addition, data can be shared with any standard Windows spreadsheet (e.g., Microsoft Excel) or relational database (e.g., Oracle®, Microsoft SQL Server, Informix®, Sybase®) either directly or using ODBC links, or by simply cutting to and pasting from the Microsoft Windows clipboard.

**GIS:** MIKE NET can share water distribution data with any ArcInfo, ArcFM (Facilities Manager), ArcView, or MapInfo GIS database. It can intelligently build a link to any GIS database structure, using attribute mapping and geocoding.

**CAD:** Input data and output results can be transferred to AutoCAD® and MicroStation® by a DXF file, allowing the network plan and analysis results to be exported.

**Model Size:** Can analyze the entire system or selected portions. Can handle large models and complex networks.

**OS:** Microsoft® Windows™ (95, 98, NT), network capability

**Head-loss Equations:** Pipe frictional loss computations can be performed using Hazen Williams, Darcy Weisbach, or Manning equations.

**SCADA Link:** MIKE NET-SCADA can be linked to any existing SCADA monitoring system. Consists of two modules: MIKE NET-SCADA On-Line and MIKE NET-SCADA Off-Line. MIKE NET-SCADA On-Line links directly to the SCADA system and will automatically perform continuous simulation runs based upon a predefined schedule—such as every 15 minutes. During each cycle, all measured SCADA data is imported into the network model and the model parameters updated. Then, a hydraulic and water quality model is performed. After the analysis, output data from the model is stored in the SCADA historical database, as well as displayed on the screen. Animations of computed values, such as water quality, can be performed. MIKE NET-SCADA Off-Line enables the user, at any time, to load a previously stored network model—which has been prepared and analyzed by MIKE NET-SCADA On-Line— and inspect the model results in greater detail.

**Presentations:** Comprehensive input data and output analysis reports can be automatically generated using the provided report templates. MIKE NET allows full customization of input and output reporting using Crystal Reports® report generator. Crystal Reports is a powerful database reporting and query tool, integrated directly into MIKE NET, providing a streamlined approach to creating reports. This allows the user unlimited flexibility and functionality in developing specialized user-defined reports. These reports can be fully customized to meet any combination of modeling criteria for any network variable and for any time period, or for simply adding a corporate logo, etc. Furthermore, due to MIKE NET's open-architecture Microsoft Access database engine, nearly any other reporting tool can be used to generate reports from MIKE NET.

**ArcSDE/Geodatabase Compatibility:** Information not available

**Scenarios:** MIKE NET provides an easy-to-use inheritance-tree type scenario manager, allowing different scenarios to be applied to the base water distribution model. This helps the user maintain a single model of the water distribution system and then quickly construct, apply, and evaluate different scenarios as they relate to the model. Scenarios can be cut, copied, and pasted between different branches in the inheritance-tree window, allowing the user to quickly combine different scenarios for a particular modeling concern. Scenarios are cumulative—as additional scenarios are applied on a branch in the inheritance-tree window, the changes to the base model are included. In addition, a batch analysis feature is provided, allowing the user to select which scenario(s) to analyze, and then having the software automatically run the different scenarios. MIKE NET' scenario manager also allows modeler to add and delete network elements, such as pipes, pump stations, valves, as well as add and delete network submodels for each scenario. This enables to modeler to analyze master plans with future growth and land use changes in mind.

**Security Specific:** The analysis engine allows modeling of "what if" scenarios, allowing the engineer to specify multiple modeling alternatives on the same pipe network. These alternatives can include user-selected changes in network configurations, demand loading conditions, and changes in physical system characteristics. MIKE NET' analysis engine can be run interactively, or in batch mode—automatically running several different scenarios on the same network. Either method allows rapid and efficient analysis of multiple modeling alternatives.
**Calibration:** An automated network model calibration and optimization module is included with MIKE NET, based upon a genetic algorithm and optimal control computational scheme. This module allows the modeler to quickly calibrate the model to match field observations, thereby validating the credibility of the network model for reliable and cost-effective engineering and planning decisions with regard to network design, rehabilitation, expansion, and replacement. The user can define what pipes in the model can have their roughness adjusted to meet observed values, as well as define the allowable range of values that can be used. In addition to calibrating the model, this module can also be used to quickly troubleshoot the model. It can automatically locate where potentially closed, degraded, or leaking pipes are located within the actual network system—allowing the modeler to assist in maintenance and rehabilitation of the system.

**Water Quality Analysis:** MIKE NET will track the movement and fate of water quality constituents (such as chlorine, chloramine, trihalomethane, total dissolved solids, nitrates, hardness, fluoride, etc.) throughout the entire network during a dynamic simulation. MIKE NET accurately models phenomena such as first-order reactions within the bulk flow, pipe wall, and storage tanks. A global kinetic rate coefficient can be assigned for the entire network or user-specified values can be assigned to selected components. Water age, travel time, and constituent source tracking can also be performed.

**Price:** See charts below for pricing.
**Support:** Company offers a wide range of consulting services. Technical support is unlimited. Claim that 96% of support calls returned within 1 hour (usually within 15 minutes). Offers training services.

| MIKE NET without Water Quality | Price |
|---|---|
| MIKE NET with 250 Pipe Version | $ 995 |
| MIKE NET with 500 Pipe Version | $1,995 |
| MIKE NET with 1000 Pipe Version | $2,495 |
| MIKE NET with 2,000 Pipe Version | $3,495 |
| MIKE NET with 3,000 Pipe Version | $4,995 |
| MIKE NET with 5,000 Pipe Version | $5,995 |
| MIKE NET with 10,000 Pipe Version | $6,995 |
| MIKE NET with Unlimited Pipe Version | $10,995 |

| MIKE NET with Water Quality | Price |
|---|---|
| MIKE NET with 250 Pipe Version | $1495 |
| MIKE NET with 500 Pipe Version | $2495 |
| MIKE NET with 1000 Pipe Version | $3995 |
| MIKE NET with 2,000 Pipe Version | $5995 |
| MIKE NET with 3,000 Pipe Version | $7495 |
| MIKE NET with 5,000 Pipe Version | $8495 |
| MIKE NET with 10,000 Pipe Version | $9495 |
| MIKE NET with Unlimited Pipe Version | $12495 |

# optiDesigner (Version 1)

| | |
|---|---|
| OptiWater | E-mail: info@optiwater.com<br>Internet: http://www.optiwater.com |

**General Description:** The OptiWater company specializes in optimization using Genetic Algorithms (GA). The products range from a general purpose GA to dedicated water network design and optimization software. They also can provide custom software for development services. Program currently has the following modules:

OptiGA 2.0.1: optiGA for VB is an ActiveX control (OCX) for the implementation of GA. No matter what is the nature of the optimization problem might be, optiGA is a generic control that will perform the genetic run for users.

optiDesigner 1.0: Windows software for optimal design of water distribution systems using GA. Program uses EPANET. Allows determination of most cost effective design, rehab, and system expansion. Program designs system pipes and finds minimal costs given constraints. Constraints can be minimum and maximum pressures at nodes; minimum and maximum velocities at network pipes, or maximum source flow

The system is drawn and the properties set using EPANET. The network is then exported to optiDesigner (as an INP file), which then runs the simulation once design options, pipes to be designed, junctions / sources constraints and optimization parameters have been set. Results can be listed or viewed using EPANET.

With optiDesigner it is easy find the most cost effective design, rehabilitation strategy and expansion strategy for a water distribution system. It can make a steady state design, do a design under a number of load patterns or run the design as an extended period simulation.

The development of optiDesigner version 2 is on its way. The next version will introduce new features like pumps design and scheduling, tank design and system.

**GIS:** Information not available.
**CAD:** Information not available.
**Model Size:** No limitation.
**OS:** Microsoft® Windows™ (95, 98, Me, NT, 2000, XP)
**Head-loss Equations:** Information not available.
**SCADA Link:** Information not available.
**Presentations:** List orientated, ASCII file (for text editor or spreadsheet), graphic through export of INP file to EPANET
**ArcSDE/Geodatabase Compatibility:** Information not available.
**Scenarios:** Information not available.
**Services:** They offer custom made software, including data manipulation, Data manipulation, hydraulic models, graphical user interface, EPANET Toolkit programming, optimization, and others.
**Security Specific:** OptiWater and Dr. Avi Ostfeld (Technion, Israel) have a new update that will include stochastic behavior of the system as well as a method to determine the source of contamination. No release date has been set, but some features will be showing at the WRPLM ASCE Conference in Salt Lake City this June.
**Calibration:** A network calibration module in development.

**Water Quality Analysis:** Information not available.

**Price:** Download the evaluation version of optiDesigner, this version is available for 30 days. To keep optiDesigner after the evaluation period, the user will be asked to register the commercial version of optiDesigner for only 350 US$. The installation package includes optiDesigner, samples, and optiDesigner's manual.
**Support:** User manual, e-mail support

# PIPE2000/KYPIPE (Version 2)


| | |
|---|---|
| Developed by Civil Engineering Software Centre<br>354 Civil Engineering Building<br>University of Kentucky<br>Lexington, KY 40506-0281 | KYPIPE, LLC Software Center<br>3229 Brighton Place<br>Lexington, KY 40509-2314<br>Telephone: (859) 263-2234<br>Fax: (859) 263-0401<br>E-mail: orders@kypipe.com<br>Internet: http://www.kypipe.com/ |


**General Description:** PIPE2000 is a general-purpose pipe network hydraulic modeling program, which handles both steady state (KYPIPE2000) and transient (SURGE2000) analysis. KYPIPE2000 provides both hydraulic and water quality modeling. PIPE2000 is typically used for steady state and transient modeling municipal and rural water distribution systems. It is also widely used for hot, chilled, and process water systems. It is used for fire protection and irrigation sprinkler systems. It is also used for other liquids (oil, etc.).

Continuous research and development over the past 20 years has resulted in the most advanced hydraulic modeling capability available. KYPIPE 4 is the engine used for hydraulic calculations for the KYPIPE2000 modeling package. KYPIPE 4 is the fourth generation KYPIPE engine, which is the most widely used and trusted hydraulic analysis engine in the world. This engine has been an industry standard for 30 years and has been verified by numerous field tests and qualified for nuclear applications. It provides many capabilities not available with other hydraulic analysis engines. EPANET developed by the EPA (USA) is utilized by KYPIPE2000 for water quality modeling. SURGE2000 is a 6th generation transient flow modeling program, which carries out complex transient modeling.

Standard PIPE2000 node elements include junctions, tanks, reservoirs, pumps, sprinklers, rack sprinklers, regulating valves, loss elements, loss elements defined by manufacturer data from a library, variable pressure supplies, active valves, check valves, hydrants, valves, metered connections, surge control devices, inline meters, and user-defined devices, etc.

The strength of PIPE2000 is in its advanced modeling capabilities, which include the direct calculation of operational and design parameters, development of system curves, optimized calibration (GA), automatedatic ageing of pipes (roughness) and many other capabilities.

The PIPE2000 advanced graphical environment is extremely user-friendly, allowing graphical Model development and data entry. PIPE2000 has also been adapted to other calculation engines in addition to KYPIPE and SURGE. These include analysing gas (GAS2000), steam (STEAM2000), fire sprinkler systems (GOFLOW2000) and stormwater systems (STORM2000).

**GIS:** GIS compatible
**CAD:** AutoCAD compatible
**Model Size:** Up to 20,000 pipes. All type of nodes, reservoirs, pipes, pumps, valves, etc.
**OS:** Microsoft® Windows™ (95, 98, 2000, NT version 4.0 or higher)
**Head-loss Equations:** Hazen-William, Manning, Darcy-Weisbach
**SCADA Link:** Information not available.
**Presentations:** Graphic, ASCII file, AutoCAD, GIS, Excel
**ArcSDE/Geodatabase Compatibility:** Information not available.
**Scenarios:** Information not available.
**Security Specific:** Information not available.
**Calibration:** PIPE2000 uses an advanced optimization method based upon the genetic algorithm approach to optimally adjust pipe roughnesses, valve settings, tank levels, demand distribution, and other data to provide a calibrated model. The program minimizes the difference between observed field data (usually fire flow test data) and model predictions considering all test data simultaneously to provide the best calibration possible. The program directly utilizes the KYPIPE data file with a small amount of additional data (Calibration Data). PIPE2000 can save tremendous amount of time and produce better models through optimum calibration.

Because calibration is an essential step for good model development, Optimized Calibration module included at no additional cost in both the Standard and Professional versions of PIPE2000. This advanced capability is not available in most competing software packages. If available, it can cost up to $5000 to add this feature.

**Water Quality Analysis:** Automatedatic ageing of pipes (roughness) and many other capabilities.

**Price:** See charts below for pricing.
**Support:** FAQ, training courses, demo versions

| The 2000 Series Models | |
|---|---|
| Professional Features* | Add $500 |
| Model | 250-pipe Version |
| KYPIPE2000, Version 2 (Water Distribution) | $1,795 |
| Upgrade from Version 1.x to 2.0 | $495 |
| Model | 50-pipe Version** |
| KYPIPE2000 Version 2 (Water Distribution) | $350 |

* The professional version includes tools to interface to GIS and AutoCad files. These features work with all the analysis engines

**Additional Piping and Professional Features may NOT be added to this package. The $350 price may be credited toward an upgrade to a 250-pipe or higher version

| Additional Pipe Pricing | |
|---|---|
| Upgrade from 250 to 1,000-pipe version | $500 |
| Each additional 1,000 pipes, up to 20,000 pipes | $500 |

| Network Version Pricing* | |
|---|---|
| Upgrade to Network Version (LAN server installation)** | $200 |
| Additional concurrent users | See Multiple Copies Discount |

* A network version may be accessed by any number of network users on 1 server. A network version will support concurrent users up to the number of purchased licenses.

**Network pricing is for single LAN server installation intended to serve a single site. If Network Version is to be used on a WAN, a license must be purchased for each location.

**Discounts and Upgrade Credits**

This is a comprehensive list of discounts and upgrades credits associated with the purchase of 2000 Series software packages and includes credits towards the purchase of other packages.

| Multiple Model Discount | |
|---|---|
| For a single user, after the purchase of a 2000 Series model license (e.g., Gas2000), discount for each additional 2000 Series model (e.g., KYPIPE2000, Surge2000, etc.). | $500 off each |

| Multiple Copy Discounts | |
|---|---|
| License for one user for an organization | Full list price |
| License for one user at different site (same organization) | 25% off list price |
| Additional users at licensed site | 50% off list price |

| Upgrade Credits (credits are cumulative – see exceptions below) | | |
|---|---|---|
| **Credit For** | **Upgrade To** | **Credit Towards List Price** |
| KY.TMP (Standard or Pro) | Pipe2000 (1,000 pipes or more) | $250 |
| KYPIPE3, KYPIPE2, or KYPIPE | Pipe2000 (1,000 pipes or more) | $250 |
| KY.TMP extra pipes: each 1,000 pipes over 1,000 | Pipe2000 extra pipes: each 1,000 pipes over 1,000 – not exceeding number of KY.TMP pipes | $250 |

# PipelineNet

| | |
|---|---|
| Technical Support Working Group, U.S. Environmental Protection Agency, Federal Emergency Management Agency, and others | Telephone:<br>E-mail: TechTrans@tswg.gov<br>Internet:<br>http://www.tswg.gov/tswg/ip/PipelineNetTB.htm |

**General Description:** In cooperation with the Federal Emergency Management Agency, the Technical Support Working Group (TSWG) has sponsored a project to develop software programs that would estimate the consequences of a terrorist attack on a city's drinking water infrastructure. The prototype system, PipelineNet, has been developed and is operational for Salt Lake City.

PipelineNet is a Geographic Information System (GIS)-based software tool with integrated database capability that can be used to model the flow and concentration of contaminants in a city's drinking water pipeline infrastructure. It contains a pipe network hydraulic model (EPANET), maps, and a US Census Population database. The PipelineNet model estimates the population at risk due to the introduction of contaminants in the public water supply and graphically maps this population.

The EPANET component of PipelineNet was developed by the Water Supply and Water Resources Division (formerly the Drinking Water Research Division) of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory.

**GIS:** The system uses Arc View GIS, which is integrated into the system.
**CAD:** Information not available.
**Model Size:** Information not available.
**OS:** The PipelineNet system is operational in the Microsoft® Windows™ 95/98/2000/NT environment on either laptop or desktop computers. The minimum requirements are 64Mb Ram, 500 Mb of free disk space. A CD-ROM drive is also required. The PipelineNet system also requires Arcview (version 3.2 or higher).
**Head-loss Equations:** Information not available.
**SCADA Link:** Information not available.
**Presentations:** Information not available.
**ArcSDE/Geodatabase Compatibility:** Information not available.
**Scenarios:** Information not available.
**Security Specific:** The PipelineNet model permits the user to model the flow and concentration of a biological or chemical agent within a city or municipal water system. This model assesses the effects of water treatment on the agent, models the flow and concentration of an agent through the water distribution system within a city or municipality, and calculates the population at risk. PipelineNet performs the following functions: simulates the flow and concentration of biological or chemical contaminants in a city or municipality's water distribution system; assesses the effects of water treatment on the contaminant; helps planners with present and future demand predictions; helps city managers with fire flow requirements; facilitates planning and design of distribution systems; aids in complying with drinking water regulations, and assesses risks to population.
**Calibration:** Information not available.

**Water Quality Analysis:** Uses EPANET for water quality analysis.

**Price:** Free – Public Domain
**Support:** Information not available.

| Pipenet™ | |
|---|---|
| Sunrise Systems Limited<br>Flint Bridge Business Centre<br>Ely Road<br>Waterbeach, Cambridge CB5 9QZ | Telephone: 01223 441311<br>Fax: 01223 441297<br>Email: pipenet@sunrise-sys.com<br>Internet: http://www.sunrise-sys.com/ |
| **General Description:** PIPENET™ is used for fluid flow analysis on pipe and duct networks, including liquids, gases, and steam. The program can be used for design of systems or to or to troubleshoot existing systems.<br>**Calculation Engine:** The program uses proprietary calculation engine that ensures reliable results.<br>**Library:** The program includes data of fittings, pipe schedules, and properties of water, gases, and steam. The user can add to these. The fluid properties can either be constant or variable.<br>**Program Modules:** There are three program modules, each capable of standalone operation:<br>PIPENET Standard Module: Enables the flow analysis of networks for general use. Includes modelling of complex networks with all parameters, include pipes, ducts, fittings, pumps, filters, nozzles, orifices, etc.<br>PIPENET Spray/Sprinkler Module: Mainly for design of fire protection systems, including ring-mains, deluge systems, sprinkler systems, and foam solution systems.<br>PIPENET Transient Module: Provides method for modeling in-house transient analysis. Can be used for the following: pressure surges, calculating hydraulic transient forces, and modelling control systems in flow networks. | |
| **GIS:** Information not available.<br>**CAD:** Information not available.<br>**Model Size:** Information not available.<br>**OS:** Microsoft® Windows™<br>**Head-loss Equations:** Information not available.<br>**SCADA Link:** Information not available.<br>**Presentations:** This can be created using Word, Write or PIPENET™ Output Browser. Meet mandatory requirements, as PIPENET™ results are acceptable to regulatory authorities.<br>**Security Specific:** Information not available. | |
| **Water Quality Analysis:** The program has "what-if" scenarios, but is advertised for broken or blocked pipes. | |
| **Price:** Information not available.<br>**Support:** All PIPENET™ modules are supplied with comprehensive documentation, which includes: tutorials, worked examples, user manuals, technical manuals, demo CD-ROMs. While PIPENET™ is easy to use even for those without prior experience; training courses are available to help users get the most out of the system. Hot line support in the use of PIPENET™ is available either direct from Sunrise Systems or from our authorized distributors. | |

## STANET® (Version 7.3)


| | |
|---|---|
| Fischer-Uhrig Engineering | Telephone: +49 30 300 993 90 |
| Wuerttembergallee 27 | Fax: +49 30 304 43 05 |
| D - 14052 Berlin | E-mail: info@stafu.de |
| Germany | Internet: http://www.stafu.de |


**General Description:** STANET is an integrated application for network analysis. Besides calculation, graphic input, output and a database browser is included. The browser may be displayed together with the graphics. STANET may be used as a network information system because it uses standard dBASE-III database files, which may be extended by the user. Because graphics and database are using the same files, data exchange with other applications is simple. The features of STANET are: flexible network constructions: calculated (i.e., unknown) and given values (pressure, inflow and load) may be set at different locations and in any number; calculation of additional values like temperature radiation into the ground and quality tracking; automated control of network topology with explicit messages for wrong or incomplete specifications; automated creation of subnetworks from closed valves and regulators; efficient functions for selective output of network parameters and results (filtering, sorting, grouping/classifying); output of background bitmap drawings (e.g., TIFF, BMP, etc.) and vector graphics (DXF AutoCad-12-Format); extensive configuration options; saving of commonly used settings (with names).

**GIS:** Integration into GIS systems in batch mode (start calculation from another system). GIS/CAD interfaces for import of network data: AutoCAD; AutoGIS; GARONE/WARONE; Gradis 2000 (Straessle); IBM-GTIS: GPG; Magellan (Geoinform); Moskito; PARIS (Hemminger); Optiplan; Pegasus; ROKA; SICAD-SQD (Siemens); SINCAL
**CAD:** Displaying background pictures in raster format (TIFF, BMP, etc.) or vector format (AutoCad DXF).
**Model Size:** Only limited by the available memory.
***Operating system:*** *Windows 9x/MW, NT 4.0, 2000, XP*
**Head-loss Equations:** Darcy-Weisbach, Prantl-Colebrook, Nikuradse
**SCADA Link:** Information not available.
**Presentations:** Information not available.
**ArcSDE/Geodatabase Compatibility:** Information not available.
**Scenarios:** Save the results of extended period simulation or single simulation results in a scenario.
**Security Specific:** none
**Calibration:** Information not available.

**Water Quality Analysis:** Stationary mixing/tracking of contents (heating value, water quality, water age).

**Price:** See chart below for pricing. Demo version with max. 15 nodes is free of charge.
**Support:** On-line help, Q&A service, training, supplemental documentation, web page, free technical support via e-mail, telephone, fax, or remote control.

| STANET Price List<br>(All prices in EURO and subject to change without notice. Taxes and duties are not included.) | | | |
|---|---|---|---|
| **A.** | **Standard Version:** STANET for Windows (32 Bit) | | |
| | Basic modules with graphic functions (mouse/digitizer input, plotting/printing, import of ASCII files, attribute coloring, database functions, report generator, diameter calculation, graphical copy and paste), 32 bit version, manual in PDF format, 1 Medium | | |
| | 1. medium: gas, water, steam, district heating | | |
| | 1.000 nodes 2.100,00<br>2.000 nodes 3.100,00<br>5.000 nodes 6.200,00<br>10.000 nodes 7.700,00<br>20.000 nodes 10.300,00<br>>20.000 nodes 12.500,00 | | |
| | | | |
| B. | Additional medium: gas or water or district heating | 60% of basic module | |
| | | | |
| **C.** | **Extensions:** (bp ... basic price of A. or B.) | | |
| C.1 | Import of raster images (36 formats) | +20% from bp | Max. 800,00 |
| C.2 | Import of vector images DXF-R12 | +20% from bp | Max. 800,00 |
| C.3 | Export of vector images DXF-R12 | +20% from bp | Max. 800,00 |
| C.4 | Load forecast from statement of meter reading (VERBRA) | +20% from bp | Max. 1.600,00 |
| C.5 | Spatial profile diagram | +20% from bp | Max. 800,00 |
| C.6 | Automatic calculation of fire hydrant flows (water only) | +20% from bp | Max. 800,00 |
| C.7 | ArcView interface (SHAPE), Import and Export | +20% from bp | Max. 800,00 |
| C.8 | MapInfo interface (MID/MIF), Import and Export | +20% from bp | Max. 800,00 |
| C.9 | Stationary mixing/tracking of contents (heating value, water quality, water age) only g/w/dh | | 800,00 |
| C.10 | STANET-Viewer: only output on monitor and printer, no simulation, no input | 20% from bp | |
| C.11 | STANET-Edit-Print: only input and output, no simulation (e.g., workstation for digitizing) | 40% from bp | |
| C.12 | STANET-Calc-Viewer: only simulation and output (monitor and printer), no network input | 40% from bp | |
| | | | |
| **D.** | **Options:** | | |
| | Printed user manual (German, English) | | 30,00 |
| | Dynamic simulation using GANESI, dynamic simulation using TASI for water | | Call |
| | Import/Export from/to special systems (SICAD, Smallworld, GANESI, GEOGRAT, etc.) | | |
| | Import from special systems (AutoGIS, Cubis-Polis, GRIPS, INGRADA, Magellan, PARIS, PolyGIS, etc.) | | |
| | German, English or Polish version | | |
| | | | |
| **E.** | **Discount for additional licenses:** | | |
| | 2 user: | 50% of list price | |
| | 3 to 5 users: | 30% of list price, each license | |
| | Additional users: | Call | |
| | | | |
| **F.** | **Upgrades:** | | |
| | Single upgrade to the latest version | | Call |
| | Software maintenance | | 1,5% per month |
| | Upgrade from smaller to bigger standard version | | Price difference |
| | | | |
| **G.** | **Installation and introduction:** one person each day (without costs for traveling or hotel) | | 800,00 |
| | | | |
| **H.** | **Shipping** | | 15,00 |

# WADISO SA (Version 4)


| | |
|---|---|
| Geustyn Loubser Streicher Inc. & GLS Engineering Software (Pty) Ltd.<br>GLS Engineering Software<br>PO Box 814<br>Stellenbosch<br>7599<br>South Africa | Telephone: +27 21 8800388<br>Fax: +27 21 8800389<br>E-mail: software@wadiso.com<br>Internet: www.wadiso.com |


**General Description:** WADISO SA is a comprehensive computer program for the analysis and optimal design of water distribution networks. It originated from the WADISO public domain model developed by Prof. Johannes Gessler of Colorado State University for the Army Corps of Engineers. The program performs steady state and time simulation analysis with the capability to optimize pipe, pump, and tank sizes for planning purposes, as well as water quality modeling. It is advertised as a local product with relevant international technology and as extremely user friendly, with menu driven structure and easy-to-use-and-understand interface between the graphical display/edit mode and the model database and results. It has a graphical display, with input and editing of any network element. It has seamless transition between modules. Non network data may also be displayed as background, e.g. parcel and street layouts.

**GIS:** Can interface with GIS applications with the open input and output data structures (ASCII, Dbase IV, Paradox, Microsoft MDB)

**CAD:** fully integrated high-speed, automatic conversion of CAD plan to hydraulic model, graphical editing and building of hydraulic model, thematic and SQL based query displays, support for large color background raster images, export of model to different CAD formats

**Model Size:** Can handle over 10,000 nodes, depending on computer memory

**OS:** Microsoft® Windows™ (95/98/Me/NT 4/2000/XP) Full 32-bit.

**Head-loss Equations:** Hazen-Williams or Darcy-Weisbach

**SCADA Link:** Can interface with SCADA on dynamic basis. In this, metered flows, pressures, tank levels, pump and valve status etc. are converted to relevant parameters and variables that are imported to update the data input files of simulations.

**Presentations:** Provides flexible query system to map results and data. Output to large format color printers. Allows inclusion of age, material, pressures, pipes, or nodes. Graphical display of results, through color coding, arrows on pipes, different line thickness, different node sizes, etc., is available. Graphical display is always geographically correct, and not schematic. Bitmap images can also be imported as backdrop.

**Calculation Technique:** Model uses a node method for calculation, which includes a non-linear loss equation for each junction being linearized and then substituted into the continuity equation at each node. A system of linear equations is thus made and solved through an iterative procedure. They stated that this has unique advantages because it allows excellent control over required and achieved accuracy.

**Optimization Technique:** The program uses a straightforward algorithm employing "exhaustive enumeration." For this, the modeler specifies sizes for each pipe and then the model tests all possible combinations or pipe sizes, determining whether pressure constraints are met.

**Security Specific:** Information not available.

**Water Quality Analysis:** Program includes seamless interface to the public domain EPANet program for modeling of water quality aspects. In the EPS mode, using the EPANet program, the model can simulate more than a one-week period in one-hour time increments, and provides a comprehensive analysis of water quality aspects in a distribution system.

**Price:** See chart below for pricing.

**Support:** Annual maintenance (hotline during working hours and assistance with installation problems: 12.5%. On-line discussion forum called Wadiso SA.

| | | | |
|---|---|---|---|
| **Wadiso SA 4.3 International Price List**<br>**(for International Customers Outside of Southern Africa)**<br>Note that the website listed prices are current until 30 September 2002 | | | |
| **1.** | **Wadiso SA 4 Basic Price for 1 Installation (1,000 Pipes, 1,000 Nodes)** | | |
| | All Modules – Steady State Analysis, Timer Simulation, Water Quality Analysis and Optimization, inclusive of Reservoir Size Optimization and Windows Stand-alone Graphics Engine | | $3,500 |
| | | | |
| **2.** | **Increasing Program Capacity** | | |
| 2.1 | Modules 1, 2, 3 & 4 – 2,000 pipes (add) | | $500 |
| 2.2 | Modules 1, 2, 3 & 4 – 5,000 pipes (add) | | $1,000 |
| 2.3 | Modules 1, 2, 3 & 4 – 10,000 pipes (add) | | $1,500 |
| 2.4 | Modules 1, 2, 3 & 4 – 15,000 pipes (add) | | $2,000 |
| | | | |
| **3.** | **Multiplier Factors for Increasing Number of Installations** | | |
| | For multiple installations or a network installation purchased at the same time, the basic price (item 1 + item 2) should be multiplied by the following factors: | | |
| | | **Factor with which basic price must be multiplied** | |
| | **Individual licenses:** | | |
| | 1 License | 1.0 | |
| | 2 Licenses | 1.5 | |
| | 3 Licenses | 2.0 | |
| | 5 Licenses | 3.0 | |
| | | | |
| | **Network Licenses:** | | |
| | 1 Roaming User | 1.5 | |
| | 5 Concurrent Users | 3.5 | |
| | 10 Concurrent Users | 5.0 | |
| | | | |
| **4.** | **Maintenance Contract** | | |
| | Annual maintenance on the current full list price of Wadiso SA 4 software (items 1 + 2 above), consisting of: | | 12.5% |
| 4.1 | Hotline (telephone, fax, e-mail) available during working hours to provide: | | |
| 4.2 | Assistance with installation problems | | |
| 4.3 | Limited assistance with the performance of modeling and simulation | | |
| 4.4 | Upgrades of the relevant version will be provided from time to time at no extra cost | | |
| 4.5 | A 20% discount on the purchase price of additional installations of the program | | |
| | | | |
| **5.** | **Notes** | | |
| 5.1 | All prices are in US Dollars and include basic airmail shipping but not local duty taxes. As the US Dollars amount will be converted to South African Rand at the daily exchange rate, the final Dollar price might be slightly less than the quoted US Dollar price. | | |

# WaterCAD

| | |
|---|---|
| Haestad<br>37 Brookside Road<br>Waterbury, CT 06708 | Telephone: (800) 727-6555<br>General: info@haestad.com<br>Support: support@haestad.com<br>Internet: www.haestad.com |

**General Description:** WaterCAD is a complete geographic information management system for water utilities in a cost-effective package. Allows analysis of water quality, determine fire flow requirements, calibrate large distribution networks, and more with WaterCAD's powerful hydraulic analysis tools.

WaterCAD is a sophisticated tool that enables engineers and decision makers to analyze and manage distribution networks with unprecedented accuracy and efficiency. The numerical computations of WaterCAD are based on the research by the U.S. Environmental Protection Agency (EPA) Drinking Water Research Division, Risk Reduction Engineering Laboratory, its employees, and consultants. Because of this, WaterCAD will generate consistent results as those obtained using EPANET.

**Engineering Libraries:** Comes with Haestad Methods' Engineering Libraries and Library Managers, which allows specification and modification objects, components, or common materials, which include materials, minor losses, and constituents

**GIS:** WaterGEMS links modeling with GIS.

**CAD:** Can be stand-alone or fully integrated. WaterCAD elements are fully accessible to all AutoCAD.

**Model Size:** Unlimited.

**OS:** Microsoft® Windows™ (98, ME, 2000, XP)

**Head-loss Equations:** Darcy-Weisbach, Chezy-Manning, Hazen-Williams

**SCADA Link:** Information not available.

**Presentations:** Create detailed reports for any element or group of elements and generate system-wide summaries and project inventories. Customize tables to present data in the order and format chosen and manipulate each table to suit system needs, making use of the built-in filtering, sorting, and editing tools. Visualize system bottlenecks quickly and create spectacular presentations with VCR-style controls for step-by-step visualization or dynamic animation. Watch color-coding, annotation, contouring, profiling, and tabular data update automatically. Generate fully customizable graphs of time-variable data such as tank levels, pump speeds, and pipe flowrates, and compare results from multiple scenarios on the same graph.

**ArcVIEW:** ArcView or ArcInfo integrated interface

**Scenarios:** Program provides scenario management, allowed analysis of unlimited "What If" calculations. The scenario contains all the data, options, results, and notes associated with a set of calculations. User can submit multiple scenarios for calculation, switch between, and then compare them. There are three basic types of scenarios: base, child, and manual fire flow. Base scenarios contain all the working data. Child scenarios inherit the data from base scenarios, and can reflect all or some of the data from the base scenario. Calculation options are not inherited between scenarios, but are duplicated when the scenario is first created. The alternatives and data records are inherited from the parent scenario so this is a permanent, dynamic link from a child back to its parent.

**Security Specific:** WaterCAD includes a scenario for selection of valves for contamination isolation and developing flushing strategies. It can also simulate the failure of critical water sources and identification of customers who will be impacted by the event. It allows quick responses by predicting the influence of these events and assessing the possible impacts of corrective actions. It also allows prioritization of physical security improvements according to component criticality and water system safety.

**Calibration:** Darwin Calibrator available for additional fee.

**Water Quality Analysis:** The program can conduct water age, trace, and constituent analysis. It tracks the movement and fate of water quality constituents as it grows or decays up to a limiting concentration. The constituent can be conservative or reactive. It analyzes kinetic reactions both in the bulk flow and at the pipe wall. Incorporates n-th order kinetics to model reactions in bulk flow. Uses zero order or first order kinetics to model reactions at pipe wall. Accounts for mass transfer limitations when modeling pipe wall reactions. The global reaction rate coefficient can be modified on a pipe-by-pipe basis. Wall reaction rate coefficients can be correlated to pipe roughness. Models storage tanks as complete mix, plug flow, or 2-compartment reactors.

**Price:** See charts below for pricing.
**Support:** ClientCare™ Program offered by Haestad includes the following: free upgrades, unlimited professional support any time throughout the year, discounts on software, books, and training. The cost of the program is based on the level of support and is a percent of the software cost. The purpose of ClientCare is to keep the user up-to-date with the technological developments as well as access to technical and engineering support. If not subscribed, Haestad offers technical and engineering support on an emergency basis per incident.

The chart below shows the pricing of the WaterCAD, based on the model size:

| # Pipes | 10 | 25 | 100 | 250 | 500 | 1000 | 2000 | 5000 | 10000 | Unlim |
|---|---|---|---|---|---|---|---|---|---|---|
| **EZPay** | $26 | $58 | $117 | $224 | $332 | $547 | $869 | $1,084 | $1,047 | $1,622 |
| **Standard** | $195 | $495 | $995 | $1,995 | $2,995 | $4,995 | $7,995 | $9,995 | $12,995 | $14,995 |

EZPay allows purchase to be divided into monthly installments that are billed automatically. Each payment includes a processing fee.

The following are additional features that may be purchased.

| Related Software Options | |
|---|---|
| Darwin Calibrator | $4,000 |
| Darwin Designer | $4,000 |
| Hammer | $4,995 |
| Skelebrator | $4,000 |
| WaterSAFE | $4,000 |

Support for the program is included below:

| | One-Year Renewable Subscription | Two-Year Subscription |
|---|---|---|
| Gold Subscription Fee | 35% | 55% |
| Silver Subscription Fee | 32% | 52% |
| Bronze Subscription Fee | 29% | 48% |

The percentages above are based on the software's current list price.

# Methodology and Characteristics of Water System Infrastructure Security: Section 5.7 Response

**Submitted to**

**American Civil Engineers Society**

**Prepared by**

**Anita K. Highsmith, William J. McShane, Stephen Margolis and Donna L. Smith**
**Highsmith Environmental Consultants, Inc. Atlanta, GA 30329**

**April 27, 2004**

**Highsmith Environmental Consultants, Inc.**
**Attention: Anita K. Highsmith**
**P. O. Box 2943** **1691 Mason Mill Road**
**Decatur, GA 30031** **Atlanta, GA 30329**

**Phone: 404-636-6886**
**Email: akhwater@aol.com**

# Methodology and Characteristics of Water System Infrastructure Security: Section 5.7 Response

**Anita K. Highsmith, William J. McShane, Stephen Margolis and Donna L. Smith**

**Highsmith Environmental Consultants, Inc. Atlanta, GA 30329**

## Introduction

In day-day activities, predictable situations such as broken mains, etc, occur that require management to make decisions. In such cases, experience allows the owner/operator to make appropriate preparations so that repairs and other responses can be implemented rapidly. The public is generally not informed unless a malfunction in infrastructure such as a main break causes disruption of services and is picked up by the news media. However, the public will be informed if a utility finds that routine sampling indicates that the drinking water samples exceed the Maximum Contaminant Levels (MCL) set by the US Environmental Protection Agency (EPA), a "boiled water notice" will be imposed (1). In the case of an unusual event, such as a terrorist attack, management will be required to assess the situation and activate a more specific and tailored response.

Most emergency responses are handled by the utility with assistance of local and state responders within the guidelines of the Federal Response Plan (FRP). The FRP is the overarching document that helps provide coordination between local, state and Federal Agencies responding to a disaster (2). The plan determines the roles of each participating agency and provides common language, communication, and actions among the first responders. This plan was utilized in the 9/11 events in New York and at the Pentagon. Other uses of the plan include the Winter Olympics at Salt Lake City and for the emergency response to Hurricane Isabelle in Virginia, North Carolina and Maryland. The development of coordination between local, state and federal agencies resulted in the Incident Command System (ICS) which provides disaster management including use of common terminology, modular organization, integrated communications, unified command structure, action planning, manageable span of control and comprehensive resource management (3).

The ability to identify and evaluate threats is paramount to the protection of the water supply infrastructure. Today we need to retain a higher sense of awareness and be prepared in the best and worse of circumstances. Physical threats may be the most visible while chemical agents are generally easier to recognize and detect than biological threats. Weapons of mass destruction (WMD) can take on many forms of disruption including elements such as: climatic events, hoaxes or intentional intrusion to the system. These events can be caused by a single or multiple agent intrusion that may be easy or difficult to detect. Some agents that do not react immediately are considered silent killers with long term consequences impacting not only on health, but food supplies, energy, transportation, as well as, economic uncertainty. It opens legal debate and causes concern with consumer confidence.

How the utility responds will depend on advanced preparation. This type of training is multi-leveled. It involves persons in the field, in the laboratory and at the management level, as well as outside experienced consultation. Advanced preparation includes training on and off camera. It also entails practice drills and tabletop exercises. Knowledge of accurate information is critical. Establishing a template for response is paramount.

Many ask the question...What is preparedness? On September 11, 2001, when four planes were hijacked, the Federal Aviation Administration (FAA) immediately landed all commercial planes and handed authority over to the military (NORAD). The military allowed no civilian air traffic. The University of Texas Medical Center in Dallas, requested permission to fly tissue for burn victims to New York. The request was denied. However, at the same time, the federal Centers for Disease Control and Prevention (CDC) loaded a small jet with more than thirty public health personnel and it was granted permission to fly to the New York area. Why was the permission granted? Because CDC had prepared for emergencies such as a catastrophic event, whereby the military took over the US air space. CDC had communicated to the military command its need to deliver the national pharmaceutical stockpile as well as epidemiologists and public health scientists to **any** disaster site.

Even if an event occurs at another site, such as nuclear power plant, sports stadium, etc., the water agency must be prepared to evaluate and protect its system. This applies whether the facility is the primary target, the secondary, or follow-up site, or "copycat" site.

In order to protect the water treatment facility and distribution system, multiple approaches to response will be required. While most emergencies are handled by local and State responders, the water utility personnel will have a critical role in providing water, and protecting the health and safety of the community. Response begins with preplanning preparation.

EPA has required Water Utilities to conduct an assessment vulnerability analysis. This evaluation provides important information for the local utility to use to make modifications and improvements to the treatment facility and its distribution system. In addition to understanding areas of vulnerability, personnel at the water treatment facility will need to consider other items as part of the response program. As part of the preplanning process, key elements are listed below as part of response to potential threats to the water utility system:

A natural disaster may give some preview for preparation while an intentional one may not. Early warning systems will aid in protecting the water infrastructure and the health and well being of the community.

## A. Treatment Facilities, Storage and Distribution Networks:

**1. Response Plans:** Treatment facilities, storage and distribution networks can all be affected by biological and chemical terrorism, chemical and toxic waste pollution, or biological contamination. Each utility is required to develop and review response plans (4). These plans must be based on the Federal Response Plan (the overarching document that helps provide coordination between local, State and Federal Agencies responding to a disaster) and the

National Incident Management System (2,3). However, these plans should reflect the local operational environment in which the utility exists (urban, country, large, small) (5).

These plans should include strategic and tactical considerations. Centers of mass should be defined. These would be the water sources (river, lake, well, other system), plant (intake, treatment, output), storage (tanks, reservoirs), and distribution systems. These centers of mass should be considered as strategic resources that require protection. At a minimum, all aspects of water production, delivery control and data systems should be protected by fencing. Secure, covert video and advanced sensor monitoring should be considered if resources are available. However, during high threat conditions, manned watches and patrols should be initiated. All personnel should be required to pass background clearances. Dual-use sources, such as recreational lakes and reservoirs, should be re-evaluated as to the appropriateness of dual-use status. The security level at any given time should be consistent with threat levels as determined by Homeland Security, FBI, local law enforcement, and various information-sharing agencies.

**2. Risk assessment/risk evaluation and risk management programs:** Risk assessment is an analysis of "risk" based upon toxicity – morbidity and mortality – data from multiple sources, i.e., bacteria to higher mammals, which are then collated and extrapolated into a computer-based model to estimate human adverse effects. The "risk assessment" model gained recognition when the EPA developed it to define risk at "superfund" sites during the 1970s and 1980s.

There are assumptions built into the risk assessment modeling process that allow the extrapolation of laboratory gleaned toxicological information on the impact on humans. The classical risk assessment yielded information in acceptable "parts per billion" of a toxic chemical in the soil, air, and/or water. Heavy metals, e.g., mercury, arsenic, lead, and organic compounds, e.g., PCBs, dioxins, vinyl chlorides were the focus of the early risk assessments. The primary criticism of the risk assessment results was that the "parts per billion" were directed to levels of cleanup, primarily in soil, and not at human exposure.

For toxic chemicals, the Agency for Toxic Substances and Disease (ATSDR) Registry of the U.S. Department of Health and Human Services has developed a CD-Rom based "Toxicological Profiles." (6). The toxicological profile describes the substance's relevant human toxicological properties, levels of significant human exposure and significant health effects. The profiles are peer reviewed and review key literature. A similar toxicological profile system does not presently exist for bacteriological agents and/or toxins. A risk evaluation focuses on all possible information related to risk and is the basis for the risk management system employed.

Risk management is a holistic approach to planning, evaluating and executing an action. It is a term used by the military and by those responsible for preparing for, responding to and directing the recovery from a terrorist event. Emergency response agencies have been utilizing the GEDAPER process

- **G**ather information,
- **E**stimate the potential course of action,
- **D**etermine the appropriate strategic goals,
- **A**ssess tactical options and resources,
- **P**lan of action, implementation,

- **E**valuation of the effectiveness of the plan,
- **R**eview the process

The GEDAPER review process has been used since the early 1990s and defines three processes: ***hazard assessment***, which identifies hazardous materials present, their location, quantity and what they do, ***vulnerability assessment*** which defines who and what will be affected if a release occurs, and ***risk assessment***, the probability of various scenarios occurring – note that this is a different definition than the EPA-based risk assessment (7).

**3. Surveillance Systems:** Preparing for an adverse event also demands use of the best surveillance system possible. This will include appropriate agent/ chemical testing at water sources, at the plant and near the end user. Surveillance also includes information on emergency room activity and hospital admissions for the catchment area, obtained in a timely manner. In addition, preparing for an adverse event also includes creating algorithms for shutting down the system or parts of the system, if attacked, and algorithms for handling increased water use burden if a neighboring system is adversely impacted. In addition, multiple alternate sources of water for the system's users should be determined and written agreements created. If an adverse event were to occur, the water system should have personnel who inform and are informed by the emergency management agency in a timely manner and be part of the overall response system. If the water system, or parts of the system, are to be closed, the timing and consequences of the shutdown should be laid out.

**4. Exercises/ Practice Drills:** Generally wastewater treatment facilities should be evaluating the industrial and agricultural toxicants that would "normally" be reaching the plant. As many realistic scenarios as possible should be created and referred to during the response with each having a preparedness, response and recovery plan. For the water system, In addition, alternate sources of water should be prepared for dissemination to the population.

**5. Laboratory Analysis:** Water testing and emergency room/hospital surveillance should be increased, looking for water ingestion related adverse effects – morbidity and mortality. The water system should be prepared to inform the using community as to the status of the water, the sources of clean water and the time frames for disruption. Sample analysis for contaminants is discussed in Section 5.1. At this time most small and moderate sized water facility laboratories are limited to the number of analyses that they can perform on a routine basis or in case of suspect event. Until RNA/DNA probes are available in the near future, broad-based testing for chemical, bacteriological and toxin type agents is not economically feasible.

**6. Line of Command:** If an incident or a perceived incident should occur, the utility and local law enforcement must be familiar with all aspects of their emergency plans. An Incident Commander (IC) will need to be selected. The IC will select heads of a Command Staff including Operations, Planning, Logistics, and Finance/ Administration and a Special Staff such as a Public Information Officer (PIO), a Safety Officer (SO), and a Liaison Officer (LO) (3). All appropriate analytical tests – biological, chemical, toxicological – must be immediately implemented for rapid threat identification and assessment.

The IC, as referenced above and applied to water system incidents, will select appropriately qualified personnel to head various General Staff functions. It is at the IC's discretion to assign any functions to whatever staff area he/she deems appropriate. It is also at the IC's discretion to combine or delete functions as necessary. The major areas are:

- ***Operations*** – responsible for decontamination, system operations, law enforcement, crisis management and mitigation, and all other operational aspects of the incident.
- ***Planning*** – normally responsible for gathering and disseminating critical information and intelligence, all chemical/biological analysis and technical expertise, situation evaluation, planning options development, forecasting, documentation, and demobilization.
- ***Logistics*** – normally responsible for all support requirements for the incident. These include medical supplies, food, fuel, communications, facilities, and transportation, ground support, maintenance.
- ***Finance/Administration*** – normally responsible for compensation and claims, cost capture, procurement, and time recording.

The IC, as referenced above and applied to water system incidents, will select appropriately qualified personnel to head various Special Staff functions. It is at the IC's discretion to assign any functions to whatever staff area he deems appropriate. It is also at the IC's discretion to combine or delete functions as necessary. The major areas of consideration are:

- ***Public Information Officer (PIO)*** – normally responsible for interfacing with all public information sources and the media, and all information releases to the press and the public. Develops clear, concise, precise information on incident size, extent, nature, and scope for public distribution. Also responsible for public information monitoring.
- ***Safety Officer (SO)*** – normally responsible for all aspects of incident safety. The SO will monitor all health and safety aspects of responder operational activities and ensures/coordinates safety procedures across agency/jurisdictional lines.
- ***Liaison Officer (LO)*** – normally responsible for all contact and coordination with other agencies, governments, volunteer organizations, and private parties.

Specifically related to a CT/BT, TIM, or chem/bio spill incident involving a water system, the following aspects and responsible agencies will also need to be addressed:

- ***Crisis Management*** – FBI, DHS, EPA; State agencies FEMA, and Police.
- ***Crisis Mitigation*** – DHS, CDC, State Public Health, Local Public Health.
- ***Public Information*** – it is very important that accurate, precise information on the nature, extent, duration of the incident be clearly annunciated to the public as soon as possible. This will greatly reduce the rumors and panic. Additionally, public safety information, medical information, should be clearly broadcast as well. These will, hopefully, reduce the "worried well", whose numbers could very easily greatly exceed greatly the actual casualties (See Section C).
- ***Security*** – Background checks for all employees, adequate security staff to ramp up to 24/7 the patrols for high threat conditions, extensive counseling for under

performing and terminated employees to possibly prevent sabotage or worse by a disgruntled employee or former employee. Adequate fencing, lighting, monitors, sensors (See Section D1).

- ***Exercises*** – Emergency plans must be practiced through joint multi-agency exercises. Any deficiencies should be captured in a "hot wash" type debriefing immediately at the conclusion of each exercise. Corrective and preventative actions can be implemented to correct errors and deficiencies.

**7. Multi-agency Emergency Interaction System:** For any wastewater treatment program and water utility system, large or small, the evaluation of risk and the management of risk are critical to appropriately prepare for an adverse event, respond to the adverse event, and organize a rapid recovery from the adverse event. Preparing for an adverse event requires that the waste water treatment program and the water system management, or a combined unit, be part of the local, state and/or regional emergency preparedness and response system, usually referred to as the "emergency management agency." The multi-agency emergency interaction system is usually led by the regional, or state emergency management agency and has representation from the following agencies/offices:

Governor's office
Mayor's office / County Commissioners
Liaison to Federal Emergency Management Association
Liaison to U.S. Office of Homeland Security
Local FBI Field Office

| | |
|---|---|
| EPA | FBI |
| Homeland Security | Military |
| Police Agency (State/Local) | Fire Department |
| Media (print, radio, TV) | |
| Emergency Medical Systems | Hospital Agency |
| Public Health | |
| Medical Association | Nurses Association |
| Natural Resources/Environmental Protection | |
| Water Utility | Nuclear/Electric/Gas Utility |
| School System | Day Care Center |
| Highway/Street Department | Mass Transit Agency |
| Social Services | Red Cross |

Non-Governmental Service Organizations
Faith-Based Organizations

Each agency/organization represented on the emergency management team should have a three tiered personnel assignment system on a 24/7 basis. The team should have a reasonably secure operations center, with compatible communications for all members.

Water utilities must carry out a planning process for preparation, response and recovery related to a terrorist event. The Chemical Stockpile Emergency Preparedness Program Training Materials (8) offers a set of planning guidance issues that should include:

Emergency Planning
Command and Control
Communications
Event Emergency Notification
Protective Action Decision Making
Protective Actions and Responses
Public Alert and Notifications
Traffic and Access Control
Special Populations
Emergency Worker Protection
Emergency Medical Services
Transportation
Community Resources Coordination
Public Education and Information
Evacuee Support
Agent Detection and Monitoring
Reentry
Training and Exercises

The list of planning guidance issues and the participants in the emergency management agency group are meant to complement each other and assure that persons with expertise are participating in the activities for which they have knowledge and managerial control.

## B. Biological and Chemical Agents Representative of Potential Risk to Health and Safety:

Section 5.1 describes contaminants in greater detail. A list of microbial, chemical, and toxic agents having lethal or incapacitating effects have been compiled. While many of these agents would have little potential for creating an actual threat to a water system, others would. It is important to remain open to the possibility of a variety of etiologic agents capable of creating an event, as opposed to a single agent. As important as the preparation for the protection of water utility and the health of the community, is the recognition that a terrorist attack can turn American against American. For example, exposed and infected persons can become a threat to others in the community. They may compete for relatively low levels of vaccines and or antimicrobials available for general population use. Sanitation issues will contribute to additional illness and disease.

Working in disfavor of early warning indictors are the ability to detect and track disease in short time. Disease detection by medical personnel may also be inadequate, since many have not seen actual cases caused by some of the potential agents. It is also feared that health care facilities, particularly the HMO's, will turn away patients showing the first round of symptoms. And, lastly, laboratories may not be equipped to collect samples and identify meaningful levels of bacterial, viral, rickettsia, protozoan, and biotoxin .contamination. This section describes agents considered with high probability and intelligence estimates.

## Methods

**1. Sampling sites:** The utility may not know the exact point of intrusion at the time of response. However, to the best of the operators ability, it is important to record all observations and to photograph each sampling site. It will be beneficial if the utility/community is able to establish a Geographic Information System (GIS). Most agencies use ARC/INFO software in order to provide a consistent database strategy as part of the preplanning work to measure and plot grids for sampling observations and sample collections. Protective garments should be used. It is also advisable to go to a site inspection in pairs, if possible, and collect samples, marking labels carefully, using water-proof paper. Intrusion into a water system may be simplistic or complex. Agents do not have the same dose response effect, nor do they survive at the same rate over time. For example, Burrows et al., estimates that for any toxic material to be introduced into a reservoir with 100 days holding time, it would require up to 30,000 times the toxic dose for each individual at risk (13).

**2. Procedures:** Procedures for general chemical, radioactive and microbiological toxicity includes at-line/on-line bioluminescence and ATP sensing instruments (see 5.1) for rapid detection and definition of an incident. This is critical to quickly establish the existence and extent of an incident, as this will prevent system wide denial of services, while awaiting definitive laboratory data allow for rapid, proactive response. Other rapid microbiological identification tools should be employed as indicated.

Smaller laboratories will require assistance from State or large public utilities laboratories on: (1) technical guidance and support for response actions (isolation, containment, decontamination); (2) access to sophisticated analytical instrumental capabilities to support incident response, utilizing instrumentation and qualified scientists trained to conduct tests and provide interpretation of the data; and most importantly (3) provide a quality assurance/quality control program. State and or large local utility will need to absorb some or all of the overhead costs for this type of assistance.

**3. Agents:** CDC has categorized biological and chemical agents representing a potential risk to health and safety (14). Selected agents are listed below. It is recommended to prioritize chemical/biological analysis based on probability and intelligence estimates:

- ***Cyanide*** – widely available, very toxic. Using GC/MS (gas chroma-tography/mass spectrometry) procedures, can be rapidly analyzed.
- ***Toxic elements, Lewisite/CVAA*** – Rapid semi-quantitative screenings can be accomplished via ICP-MS (inductively coupled plasma-mass spectrometry) and ICP-DRC-MS (inductively coupled plasma-dynamic reaction cell-mass spectrometry).
- ***Radio nuclides*** – on-line or at line beta, gamma detectors. Alpha particle emitters may require isolation. ICP-MS may also be used as a screening tool.
- ***Nerve Agents, TIMs*** – GC/MS may be used with EPA water methods for organophosphate pesticides and TIMs. Modifier CDC methods may be applied to organophosphate hydrosolates ( hydrolysis may occur rapidly).

- ***Sulfur and Nitrogen mustards*** – rapid total sulfur and nitrogen methods may indicate a possible presence. LC/MS (liquid chromatograph-mass spectrometry) will be required for definitive analysis.

**4. Other Agents of Concern:** Toxins are biological agents produced by living organisms such as animals, plants, or microbes. Toxins differ from replicating agents – viruses, Mycoplasma and bacteria – in that toxin cannot replicate or be replicated in a human system. At times, toxins have been claimed to be "chemicals," i.e., saxitoxin, and are treated as if they are chemical agents of concern.

Toxins are not volatile as compared to chemical agents, and with rare exceptions do not cause dermatological effects. Thus, for a toxin to be effective it would have to be prepared in a respiratory aerosol, allowing contact with the inner surfaces of the lung. Aerosol particles between 0.5 and 5 um in diameter are retained in the lung, and aerosolized particles smaller than 0.5 um can be inhaled, but most are exhaled. Toxin particles larger than 5-15 um lodge in the nasal passages and do not reach the lung. Finally aerosolized toxin particles bigger than 15 um drop to the ground. Thus, the human risk could come by exposure to shower water or hose sprays containing aerosolized toxins.

**5. Sample Collection and Transport:** In the event of an attack, CDC has outlined methods for packaging and shipping biologic and chemical samples to appropriate locations (15). For toxins, the following procedures are recommended. Swabs taken from water should be placed in sealed glass or Teflon (polytetrafluoroethylene) containers and kept dry and as cold as possible until analysis. Handling a toxin sample can be dangerous because the toxin can be inhaled. Immunological, analytical and/or chromosomal assay methods are, or will become, available for most of the toxins known. The enzyme-linked immunosorbent assays – ELISAs – are sensitive to 1-10 ng/mL and take 4 hours to develop. Chemical methods are available for toxins at the low microgram to high nanogram level and require 2 hours to develop. The polymerase chain reaction – PCR – can identify the genetic material of a toxin from any living organism – bacterial, animal or plant. In addition, extremely small quantities of toxins can be detected by a combination of immunoassay and PCR analysis.

## C. Advisories to the Public:

Response to any event becomes personal and impacts on each of us. There is a need to reach the community with timely and accurate information. Yet, there is a great deal of controversy over the public discussion of bio-terrorism. Getting the message to the public and private sector depends on data. In the case of an attack, the best information may be based on three types of testing: cheap, dirty or accurate. The lack of a monitoring program may be one of the weak links in the event of a rapid response need. Improved standardized methodology for the detection of microbiologic agents is important for officials to use in order to have the most accurate data to issue advisories to the community core and to adjacent areas, be it a county or state.

Exposing the public to unfounded information can be very unsettling. Preparing to develop a well thought out plan for constituents during a natural act or actual attack may contribute greatly to maintaining the health and safety of the US population.

One approach to public advisories is through the use of the message wheel developed for emergency response training (16). The message wheel helps to maintain a clear and accurate delivery of information, as it is made available.

Preparation for media and print interviews are best handled by a spokesperson in a consistent location, never in a laboratory. Start with Segment 1 and proceed to
Segment 5, repeating information as it develops. For example:

- Segment 1: Read the most succinct one sentence response to the issue/incident at this stage.
- Segment 2: Insert additional and progressively more detailed responses in the next four sections.
- Segment 3: Place additional information, statistics, regarding your response to the issue/incident statement listed above.
- Segment 4: Again, place useful, informative statements. Repeat from top if no more information is available.
- Segment 5: Read this segment last and remember to write your information succinctly. Read the information, don't paraphrase. While you should not share this internal document with the media, you should try and present it in a way that they are able to capture the information completely.

Preparation for clear communication starts with establishing a capacity to effectively communicate risk, and exchange information to colleagues and to the public. Practice drills are imperative to delivering the message to appropriate channels. This begins with an in-house communication system. It includes frequent updates of a list of staff members, who have authority to collect samples, enter the buildings (laboratory) and/or perform test; more importantly, recognize that plan A may lead to plan B and that errors may/will occur.

One of the primary goals of an act of terrorism, or the appearance of an act of terrorism is to instill fear in the greatest number of people as possible. The best remedy for this is clear, concise

and timely information to the public, in many formats. The message should be clear and unified among all agencies involved in the emergency management organization. For a water utility, there are many scenarios that yield prepared messages that need only to be modified for the specific event. Finally, the regional emergency management organization should have designated public affairs and or media liaison personnel. The fewer the number and types of people presenting information to the public and the media, the less chance of contradictory and/or confusing messages. Historically, during catastrophic events, too many "official" people present information and/or opinions to the public via the media.

## D. Security for Water Treatment Action Plan:

In addition to collection of water samples and other materials certain steps need to be taken to control the area. This involves security measures listed but not limited to items shown below in Table 1.

## Table 1 Plan of Operation: Security for Water Treatment Action Plan

| Element | Responsibility |
|---|---|
| I. Incident Command Operations | Supports security detail for physical operations<br><br>Prevents unauthorized and non-essential personnel from site entrance for security and possible crime scene preservation.<br><br>Establishes a list of authorized personnel (name, SSN/ID Badge No., DOB, and country of citizenship; Law Enforcement (Police, FBI), Public Health (State, Federal), Environmental (State, Federal).<br><br>Develops logs for site access, sampling (who, where, when, and going to whom, chain of custody), incident log.<br><br>Secures Data Management i. e. who gets the samples and generates data (lab personnel), who gets the data (Utility management, IC, Public Health, Environmental, Law Enforcement), how it is treated/interpreted (Technical experts, Utility management, IC, Public Health, Environmental), and how it is disseminated (Utility management, IC, Public Health, Environmental, Law Enforcement, PIO). |
| II. Master Security Plan. | Supports security for physical operations<br>Requires mandatory 5 yr. background checks for all employees, no exceptions.<br>Sets up limited/secure access – personnel access on a need-to-be-there basis.<br>Secures security perimeter i.e. fences, cameras, excess lighting, perimeter and intruder sensors. These should be installed on all sources, plants, storage, and distribution assets. |

Table 1 continued

| | |
|---|---|
| | Establishes security force – adequate sized force for 24/7 operations with reach-back surge capability through MOUs with other agencies for expanded operations during high threat warnings and incidents.<br><br>Provides intelligence, reconnaissance – threat assessments from DHS, State HLS, FBI, intel sharing associations. Observations of subjects acquiring photographic intel on facilities, loitering around facilities, trying to gain access to facilities, asking too many questions about utility personnel or facilities. |
| III. Operational Security | Sometimes referred to as OPSEC<br>Works with staff to stress that utility details are sensitive and are on a need-to-know basis including not discussing utility details outside of work. Reports subjects asking lots of questions about the sources, physical plant, treatment/storage facilities, distribution systems. Develops a list of personnel with access to critical control systems and infrastructure should be maintained and reviewed on a regular schedule by Security and senior plant management. |
| IV. Human Resources | Aids in identifying and counseling all potential seriously disgruntled employees. Former employees should be identified and counseled to prevent sabotage. |
| V. Chemical Storage | All chemicals must be kept in secure storage areas, in particularly chlorine, a chemical used for sterilization and prophylaxis of treated water and as a chemical weapon in WWI. Water treatment facilities typically have large quantities of chlorine. A typical chlorine tank will contain 2000 lbs of liquid chlorine (boiling point = 29°C). Explosive charges would turn the cylinder into a WMD and would require immediate evacuation of the surrounding area for a considerable distance. The toxic plume would then need to be tracked and a rolling evacuation initiated. |
| VI. Storage/Distribution System | Access points to the storage/distribution system should be limited and secured as much as possible, but total security is impossible (at some point customers will have to use the water or alternative supply). General toxicity and microbiological testing of distributed water should be conducted at random points on an on-going basis. |

**Remediation:** After determining if groundwater and or surface water or both are implicated, a minimum of three events take place after a chemical or biological agent has been *indicated or identified*

1. ***Indicated*** – If an agent has been ***indicated,*** isolate the affected volume of water (reservoir, tanks, pond, side stream, pipeline).

2. ***Identified agent*** – If the chemical or biological agent has been ***identified*** the water source may be impounded, or depending on the specific toxicity of a chemical agent, dilution with clean water to below action limits and emergency rerouting to a stream or river may be the simplest and most cost effective method of disposal. This would be applicable to labile chemical species such as cyanide, which while toxic, are not as toxic as chemical warfare agents and will naturally oxidize as HCN (removal and oxidation) and *in situ* oxidation and detoxification.

3. ***Diversion*** – Major parts of the water system should have the capability to ***divert*** affected water for temporary storage and treatment. Methods for handling the diversion, depending on agents, are shown in Table 1. Careful consideration should go into the selection of detoxification/ remediation agents since inappropriate choices can lead to harmful consequences such as increased lead levels (14,16).

## Table 2: Selected Treatment agents for Remediation

| Material | Effect |
|---|---|
| Chlorine, $Cl_2$ | Good general oxidizer/disinfectant. It will oxidize most, but not all, organic compounds. Some organisms have become resistant. Can form chlorinated VOCs. |
| Chloramine | An allegedly environmentally friendly substitute for chlorine. More corrosive to piping however and can have adverse consequences such as lead release [5,6]. |
| Chlorine Dioxide, $ClO_2$ | Effective disinfectant. Strong oxidizer, although chemistry not well characterized. Must be generated *in situ* from $NaClO_3$. Some explosive potential. |
| Ozone, $O_3$ | Powerful oxidizer. Will attack most bacteria, viruses. Will oxidize most organic compounds, organometallic compounds, and metals. |
| Activated Carbon | Will adsorb a wide variety of organic chemicals. Unknown applicability for ionic species (eg., $[CN]^-$); organophosphates (pesticides, nerve agents, and their hydrolysis products); Lewisite/CVAA (chlorovinyldichloroarsine and chlorovinylarsenious acid, equally toxic hydrolysis product, respectively); and metals. |
| Ferric Chloride, $FeCl_3$ | Will form $Fe(OH)_3$ flocculates at pH > 4-5. This will tend to occlude many chemical and bacterial species. The flocculent materials must be disposed of properly. |
| Ion Exchange | Many toxic metals can be removed by ion exchange or water softeners. |

Table 2 continued

| | |
|---|---|
| System Component | This drastic step may be necessitated by two possible Removal scenarios: Mercury, Hg – This element may be very challenging to mitigate or remove from a water system. Mercury, a heavy, somewhat inert, liquid, is a toxic metal that will flow to the lowest point of a water system. Mercury may even amalgamate with system piping. The element will then gradually be leached into the water stream, providing a constant mercury background contamination. |
| Radionuclides | These elements may be very challenging to mitigate or remove from a water system. Radio nuclides, though more complex and mostly short term, reside in piping systems than Hg, can exhibit similar behavior if introduced as sparingly soluble compounds. They will be carried to dead zones and/or the lowest point of a water system.. These elements will then gradually be leached into the water. As this is a direct ingestion route for radioactive materials, the possibility exists for the metabolic uptake of biologically significant radio nuclides (I, Ba, Sr, Cs) and resulting adverse health effects.<br><br>Given mercury's toxicity and the radiological implications of radio nuclide uptake (cancer, deformities, genetic damage), these would most certainly be unacceptable scenarios for any water utility or public health/ environmental protection agency. The only timely course of action would be the costly and time consuming removal, disposal as a hazardous waste, and replacement of water system components. |

# In Summary

One of the great benefits for water utilities of being an active member of the regional emergency management group is the availability of planning information and assistance, testing resources, and training venues and training resources. Federal funding is being directed to states that integrate the coordination of emergency event preparedness, response and recovery activities. There are, in addition, Web-based and CD-Rom-based resource and training materials that can be utilized by water utilities for staff preparedness education: e.g., Managing *Hazardous Materials Incidents, Including TOXFAQs*, ATSDR, DHHS, 2001, CD-Rom, www.atsdr.cdc.gov; *Nuclear, Biological, Chemical Terrorism*, Scenario Training, The Center of Excellence in Disaster Management and Humanitarian Assistance, CD-Rom, 1998, http://www.coe.tamc.amedd.army.mil; *Chemical Stockpile Emergency Preparedness Program Training Materials;* Lockheed Martin Energy Research Corporation, 1997; CD-Rom; *ATSDR ToxProfiles 2002,* ATSDR, DHHS, www.atsdr.cdc.gov.

If the water system is a primary target of a terrorist attack, one of the potential problems limiting a water utility's ability to respond is the fact that part, or all of the water delivery system (pumping station(s), feeder lines) become a federal crime scene. Once law enforcement agents arrive and mark off the site it is officially controlled by them. Being an active member of the regional emergency management organization, as described above, is the foremost method for ensuring access and participation during a terrorist event. This requires detailing for law enforcement the names and identifications of all personnel (laboratory, mechanical, technical, administrative) who need access to the site(s) and to educate staff on appropriate behavior and movement within a crime scene site.

For all three aspects of preparation, response and recovery, the water system should have, or be part of, a systematic and timely public information system. Information should include the level of risk, means of protection, time course of the event, and adverse health effect signs and symptoms and where to seek assistance.

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# Water Infrastructure Security Enhancements - Standards Committee
# American Society of Civil Engineers
# Spring 2004

## Guidance for Designing On-Line Contamination Monitoring Systems - GRA-SEW-RFP-01

## Chapter 7 - Communications

1. Describe the specific topic being addressed and its connection with other topics
2. Briefly review and reference pertinent reports, papers, etc.
3. Identify and explain the factors and issues important to providing and understanding guidance on the topic
4. Provide an analysis of tradeoffs and options appropriate to the topic
5. Provide guidance language on the topic appropriate for guiding the design and implementation of an online contaminant detection and monitoring system

## Description of the topic

A communications network is the necessary element in an online contamination monitoring system that provides the connectivity between the monitoring, analytic, and control devices in the system and human managers, decision-makers, and response teams.

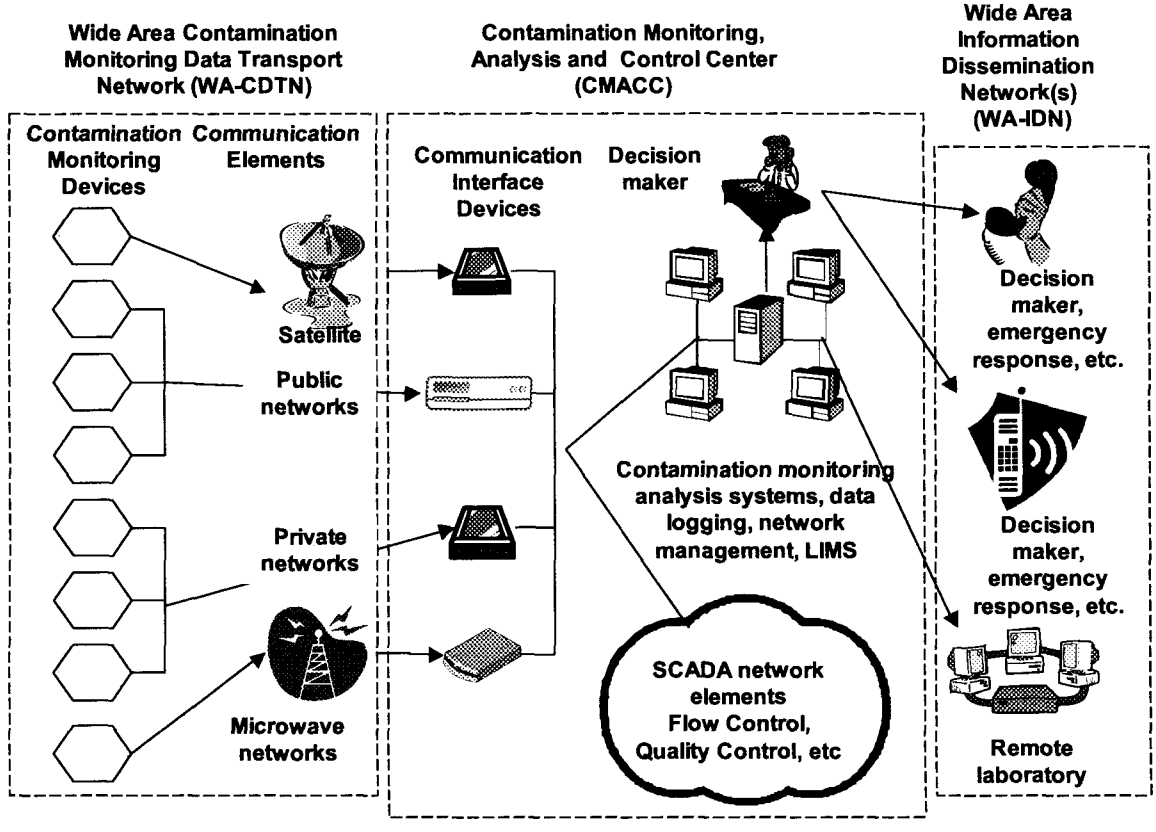



**Figure 1- Contamination Monitoring Network**

This paper briefly describes the relationship of the network to the other guidance areas for contamination monitoring (0). It lists some of the relevant literature that applies to the topic of designing networks in general and secure networks for utilities in particular (0).

The paper then discusses in detail the factors that impact the network design:

- The policy issues that must be investigated prior to designing the network (0)
- The major functional requirements that must be considered when designing a contamination monitoring communications network (0)
- The choices of different communications elements that are available to the network design for this type of network (0)

Finally, we provide guidance language to summarize the key recommendations (0).

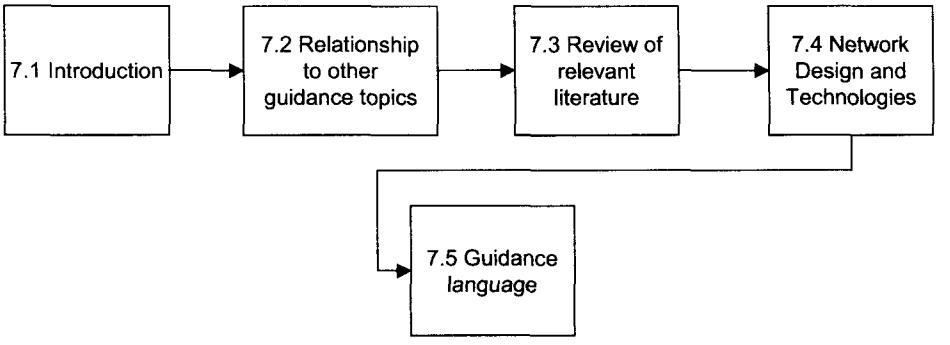



**Figure 2 Structure of this Paper**

## Relationship of the Communications Network to Other Elements of the Contamination Monitoring System

Table 1, below, summarizes the functionality the communications network provides for each of the related topics in this guidance paper:

**Table 1- Relationship between the Communications Network and Other Guidance Topics**

| Guidance Topic Area | Communications Network Functionality |
|---|---|
| Contaminants and concentrations of concern | Must provide accurate, complete, real-time, secure, and reliable[8] transport of data as generated. |
| Selection of instruments and platforms | Must match the communications interfaces available on the instruments, and provide accurate, complete, real-time, secure, and reliable transport of data between the devices and the Contamination Monitoring, Analysis, and Control Center (CMACC). |
| Models for use in data analysis | Must provide local area connectivity in the Contamination Monitoring, Analysis, and Control Center between incoming data, data logging/recording devices, and analytic devices.<br><br>Must provide connectivity to remote centers via the Wide Area Information Dissemination Networks to permit analysis and decision-making at locations remote from the Contamination Monitoring, Analysis, and Control Center (CMACC). |
| Siting instrument platforms | Must provide accurate, complete, real-time, secure, |

[8] Accurate - transports data exactly as received; Complete - does not lose data due to communication errors; Real-time - transports data immediately when received; Secure - is secure against penetration (e.g., by hackers or other malfeasants); Reliable - is available at a defined level of dependability - typically 99.9999% up-time.

| Guidance Topic Area | Communications Network Functionality |
|---|---|
| | and reliable communications capability from the instruments at each site to the CMACC.<br><br>Must be able to provide accurate, complete, real-time, secure, and reliable communications capability from the CMACC to each site for purposes such as remote instrument testing, calibration, power on/off, etc., depending on the capabilities of the instrument. |
| Data analysis requirements | Must provide accurate, complete, real-time, secure, and reliable data connectivity at the CMACC that permits incoming data to be logged and moved to and between analysis devices and workstations.<br><br>Must provide accurate, complete, real-time, secure, and reliable data connectivity from/to the CMACC so data and/or analytic results can be moved to and between remote locations (e.g., a laboratory) or devices (e.g., PDAs, laptops) for logging, analysis, decision-making, response or regulatory purposes. |
| Responses to contamination events | Must permit immediate, accurate, complete, real-time, secure, and reliable data, voice and fax connectivity from and to the CMACC to decision makers, emergency response teams, and field operatives.<br><br>May provide data connectivity to one or more decision-making elements in the SCADA system so that automatic procedures can be implemented following a contamination event. Communications with the SCADA network must be accurate, complete, real-time, secure, and reliable |
| Interfacing with existing water quality surveillance system | Must provide accurate, complete, real-time, secure, and reliable data connectivity between the CMACC and the existing surveillance system. |
| Operational and upgrading considerations | The contamination monitoring network system must be reliable (e.g., in the event of a power failure, or natural disaster or terrorist event), physically and electronically secure, and capable of handling all required transmission rates and data volumes with complete accuracy (no lost information).<br><br>Must permit immediate, accurate, complete, real-time, secure, and reliable data, voice and fax |

| Guidance Topic Area | Communications Network Functionality |
|---|---|
| | connectivity from and to the CMACC to decision makers, emergency response teams, and field operatives.<br><br>Must provide accurate, complete, real-time, secure, and reliable data connectivity from/to the CMACC so data and/or analytic results can be moved to and between remote locations (e.g., a laboratory) or devices (e.g., PDAs, laptops) for logging, analysis, decision-making, response or regulatory purposes.<br><br>Should use standard communications protocols to reduce cost, design and maintenance complexity, and permit acquisition of compatible equipment from multiple vendors.<br><br>Must be scalable so that if additional monitoring, logging, or analytic devices are added to the system the network can be easily scaled to handle additional data transmissions.<br><br>Must be scalable for voice communications so that as requirements for additional voice and fax communications are added the system can be easily scaled to handle additional voice and fax requirements. |

## Reports and Papers Relating to Communications Networks in Infrastructure Utilities

Numerous standard texts provide instruction on the elements of network design, management, and maintenance. We cite examples of well-known standard texts below, including the frequently referenced text by Boyer on SCADA systems

More directly relevant to the topic are numerous reports, papers, and articles available dealing with the matter of communications in utilities. Although many refer to utilities in other industries (e.g., gas, oil, energy), and generally focus on the SCADA systems used, the communications issues are similar in many respects and they provide excellent additional material to be consulted when designing a water contamination network.

## Standard texts (examples)

**Data and Computer Communications**, Seventh Edition; William Stallings

- **Hardcover:** 864 pages; Dimensions (in inches): 1.45 x 9.70 x 7.02
- **Publisher:** Prentice Hall; 7th edition (May 8, 2003)
- **ISBN:** 0131006819

**Computer Networks**; Fourth Edition; Andrew S. Tannenbaum

- **Hardcover:** 912 pages; Dimensions (in inches): 1.51 x 9.46 x 7.26
- **Publisher:** Prentice Hall PTR; 4th edition (August 9, 2002)
- **ISBN:** 0130661023

**SCADA: Supervisory Control and Data Acquisition**; Stuart A. Boyer

- **Paperback:** 215 pages; Dimensions (in inches): 0.25 x 10.75 x 7.25
- **Publisher:** ISA - The Instrumentation, Systems, and Automation Society; 2nd edition (January 1, 1999)
- **ISBN:** 1556176600
- 3rd Edition (when available) - **ISBN** 1-55617-877-8

**SNMP, SNMPv2, SNMPv3, and RMON 1 and 2, 3rd Edition,** William Stallings

- Dimensions 7-3/8x9-1/4; Pages: 640; Edition: 3rd.
- **ISBN:** 0201485346;
- **Publisher:** Addison Wellesley Professional; Dec 22, 1998; Copyright 1999;

## Reports, Papers, and Articles Referring Specifically to Communications in Utilities

Although many, or most, of the reports, papers and articles cited below refer to SCADA systems, their content provides excellent guidance for the design of a secure, reliable, water contamination monitoring system.

In addition, many of the manufacturers of SCADA equipment maintain application libraries on their web sites that contain up-to-date and informative design information. Many of the papers referenced were written by representatives of commercial organizations; citing them here does not represent an endorsement of any company or equipment referenced.

Examples of useful basic guides from commercial sources, though by no means the only ones[9], are:

**Bristol Babcock Application note D415AD-45 - Water Security – the Role of the SCADA System**; Available at the Bristol Babcock, Inc. website:

http://bristolbabcock.com/news/article%5Farchives.htm

**Calculating Fiber Loss and Distances;** Available at the IMCNetworks website:

http://www.imcnetworks.com

**Cisco Wireless Bridging Solutions Guide**; Cisco Systems; available at the Cisco Systems website:

http://www.cisco.com/en/US/products/hw/wireless/ps5279/prod_brochure_list.html

[9] These guides are provided as examples that provide useful general application information, and are not a recommendation of any vendor or equipment

**Deploying Network Taps with Intrusion Detection Systems;** Fiber optic security and monitoring; Available at the NetOptics website: http://www.netoptics.com/support/white_paper.asp?Section=support

**How Secure is Your Wastewater Facility?** – GE Interlogix; Available at the GE Interlogix Website: http://www.geindustrial.com/ge-interlogix/solutions/water/index.html

**Rockwell Automation – Allen Bradley – Flexible Solutions for your Supervisory Control and Data Acquisition Needs;** Available at the Rockwell Automation/Allen Bradley website: http://www.ab.com/index.html

**Information on VSATs**; Available at Quantum Prime Communications, LLC, website: http://www.qpcomm.com/vsat_info.html

Much of the material referenced below refers to ensuring the security of SCADA networks, and is directly applicable to networks that will be used for contamination monitoring. We also include useful papers, publications and articles, and several relevant industry association and vendor websites[10]. The list is far from exhaustive.

**21 Steps to Improve Cyber Security of SCADA Networks** – Crypticom Inc.; http://www.crypticom.com/download/download.htm

**A Future of SCADA and Control System Security –API Industry Security Forum (24 April '03)** - Mathew Franz; Cisco Systems Critical Infrastructure Assurance Group (CIAG) http://www.cisco.com/go/ciag/

**American Gas Association (AGA)/Gas Technology Institute (GTI) SCADA Encryption Web Site AGA Draft 12** - http://www.gtiservices.org/security/

**Assessment and Remediation of Vulnerabilities in SCADA and Process Control Systems** – Internet Security Systems; http://www.iss.net/products_services/market_solutions/scada.php

**Band Selection**; Interactive selection table providing information regarding coordination and licensing of frequency bands, requirements and pending regulatory proceedings that could limit or prohibit the use of a frequency band; available at ComSearch website; http://www.comsearch.com/microwave/design1.jsp

**Critical Infrastructure Protection – Challenges in Securing Control Systems**; Statement of Robert F. Dacey, Director, Information Security Issues; October 1, 2003; United States General Accounting Office

**Federal Information Processing Standard 140-2(FIPS 140-2) Overview** - http://www.rycombe.com/short140.htm

**FREE-SPACE OPTICAL ALLIANCE**; Industry Alliance website; http://www.wcai.com/fsoalliance/

**How to Protect SCADA Systems from Cyber-Attack**; William F. Rush and John A. Kinast; Gas Industries magazine, July 2003

[10] These guides are provided as examples that provide useful general application information, and are not a recommendation of any vendor or equipment

**IT Security for Industrial Control Systems**; Joe Falco, Keith Stouffer, Albert Wavering, Frederick Proctor; Intelligent Systems Division, National Institute of Standards and Technology (NIST), Gaithersburg, MD; In coordination with the Process Control Security Requirements Forum (PCSRF) - http://www.isd.mel.nist.gov/projects/processcontrol/

**National Security Telecommunications Advisory Committee (NSTAC), "Information Assurance Task Force Risk Assessment"**, http://www.ncs.gov/n5_hp/reports/EPRA.html (October 10, 1997).

**Risks of Cyber Attack to Supervisory Control and Data Acquisition for Water Supply**; United States Army Captain Barry C.Ezell - A Thesis Presented to the Faculty of the School of Engineering and Applied Science, University of Virginia In Partial Fulfillment of the Requirements for the Degree Masters of Science (Systems Engineering); May 1998

**Security Features of SNMPv3**; *Uri Blumenthal, , Bert Wijnen, IBM Watson Research* ; http://www.simple-times.org/pub/simple-times/issues/5-1.html#operations

**SECURITY REQUIREMENTS FOR CRYPTOGRAPHIC MODULES, FEDERAL INFORMATION PROCESSING STANDARDS PUBLICATION** (Supercedes FIPS PUB 140-1, 1994 January 11)

**Selecting a VPN solution? Think security first;** By Linda Christie, M.A.; SearchNetworking, 18 Apr 2001; http://searchnetworking.techtarget.com/originalContent/0,289142,sid7_gci542380,00.html

**Supervisory Control and Data Acquisition Systems for Water Supply and Its Vulnerability to Cyber Risks.** Ezell, Barry, (August 1997).

**Survey of SCADA System Technology and Reliability in the Offshore Oil and Gas Industry;** A Final Report to Dept. of the Interior, MMS TA&R Program - Program SOL 1435-01-99-RP-3995

**Trends in SCADA for Automated Water Systems**; Synchrony (magazine); Published: November 2001

**Useful quick reference to wireless technologies:** http://www.hackfaq.org/wireless-networks/wireless-networks.shtml

**VSAT Networks**; http://www.nttmsc.com.my/images/Beginner_Level/ Day_1/Topic3_2.pdf

**What is Free Space Optics (FSO)?** FSO Technology Insight; http://www.freespaceoptics.org/

**Wireless Communications Association International (WCA)**; Industry Alliance website;http://www.wcai.com/index.html

**Wireless Data Communications Via Ethernet Saves Money And Time In California**; Jonathan A. Brown, Control Systems Engineer, Northstar Industries, Methuen, MA, and Robert Findley, Regional Sales Manager, Bristol Babcock, Watertown, CT; Published in Pipeline & Gas Journal/September 2002/ http://www.pipelineandgasjournalonline.com ; also available at the Bristol Babcock, Inc. website; http://bristolbabcock.com/news/article%5Farchives.htm

**WIRELESS TASK FORCE Findings**, Security of Internet-Enabled Wireless Devices, January 2003; Wireless Task Force Findings on Security of Internet Enabled Divices (NB: Misspelling is in the URL)

**Wireless Wonders**; Light Reading magazine; useful introduction to last mile wireless technologies; http://www.lightreading.com/document.asp?site=lightreading&doc_id=1207&page_number=1

# Factors and issues important to designing, implementing, and managing a contamination monitoring system

## Introduction

The network designer must design a network that meets the overall objectives of the facility, or business, that it serves.

In order to design a contamination-monitoring network, therefore, the designer will need to answer questions such as:

- What policies and regulations will affect the design and implementation?
- What are the key management, functional and operational objectives?
- What devices will be attached to the network?
- What information will be transported over the network?
- What are the physical characteristics of the network
  - Where will the network elements be located?
  - What distances must be covered?
  - What terrain conditions must be accounted for?
  - How will the network equipment obtain power?
- What technologies are available to use in the network, and which are most appropriate for each part of the network?
- How will the network be managed?
- How will the network be secured?
- Who will need access to the network, and who will need to be contacted via the network?

We propose that the designer use the systematic design approach illustrated in the diagram below:

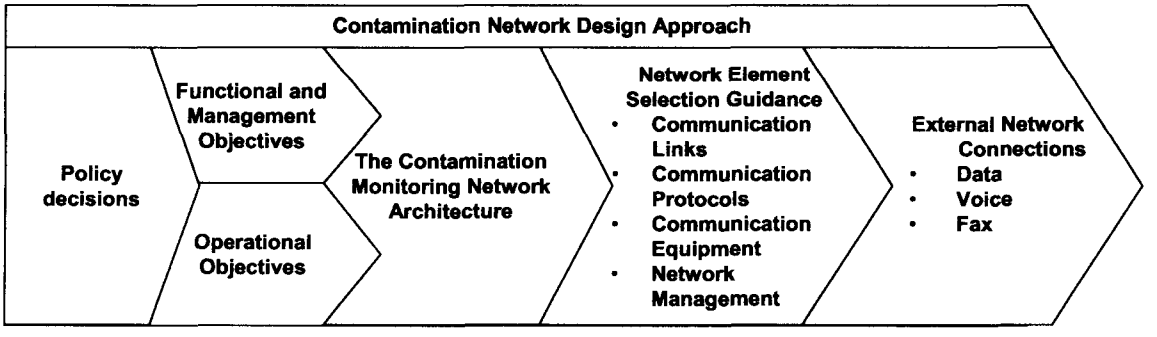



**Figure 3 – Contamination Network Design Approach**

Table 1 in the Introduction to this White Paper shows the relationship of the communications network with the other elements of a contamination monitoring system network and the needs it must meet in order that the system as a whole is well-served by the network.

In addition, the contamination-monitoring network must meet the objectives of those responsible for the proper operation of the facility, and those responsible for the proper monitoring of contamination and response activities in the event of a contamination event.

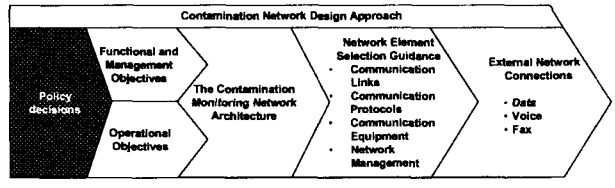
We therefore provide guidance to the network designer regarding the type of policy issues to investigate that will govern the network's functionality, and that will govern trade-offs of cost versus performance in many cases (Table 2 in Par 0 below).

Once the policy issues are identified, it is possible to establish the set of functional requirements (architectural, management, and operational objectives) that govern the network design in order that it to provide the functionality required.

We then postulate a generic architecture suitable for a contamination-monitoring network and describe the choices of elements that comprise each sub-system in the network and for connection to external networks.

## Policy decisions

The contamination monitoring system designer should investigate the inputs from "policy makers" that include at least the personnel who:




- Establish the operational, response, and mitigation policies for the contamination monitoring system and the facility as a whole
- Operate the facility and network
- Analyze the contamination data received over the network

The designer should conduct a set of interviews with decision-makers and operational personnel in order to elicit answers to all policy matters that affect the design and functionality of the network. Table 2 –Sources the Network Designer Should Interview provides examples of the decision-makers and operational personnel who should be consulted to define the high-level policies that the network designer should consider before work begins on the actual technical design.

The list is unlikely to be exhaustive, especially as new contamination monitoring challenges arise and response requirements evolve. Each facility may have specific and special additional policy requirements that could affect the network design. The network designer should account for these specific needs in developing the network design and evaluating the tradeoffs that will inevitably have to be made.

**Table 2 –Sources the Network Designer Should Interview**

| "Policy Makers" | Typical Roles and Responsibilities | Typical Policy Guidance Inputs |
|---|---|---|
| Human Decision Maker (s) | • Implements Critical Infrastructure Policy<br>• Ensures regulatory compliance<br>• Prepares operational plans<br>• Prepares mitigation plans<br>• Decides if to initiate mitigation plans<br>• Validates action in the field | • Acceptable mitigation methods<br>• Methods for initiation of response<br>• Methods for communicating with/escalation to other HS responsible organizations<br>• Use of automated responses to contamination events |
| Facility manager | • Operations<br>• Budgets<br>• Maintenance<br>• Upgrades<br>• Training<br>• Hiring<br>• Regulatory compliance | • Operational requirements<br>• Budget constraints<br>• Staff capabilities<br>• Maintenance methods and constraints |
| Control room/network operator | • Monitors the network<br>• Responds to communications alarms<br>• Conducts routine maintenance and equipment replacement or upgrade<br>• Provides input to policy and network design on requirements and functionality | • Technical network monitoring policies<br>• Control system requirements<br>• Escalation policies<br>• Maintenance policies |
| Contamination evaluation expert | • Analyzes contamination event data from the field devices<br>• Notifies decision-maker(s) if a contamination event has occurred | • Monitoring requirements<br>• Local analytical devices required (e.g., in a laboratory at the facility)<br>• Remote communications required (e.g., to decision makers and/or to a remote laboratory or response team)<br>• See also Table 1 for additional functional requirements related to contamination monitoring |

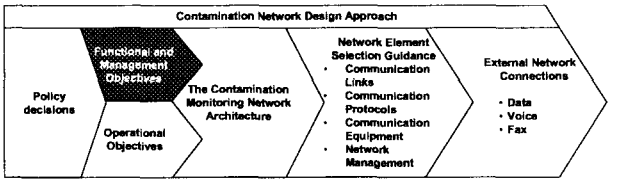
## Functional, Management and Operational Requirements

We propose six design objectives that are at the functional and management levels in Par. 0. The findings on Policy Decisions will be critical in establishing the appropriate architectural and management strategies for each network implementation. We provide examples of appropriate design strategies are to achieve these six design objectives in Table 3.

In Table 1, we defined five operational objectives for data transfer that the network must meet if it is to provide the functionality required by the contamination monitoring system. Table 4 provides a set of design strategies to achieve these objectives.

Taken together, these define a set of functional requirements for the network.

Functional and Management Objectives




The network design should address six high-level functional and management objectives:

- Geographically sufficient – it must connect all the required monitoring devices, many of which will be remote from the operations center, off-site laboratories or other related facilities, maintenance staff, and decision makers and response teams, who will generally be (initially) remote from the plant site
- Scalable – since there is the potential to add more devices after the initial network installation (e.g., devices that detect additional contaminants, or devices located in other sections of the physical system), the network must scale easily, without the need to invest in large scale equipment replacement
- Maintainable – it should be easy to detect and repair problems, and carry out equipment upgrades, moves, and changes
- Cost effective – the design should account for the budgetary constraints of the facility
- Compliant with regulatory requirements – e.g., maintenance of records of network availability, maintenance or other performance characteristics
- Staffing – the network should use commonly available equipment and protocols to avoid the need for very specialized network technicians
-

Table 3 indicates which design strategies best meet the architectural and management objectives (Section 0 discusses the choice of specific network elements).

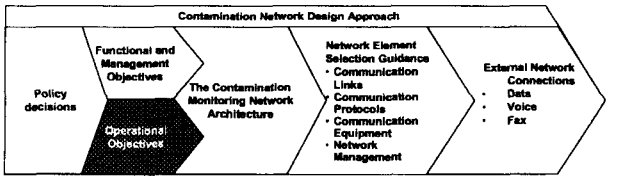
**Table 3 - Design Strategies to Achieve the Functional and Management Objectives**

| Design Strategy | Functional and Management Objectives | | | | | |
|---|---|---|---|---|---|---|
| | Geography | Scalability | Maintainability | Cost Effectiveness | Regulatory Compliance | Staffing Needs |
| Wireless technology | X | X | X | X | | X |
| Fiber technology | X | X | X | | | X |
| Copper | | | X | X | | X |

| Design Strategy | Functional and Management Objectives | | | | | |
|---|---|---|---|---|---|---|
| | Geography | Scalability | Maintainability | Cost Effectiveness | Regulatory Compliance | Staffing Needs |
| technology | | | | | | |
| Public networks (PSTN, Frame Relay, etc.) | X | X | X | X | X | X |
| Shared SCADA links | | | | X | ? | X |
| Multiple vendor sourcing | | | X | X | | |
| Dedicated network management system | | X | X | | X | |
| Shared network management system | | X | X | X | ? | X |
| Standard protocols | X | X | X | X | | X |
| Network performance logging | | | X | X | X | |
| Redundant network links | | | X | | X | |
| Remote site connectivity | X | X | | X | ? | |
| Mobile and terrestrial communications | X | X | X | | ? | |
| Fax communications | X | X | X | X | ? | |

Network Operational Objectives

The network must provide for data transfer that is:




- Accurate - transports data exactly as received;
- Complete - does not lose data due to communication errors;
- Real-time - transports data immediately when received;
- Secure - is secure against penetration (e.g., by hackers or other malfeasants);
- Reliable - is available at a defined level of availability - typically 99.9999% availability[11].

There are a number of strategic design choices that are available in order to In order to accomplish these objectives. Some choices are purely technical (e.g., the choice of an encryption

[11] This level of reliability or availability may seem excessive, but is necessary for a secure network. It represents downtime of about 31 seconds per year. Reducing the availability to 99.999% would permit an acceptable downtime of about 5 minutes – enough for someone to tamper with the network without exceeding any alarm guidelines. The goal can be achieved using redundant connections to each monitoring device.

method, or a protocol, or type of connection link) while others will influence the ability to control and monitor the network, and report contamination events reliably, immediately, and securely.

Table 4 indicates which design strategies best meet the operational objectives ((Section 0 discusses the choice of specific network elements).

**Table 4 – Design Strategies to Achieve the Operational Objectives**

| Design Strategy | Operational requirements[12] | | | | |
|---|---|---|---|---|---|
| | Accurate | Complete | Real-time | Secure | Reliable |
| Public networks (PSTN, Frame-relay, etc.) | X | X | X | ?[13] | X |
| Redundant network connections | | X | X | X | X |
| Digital communications[14] | X | X | X | | X |
| Well-proven network protocol stack | X | X | | | X |
| Encryption | X | X | | X | X |
| Multiple transmission media | | X | | | X |
| Equipment polling/heartbeat | X | X | | X | X |
| Connection to control elements managed by the SCADA system | | | X | | |
| Multiple contact mechanisms to decision makers – phone, cell-phone, e-mail, fax, pager | | X | X | X | X |
| 24 x 7x365 control room | X | X | X | X | X |
| Additional training in communications for technicians | | | | | X |
| Paper record/redundant report collection | X | X | | | X |
| Network management | X | X | X | X | X |
| Diagnostics | | X | | X | X |
| Monitor physical security devices | X | X | | X | |

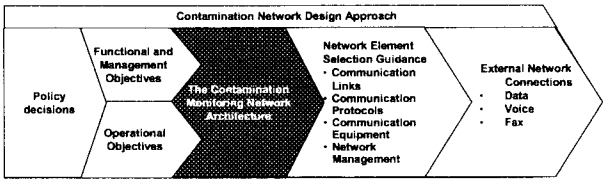
[12] Accurate - transports data exactly as received; Complete - does not lose data due to communication errors; Real-time - transports data immediately when received; Secure - is secure against penetration (e.g., by hackers or other malfeasants); Reliable - is available at a defined level of availability - typically 99.9999% up-time

[13] The public networks are secure, in many senses, but are vulnerable in terms of permitting a remote user to find ways to access a utility's network.

[14] Monitoring equipment that generates analog signals should be equipped with an intervace to convert them to digital form

| Design Strategy | Operational requirements[12] | | | | |
|---|---|---|---|---|---|
| | Accurate | Complete | Real-time | Secure | Reliable |
| 24x7x365 power supplies | X | X | X | | X |

## The Contamination Network Architecture




Earlier, we described the kinds of policy decisions that the network designer must take into account so that the network meets the operational requirements of decision makers involved in planning for, managing and responding to contamination events.

Once policy decisions are established, Pars. 0 and 0 demonstrate how functional, management, and operational guidelines can be created. Clarification of these high level objectives permits the designer to create an architecture for the network that will meet all the objectives.

For the purposes of this White Paper, we hypothesize a likely generic network architecture derived from the general objectives discussed earlier. We divide the network architecture into three major components (Figure 4):

- Wide Area Contamination Monitoring Data Transport Network (WA-CMDTN)
- Contamination Monitoring, Analysis, and Control Center (CMACC)
- Wide Area Information Dissemination Network(S) (WA-IDN)

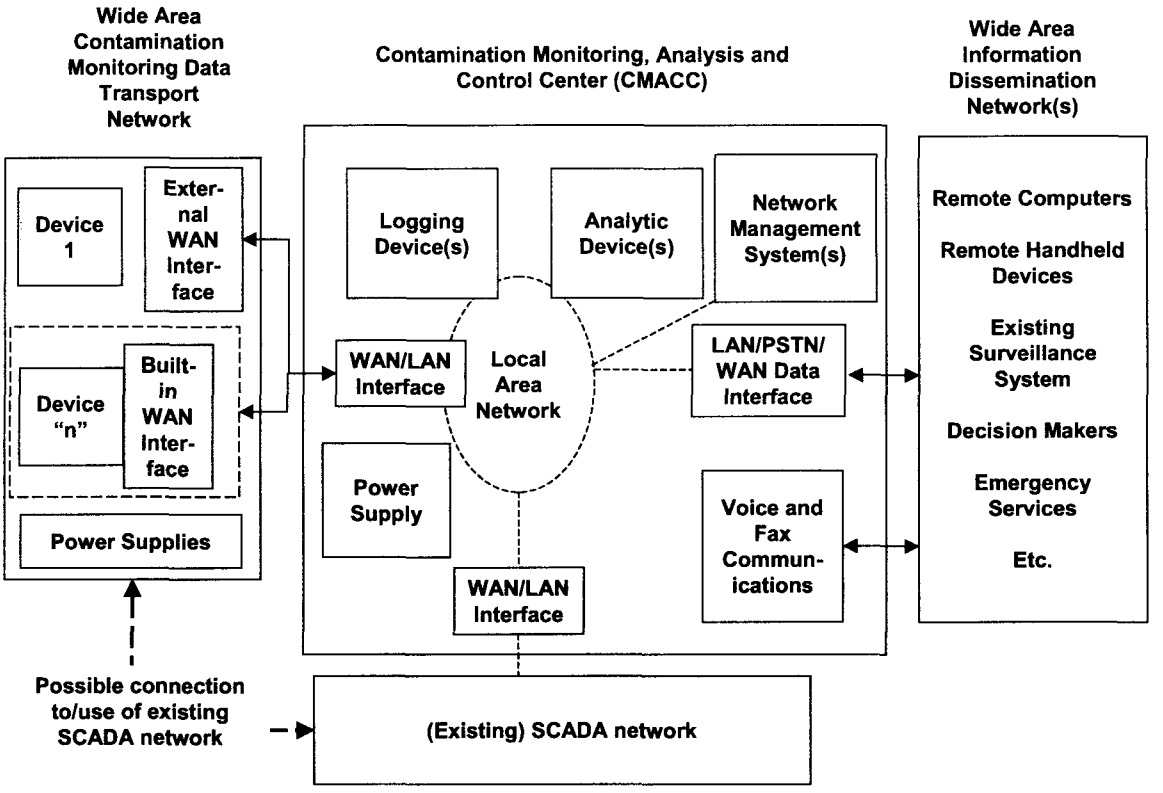



**Figure 4- Contamination Monitoring Network Architecture**

## Contamination Monitoring Analysis and Control Center (CMACC)

The Contamination Monitoring Analysis and Control Center (CMACC) contains, conceptually, a set of communications and network management devices and analytic and logging devices which may or may not be co-located in a control room. The functionality could be spread over more than one physical location for reasons of convenience, cost, or security.

In a SCADA network, the devices that monitor and control the network are often referred to as Master Terminal Units (MTUs). These devices have higher-level capabilities used to communicate, control, monitor, and manage the remote devices placed throughout the physical plant and network(s). The typical functionality of an MTU is illustrated in the following diagram by Boyer[15] (Figure 5), and it is to be expected that devices in the CMACC will include several of the same electronic functions:

[15] SCADA: Supervisory Control and Data Acquisition; Stuart A. Boyer; Paperback: 215 pages; Publisher: ISA - The Instrumentation, Systems, and Automation Society; 2nd edition (January 1, 1999) ISBN: 1-55617-660-0; 3rd Edition (when available) - ISBN 1-55617-877-8

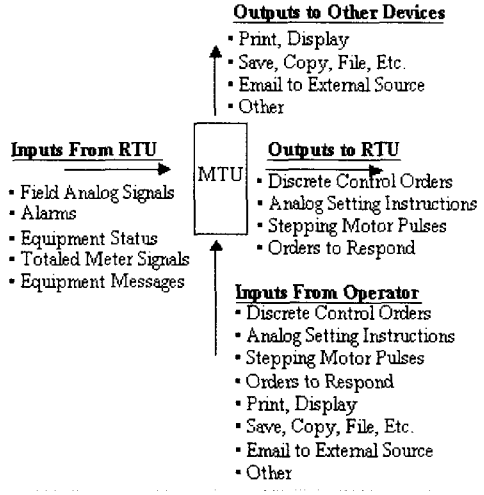



**Figure 5 - Inputs & Outputs for MTU (Boyer 1993)**

In this paper, we are concerned only with the communications aspects of the contamination-monitoring network. The related White Papers cover the monitoring capabilities and functionality of the devices.

Although the power supplies in the CMACC and remote sites shown in Figure 4 are not, strictly speaking, elements of the network, clearly the monitoring, logging, and analytic devices themselves and the network communications devices need reliable, continuous sources of power in order to perform their functions.

As part of the architecture, we also show a possible connection to an existing SCADA system used to manage the regular operation of the facility. It is possible that, for reasons of cost or convenience, the communications capabilities of part or all of an existing SCADA network are used to provide communications for the contamination network. The benefits of cost-savings and convenience must be weighed against the possibility of reduced security and any functional inadequacies (e.g., in the case of an older SCADA system that does not meet the requirements described later in this guideline).

It is also possible that the network management system, if any, used for an existing SCADA system could be used to monitor and manage the contamination-monitoring network, even if the contamination monitoring communications network is completely separate from an existing SCADA network in every other respect. (Clearly, use of an existing system will depend on its ability to monitor and manage the additional, possibly more advanced, network elements in the contamination-monitoring network). Use of an existing system, if possible, should provide cost and training benefits.

In addition to the possible use of the SCADA network, the overall system design may call for automatic action on the part of certain elements controlled through the SCADA network if a contamination event is detected by the contamination monitoring system (as opposed to commands to the SCADA system issued by a human operator in response to a contamination

event). This capability requires direct connection between the contamination-monitoring network, probably via an automated decision element in the CMACC, to the SCADA system.

## Wide Area Contamination Data Transport Network (WA-CDTN)

We refer to this network as a "contamination data transport" network to distinguish it clearly from the SCADA network, which carries the supervisory and control functions for the plant. The contamination-monitoring network is intended to carry data from remote sensing devices to the CMACC. The SCADA network or human operators will perform control actions (e.g., closing a valve) that result from the analysis of this data.

In a SCADA network, the controllable field devices are often referred to as Remote Terminal Units (RTUs) or Remote Stations. They typically include a Programmable Logic Controller (PLC) or Distributed Control System (DCS) controller with communications capability. Their typical functionality is illustrated in the following diagram by Boyer (Figure 6). Monitoring devices will include several of the same electronic functions, even though their operational purpose is very different from the controls in a SCADA system.

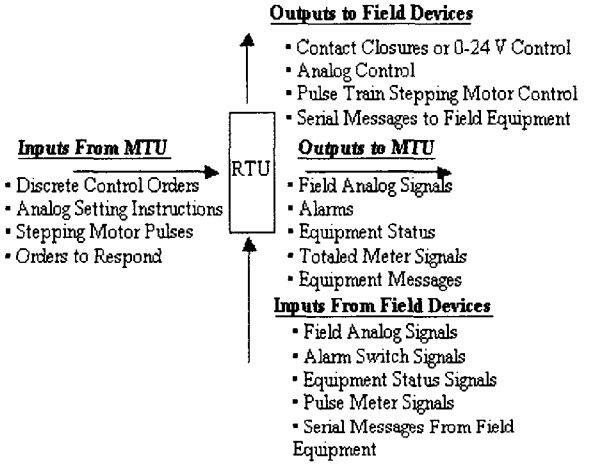



**Figure 6 - Inputs & Outputs for RTU (Boyer 1993)**

The PLC or DCS performs local control functions in response to signals from the unit(s) that control and monitor them from the central, or master, location - the MTUs (Master Terminal Units), or Master Stations.

As described above, one tradeoff the designer will consider is to use the same network, or parts of the same network, for SCADA and contamination monitoring functions. However, they are conceptually and logically separate, even if SCADA and contamination monitoring signals use the same physical network.

In the case of the contamination-monitoring network, the data flow is primarily from the devices to the CMACC (the opposite from the predominant situation in a SCADA network). Nevertheless, the network must be capable of bi-directional data transmission, since the remote

devices will be monitored and possibly controlled in various ways from the CMACC (e.g., for calibration or testing).

The remote devices are shown in two configurations:

- Devices which are connected to an external wide-area-network (WAN) interface (modem, router)
- Devices which have a built-in WAN interface

The actual device configuration will depend on the functionality provided by the vendors. From a network perspective, they are equivalent, though devices without a built –in WAN interface permit the designer more flexibility.

Not shown, but implicit in the WAN, are the actual physical (PHY) layer transmission devices – terrestrial or wireless. Copper, fiber, and radio devices are typical physical transmission devices. They usually use a special encoding scheme to improve transmission reliability. The PHY layer decoders make these schemes transparent at protocol layers above the PHY layer. A recent development is the use of photonic or free space optic systems that use laser beams for communications, which have advantages in terms of security. Each technology is discussed in 0.

As in the case of the CMACC, the power supplies are critical elements of the network. Devices that perform monitoring functions will require 24x7x365 power available to them. In addition, the power may have to be available within very tightly controlled limits in order to ensure that delicate measuring instruments remain properly calibrated. This may call for special solutions in the field, such as solar-powered sources equipped with battery-backup units.

## Wide Area Information Dissemination Network (WA-IDN)

In order for the information that is collected and analyzed by the contamination-monitoring network to be used, it must be available to a wide variety of human and computerized elements that are likely to be located remotely from the facility.
These may include decision makers, operational staff, remote computers, remote handheld devices, remote laboratories, analytic staff at these remote locations, emergency response teams, etc.

Therefore, it is important to establish who and what needs to receive information from the CMACC, and under normal operation and emergency conditions. The form of the information must be determined – electronic (e.g., computer to computer), voice, or fax. These needs should be established by the designer during the initial interviews conducted to establish the network requirements.

The CMACC will need to provide a broad set of communications interfaces from the Local Area Network (LAN) and staff in the physical CMACC:

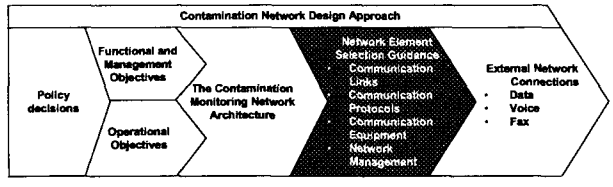
- WAN – for computer-to-computer communications with computers and/or PDAs at remote locations used for analysis, logging, and field maintenance
- PSTN – for dial-up access
- Voice – to communicate with operations staff, response teams, decision makers, etc.
- Fax – if required for policy, regulatory, or other reasons

- Pagers – to communicate with maintenance staff, managers, decision makers

The considerations for each of these communications needs are discussed in the following section.

#### Technology Choices in the Contamination Monitoring Network

This section describes the technologies available to the designer and tradeoffs that should be considered when designing each the major architectural subsystems that comprise the contamination monitoring system and the connections to the external networks:




- Wide Area Contamination Monitoring Data Transport Network (WA-CMDTN)
- Contamination Monitoring, Analysis, and Control Center (CMACC)
- Wide Area Information Dissemination Network(s) (WA-IDN)

We examine the technology solutions available for use in each of these sub-systems, and provide guidance regarding the options and tradeoffs that are available to the designer:

- Communication links
- Communication protocols
- Communication equipment
- Network management
- A brief guide to various wireless technologies and spectrum issues

The widest range of technology alternatives that confront the designer exists for the WA-CMDTN. These are examined in considerable detail in 0. More general guidance is provided for the CMACC and the WA-IDN, since the characteristics of the various technology alternatives will already have been covered in the earlier discussion

## Network Elements Selection Guidance in the Wide Area Contamination Monitoring Transport Network

### Communication links in the Wide Area Contamination Monitoring Transport network

Communication links comprise the "physical" links (although this terminology also refers to wireless or photonic links) that are used to connect the various elements of the network. These comprise the physical, or PHY, layer of the network. The designer has five major options for physical connectivity – two terrestrial or wireline options, and four principal wireless options:

- Wireline
  - Copper
  - Fiber

- Wireless
  - Radio
  - Microwave
  - Satellite
  - Photonic

Each technology is described in the tables below, with emphasis on its fit with the functional requirements previously described in 0 above.

**Table 5 - Terrestrial Communications Links - Copper**

| | **Terrestrial Communications Links - Copper** |
|---|---|
| Geography | • Limited by copper quality and transmission speeds (higher speeds generally reduce the distance the link can cover).<br>• Easy connection by modem to the PSTN permits essentially unlimited distances to be covered once the initial connection to a public carrier's central office is made (This may be limited to about 12,000 feet by the carriers). |
| Scalability | • Equipment such as modems, switches, routers are widely available to permit expansion of the network<br>• Scalability limited by distance to a central office or other site providing long-distance communications capability<br>• If the utility must install its own copper, will require ducts, trenches, poles, bridges and other engineering to install and carry or bury the copper. |
| Maintainability | • Simple to maintain<br>• Expertise widely available<br>• Susceptible to natural or man-made damage<br>• Ducts, trenches, poles, bridges, etc. must be easily accessible to repair crews |
| Cost effectiveness | • Highly cost effective if using installed copper (e.g., from a carrier)<br>• Very expensive if route must be prepared by trenching, adding poles, bridges etc. |
| Regulatory compliance | • Local or regional building codes must be observed if new copper is installed<br>• Environmental codes must be observed (e.g., habitat protection regulations) |
| Staffing needs | • Technology widely known to technical staff |
| Accuracy | • Digital communication protocols coupled with proper choice of higher-level protocols will transfer data from the field accurately |
| Completeness | • Higher-level communication protocols overcome susceptibility to electrical and magnetic interference from natural or man-made causes and recover from any brief disruptions in the link |
| Real-time | • Always available unless link is cut |
| Security | • Relatively easy to penetrate<br>• If the same cables are used for SCADA and monitoring, an event that disrupts either system may disrupt both, preventing |

| | |
|---|---|
| | both monitoring for contamination and the ability to activate control systems |
| Reliability | • Physical damage is the major concern - - must be protected against interference by humans and animals (e.g., rodents) |

**Table 6 - Terrestrial Communications Links - Fiber**

| | Terrestrial Communications Links - Fiber |
|---|---|
| **Geography** | • Essentially unlimited for many practical purposes. High-powered single-mode photonic devices and fiber-optic cables will allow transmissions of up to 10-12 km with little difficulty, and up to 50 km or more at a price.<br>• Lower cost multimode devices and cables are suitable for distances of 1 – 2km.<br>• 1300nm or 1550 nm fiber cables will provide the best options for longer distances. Very long links will require repeaters, though some vendors claim transmission distances of<br>• For smaller distances (1 – 2 km) small low-powered units are available |
| Scalability | • Equipment such as electronic to photonic converters, switches, routers widely available to permit expansion of the network<br>• For many practical purposes, there is no distance limitation<br>• If the utility must install its own fiber, will require ducts, trenches, poles, bridges and other engineering to install and carry or bury the fiber. |
| Maintainability | • Not quite as simple to maintain as copper since breaks in the fiber are more difficult to repair<br>• Expertise is widely available, but less than for copper<br>• Susceptible to natural or man-made damage<br>• Ducts, trenches, poles, bridges, etc. must be easily accessible to repair crews |
| Cost effectiveness | • Highly cost effective if using installed fiber (e.g., from a carrier)<br>• Very expensive if route must be prepared by trenching, adding poles, bridges etc. (70% or more of the cost of a typical exterior fiber installation is in the route development).<br>• Installation cost can be reduced if installed along existing power lines<br>• Many vendors supply devices to convert the electronic signals from a device port (typically RS-232C, RS-485 or Ethernet) to photonic signals on the fiber at quite low cost. |
| Regulatory compliance | • Local and regional building codes must be observed if new fiber is installed<br>• Environmental codes must be observed (e.g., habitat protection regulations) |
| Staffing needs | • Staff must have experience in installing and repairing fiber, using fiber-optic repair tools and fiber optic instruments for measuring fiber and joint quality |
| Accuracy | • Bit error rates are very low – 1 x10E-9 BERR is easily |

| | Terrestrial Communications Links - Fiber |
|---|---|
| | attainable, 1x10E-12 possible<br>• Digital communication protocols coupled with proper choice of higher-level protocols will transfer data from the field accurately |
| Completeness | • Essentially no data loss even at the fiber level<br>• Higher level protocols will ensure completeness |
| Real-time | • Transmission speeds in excess of 100Mb/s easily attainable, so little or no delay in transmission |
| Security | • If the same cables are used for SCADA and monitoring, an event that disrupts either system may disrupt both, preventing both monitoring for contamination and the ability to activate control systems |
| Reliability | • Highly reliable except for physical damage to the cable - must be protected against interference by humans and animals (e.g., rodents)<br>• Unaffected by electrical or magnetic interference |

The topic of wireless communications is very broad, and entire books are written about each type of wireless technology. The following table provides a high-level overview of several wireless alternatives, and is by no means exhaustive. We treat microwave, another and widely-used wireless technology, as a separate topic as its characteristics are quite specific to that technology.

**Table 7 - Wireless Communications Links - Radio**

| | Wireless Communications Links - Radio |
|---|---|
| **Geography** | • Many different wireless technologies are available that cover all ranges from in-building to "last mile" to tens of miles.<br>• Useful for remote sites where it is expensive or impractical to provide terrestrial links<br>• Useful for in-building or between-building or "last mile" communications when copper or fiber links are not available or expensive to install<br>• Transmission ranges of 10+ km are easily achieved at low data rates with standard wireless transmitters and receivers. However, one vendor states that for radio devices doubling the data rate can reduce range by 29%[16]<br>• Some technologies require line-of-sight, while other radiate very widely<br>• New technologies from the 802.11 family (WiFi, Wireless LAN, WiMax) offer high data rates over a variety of ranges<br>• Cellular communications over a wireless carrier's network can be used for wide-area data communications (as well as voice), primarily to portable devices such as PDAs and laptops in the |

[16] http://www.maxstream.net/spotlight/find-rf-solution.php?t5=true

| | Wireless Communications Links - Radio |
|---|---|
| | field<br>o Using a carrier's data service (GPRS[17], EDGE[18], CDMA-2000/1xRTT[19], EV-DO[20]) for rates between 19.2 Kbps to about 100kbps or more in burst mode<br>o Using a packet service like CDPD[21] (Cellular Digital Packet Data) at rates up to about 19.2 kbps |
| Scalability | • Low data rates over long distances might limit applicability if many devices are installed, and the data volume is high. In practice, most networks of this type have low data rate requirements from the field since the field devices transmit small volumes of data relatively infrequently.<br>• Easily expanded by adding more transmitters and repeaters if needed<br>• Use of a cellular carrier's network makes scalability easy, but the network is vulnerable to overload by users during crisis times<br>• Multichannel devices reduce the amount of extra equipment needed<br>• Spectrum usage may be an issue<br>o Devices must operate in allocated spectrum, and the presence of other users may reduce the available bandwidth for each user (see discussion of spectrum issues in section XXX). The potential for interference from other users or devices in "license exempt" bands (900 MHz, 2.4 GHz, 5 GHz) should be considered a limiting factor on scalability and other functions<br>o The FCC is reviewing the use of spectrum in various frequency bands (particularly bands used in rural communications), so, to the extent that changes are known, devices selected should be simple to upgrade to operate in new frequency bands<br>• Probably not suitable for remote field devices with high-speed interfaces (e.g., Ethernet) since radio equipment in remote sites will usually have low transmission rates<br>• Useful for adding in-building or between-building networked elements using various 802.11 (wireless LAN) technologies<br>• Some new 802 family technologies are expected to offer |

[17] GPRS (General Packet Radio Service) is a specification for data transfer on TDMA and GSM networks. GPRS utilizes up to eight 9.05Kb or 13.4Kb TDMA timeslots, for a total bandwidth of 72.4Kb or 107.2Kb. GPRS supports both TCP/IP and X.25 communications. Source: http://www.hackfaq.org/

[18] EDGE (Enhanced Data-Rates for GSM Evolution) enabled GSM networks are able to implement EGPRS (Enhanced General Packet Radio Service), an enhanced version of GPRS. EGPRS increases the bandwidth of each timeslot to 60Kb; Source: http://www.hackfaq.org/

[19] CDMA-2000 1xRTT is a 3G wireless technology based on the CDMA platform. The 1x in 1xRTT refers to 1x the number of 1.25MHz channels. The RTT in 1xRTT stands for Radio Transmission Technology.

[20] "Evolution Data Optimized" is at least one expansion of the acronym "EV-DO." Data rates of greater than 300 kbps are promised, and the service works well even while in motion – e.g., in a car or service truck

[21] CDPD (Cellular Digital Packet Data) is a specification for supporting wireless access to the Internet and other public packet-switched networks over cellular telephone networks. CDPD supports TCP/IP and Connectionless Network Protocol (CLNP). CDPD utilizes RSA's RC4 algorithm with for 40 bit keys for encryption; Source: http://www.hackfaq.org/

| | Wireless Communications Links - Radio |
|---|---|
| | greater range – e.g., WiMax is intended to reach ranges of tens of kilometers<br>• Many flavors of radio are useful for high-speed "last-mile" applications – e.g., between building in a facility, or from a facility to carrier's CO<br>• Some technologies require line-of-sight, which can limit range and usefulness |
| Maintainability | • Easy to maintain if interference not present since no physical connections – maintenance is limited to transmission equipment<br>• If electric or wireless interference is prevalent, may cause consistent and unresolvable maintenance problems<br>• Higher frequency technologies (operating about the 900 Mhz band) are affected by rain |
| Cost effectiveness | • Highly cost effective since no physical media need be provided<br>• Nevertheless, may prove more costly than anticipated if towers must be constructed to carry the antennas<br>• If "license exempt" devices are used, no charge for spectrum<br>• Many vendors supply devices to convert the electronic signals from a device port (typically RS-232C, RS-485) to radio signals |
| Regulatory compliance | • Equipment must meet FCC spectrum usage regulations<br>o Free spectrum is available at 900 MHz, 2.4 GHz, and 5 GHz<br>o A variety of Fixed Broadband Wireless Access technologies intended for other applications (e.g., for Wireless ISPs, or WISPs) could be potential candidates for last mile communications under special circumstances. If they use licensed spectrum, the fees and regulations involved must be understood<br>o Cellular operators will already have regulatory approval for the frequencies they use |
| Staffing needs | • General purpose radio equipment is generally easy to install and requires no special skills to operate<br>• In the event of interference problems, expert assistance (e.g., from a vendor or consultant) is likely to be required to resolve problems, if at all possible |
| Accuracy | • Bit error rates are greater than fiber or copper, in general, so equipment selected must include air-link level error detection and correction.<br>• Digital communication protocols coupled with proper choice of higher-level protocols will transfer data from the field accurately |
| Completeness | • Equipment selected must include air-link (PHY) level error detection and correction. Higher-level protocols would overcome the problem, but the preferred protocols are inefficient on error-prone connections. |
| Real-time | • Transmission speeds are generally appropriate for the |

| | Wireless Communications Links - Radio |
|---|---|
| | requirements<br>o Long distance communications are needed from the field to a central data collection point, but field devices are likely to have very low data rates and possibly quite infrequent transmissions<br>o "Last-mile" solutions are available running at 54 Mbps for medium range networks – e.g., for connectivity to/between facility sites within a metro area.<br>o Local wireless technologies support data rates into the 100 MHz+ range, so are generally more than adequate for in-building, inter-building, and "last mile" applications<br>o A cell-based system (e.g., using a data service from a mobile wireless carrier) could be useless during an emergency when the network overloads due to a sudden increase in the number of subscribers trying to use their cellular service |
| Security | • Wireless is inherently less secure than any other medium due to the relative ease of monitoring transmissions, interfering with or jamming transmissions, or inserting transmissions into the network<br>• Critical that wireless transmissions be encrypted to reduce risk of transmissions being intercepted and understood, or unwanted transmissions being injected into the network<br>• Some equipment will provide encryption of the data moving over the air-link; even in this case, data should be encrypted before transmission over the air-link<br>• Critical that network management systems monitor the equipment constantly to detect interference or jamming |
| Reliability | • Highly reliable except for physical damage to the equipment or jamming<br>• More likely to be affected by electrical or magnetic interference, and conditions like rain, cloud, fog, and sandstorms.<br>• Less likely to be affected by natural disasters or physical human or animal interference provided power is maintained (e.g. from a local UPS) |

**Table 8 - Wireless Communications Links - Microwave**

| | Wireless Communications Links - Microwave |
|---|---|
| **Geography** | • Useful for remote sites where it is expensive or impractical to provide terrestrial links<br>• Transmission ranges almost any distance can be achieved by through a combination of antenna placement, equipment power, repeaters and terrestrial backhaul<br>• Line-of-sight technology |
| **Scalability** | • High data rates easily achieved |

| | Wireless Communications Links - Microwave |
|---|---|
| | • Easily expanded by adding more transmitters and repeaters if needed.<br>• Multichannel devices reduce the amount of extra equipment needed<br>• Useful for high-speed "last-mile" applications – e.g., between building in a facility, or from a facility to carrier's CO, or to connect sites in a metro area<br>• Some technologies require line-of-sight, which can limit range and usefulness |
| Maintainability | • Easy to maintain if interference not present since no physical connections – maintenance is limited to transmission equipment<br>• If electric or wireless interference is prevalent, may cause consistent and unresolvable maintenance problems |
| Cost effectiveness | • Highly cost effective since no physical media need be provided<br>• Nevertheless, may prove more costly than anticipated if towers must be constructed to carry the antennas<br>• If "license exempt" devices are used, no charge for spectrum<br>• Many vendors supply devices to convert the electronic signals from a device port (typically RS-232C, RS-485) to radio signals |
| Regulatory compliance | • Equipment must meet FCC spectrum usage regulations<br>• Frequency coordination is required by the FCC and begins when the system design is complete. An interference analysis is performed to determine frequencies that will not cause harmful interference to other existing and proposed microwave paths and earth stations in a particular band. Frequency coordination requirements differ based upon the FCC rule section under which your service falls.<br>o Part 101 Services - Operation Fixed Services (OFS), Common Carrier (CC)<br>o Part 74 Services - Broadcast Auxiliary Service (BAS)<br>o After frequencies are selected, a Prior Coordination Notice (PCN), including a path data sheet, must be sent to all existing microwave users in the area to notify them of the proposed path. The FCC rules state that existing users have 30 days to object to the proposal. Once the 30-day period expires and any objections are resolved, a supplemental showing must be included with your FCC license application. [22] |
| Staffing needs | • Simpler equipment is likely to be easy to install and require no special skills<br>• In the event of interference problems, expert assistance (e.g., from a vendor or consultant) is likely to be required to resolve problems, if at all possible |

[22] Source: http://www.comsearch.com/microwave/design6.jsp

| | Wireless Communications Links - Microwave |
|---|---|
| Accuracy | • Bit error rates are greater than fiber or copper, in general, so equipment selected must include air-link level error detection and correction<br>• Digital communication protocols coupled with proper choice of higher-level protocols will transfer data from the field accurately |
| Completeness | • Equipment selected must include air-link level error detection and correction to ensure that transmissions are complete. Higher-level protocols would overcome the problem, but the preferred protocols are inefficient on error-prone connections. |
| Real-time | • Transmission speeds are generally appropriate for the requirements<br>o Long distance communications are needed from the field to a central data collection point, but field devices are likely to have very low data rates and possibly quite infrequent transmissions<br>o "Last-mile" solutions are available running at 54 Mbps for medium range networks – e.g., for connectivity to/between facility sites within a metro area.<br>o Local wireless technologies support data rates into the 100 MHz+ range, so are generally more than adequate for in-building, inter-building, and "last mile" applications |
| Security | • As mentioned in Table 7, wireless is inherently less secure than any other medium due to the ease of monitoring transmissions and interfering with transmissions. However, microwave transmissions are line-of-sight, relatively narrow beam, and so are more difficult to intercept and interfere with than basic radio<br>• Wireless transmissions should be encrypted to reduce risk of transmissions being intercepted and understood; for best security, data should be encrypted before transmission over the air-link<br>• Critical that network management systems monitor the equipment constantly to detect interference or jamming |
| Reliability | • Highly reliable except for physical damage to the equipment or jamming<br>• More likely to be affected by electrical or magnetic interference, and conditions like rain, cloud, fog, and sandstorms.<br>• Less likely to be affected by natural disasters or physical human or animal interference provided power is maintained (e.g. from a local UPS) |

Table 9 Wireless Communication Links - Satellite

| | Wireless Communications Links - Satellite |
|---|---|
| **Geography** | • Useful for very remote, dispersed sites where it is expensive or impractical to provide terrestrial links and other radio technologies do not provide adequate range – e.g., where |

| | Wireless Communications Links - Satellite |
|---|---|
| | terrain does not permit line-of-sight communication with the CMACC without building many towers to hold repeaters<br>• Transmission ranges almost any distance can be achieved |
| Scalability | • High data rates easily achieved with technologies like VSAT (Very Small Aperture Terminal), which is the most commonly used satellite technology<br>• Easily expanded by adding more satellite antennas<br>• Does require line-of-sight to the satellite, which can limit usefulness occasionally<br>• A variety of protocols and network configurations are available, and vendors should be asked to demonstrate which is best for your needs:<br>• VSAT Technologies<br>o SCPC (Single Channel Per Carrier)<br>o ACT Clarent SkyperformerMESH SCPC<br>o TDMA (Time Division Multiple Access)<br>o DAMA (Demand Assign Multiple Access)<br>• Topologies<br>o Star Network<br>o Hybrid<br>o Full Mesh Any-to-Any |
| Maintainability | • Easy to maintain since there are no physical connections – maintenance is limited to transmission equipment<br>• The network is generally monitored and managed by the VSAT service provided. The network management system must account for the special characteristics of satellite technology[23], but this is essentially hidden from the service-provider's customer |
| Cost effectiveness | • Highly cost effective when large distances must be covered to connect many devices since no physical medium needs be provided<br>• Nevertheless, may prove more costly than anticipated if the space segment (satellite and transmission charges) are excessively costly<br>• Vendors supply devices to connect the electronic signals from a device port (typically RS-232C, RS-485, Ethernet) to the antenna<br>• Given the broadband capabilities of the technology, it is possible to use the terminals for additional communications purposes – e.g., voice communications in the field at a very remote site. This could be very cost effective if regular radio communications are not possible due to terrain or distance. |
| Regulatory compliance | • Equipment must meet FCC spectrum usage regulations for satellite communications, but this is designed in by any |

[23] Network Management Considerations for VSAT Technology; Guy Adams, Head of Operations Parallel Ltd.; www.parallel.ltd.uk/documents/network_management_considerations_for_vsat_whitepaper.pdf

| | Wireless Communications Links - Satellite |
|---|---|
| | reputable vendor<br>• Generally, these systems operate in the Ku-band and C-band frequencies[24].<br>o Ku-band based networks are used primarily in Europe and North America and utilize the smaller sizes of VSAT antennas.<br>o C-band systems, used extensively in Asia, Africa and Latin America, require larger antenna. |
| Staffing needs | • The antennas are simple to install and require no special skills to align and connect to the monitoring devices<br>• In the event of interference problems, expert assistance (e.g., from a vendor or consultant) is likely to be required to resolve problems, if at all possible |
| Accuracy | • Digital communication protocols coupled with proper choice of higher-level protocols will transfer data from the field accurately |
| Completeness | • Bit error rates are greater than fiber or copper, in general, so equipment selected must include space-link error detection and correction. Higher-level protocols would overcome the problem, but the preferred protocols are inefficient on error-prone and high-latency/long-delay connections.<br>• At least one vendor suggests that guaranteed availability exceeding 99.95% with a BER better than 10 e-8 performance is available[25]<br>• Since this is inherently a bi-directional point-to-multipoint technology, and the satellite (or transponder) is possibly shared between several users, there is slight potential for transmission loss or delay if the network is overloaded<br>• Rain-fade can be a problem for Ku band systems and should be considered if the terminal is placed in an area with regular and heavy rainfall<br>• Occasional outages can occur for brief periods of time when the satellite used for the network eclipses the sun. By one estimate, this generally occurs for about 10 minutes, once a year[26] |
| Real-time | • Transmission speeds are generally appropriate for the requirements. For example, one vendor offers 8 Mbps outbound, and 153 kbps inbound – more than enough for monitoring applications<br>o Long distance communications are needed from the field to a central data collection point, but field devices are |

[24] http://www.qpcomm.com/vsat_info.html

25 VSAT technology - TDMA and DAMA technologies to provide solutions for your IP connectivity!; http://www.mainsat.com/vsat.html

[26] Real Time GPS Data Transmission Using VSAT Technology; Michael E. Jackson, Chuck Meertens, Oivind Ruud, Spencer Reeder, Warren Gallaher, University NAVSTAR Consortium (UNAVCO), and Chris Rocken, GPS Science & Technology (GST) Program, University Corporation for Atmospheric Research (UCAR) Office of Programs; http://www.unavco.org/facility/science_tech/dev_test/communications/vsat.html

| | Wireless Communications Links - Satellite |
|---|---|
| | likely to have very low data rates and possibly quite infrequent transmissions<br>o Since this is inherently a bi-directional point-to-multipoint technology, and the satellite (or transponder) is possibly shared between several users, there is slight potential for short transmission delays in very large networks |
| Security | • It is difficult to interfere with satellite communications, for obvious reasons. With a great deal of effort, transmissions from the space segment to ground could be intercepted, but it would be difficult to inject transmissions into the antenna, or jam the transmissions from space. Transmissions from the ground-based antenna to the satellite are even more difficult to intercept and interfere with than basic radio.<br>• On the other hand, since data will be transferred from a satellite ground station to the utility over other communications media (e.g., the Internet, PSTN, fixed copper lines, etc.), for best security data should be encrypted before transmission over the space-link<br>• Critical that network management systems monitor the connection to the ground station, and receive input about the satellite network's health constantly to detect interference, jamming, or network failures |
| Reliability | • Highly reliable except for physical damage to the equipment<br>• One vendor[27] claims that typical hub availability figures usually range above 99.9985% on a year-over-year basis<br>• More likely to be affected by rain<br>• Less likely to be affected by natural disasters or physical human or animal interference provided power is maintained to the terminals (e.g. from a local UPS) and the ground station |

[27] Spacenet; http://www.spacenet.com/about/media/topten.html

**Table 10 Wireless Communication Links – Photonic (Free-Space Optics - FSO)**

| | Wireless Communications Links - Photonic/FSO |
|---|---|
| **Geography** | • Useful for short range (1 – 4 km) high speed (100Mbps or more) line-of-sight communications |
| **Scalability** | • Easily scaled by adding more transmitters and receivers<br>• Similar to microwave in many ways, with higher speed and shorter range |
| **Maintainability** | • Easy to maintain since there are no physical connections – maintenance is limited to transmission equipment<br>• Some types can be installed behind a window, so are even less likely to encounter environmental hazards or degradation |
| **Cost effectiveness** | • Highly cost effective in metro areas since no physical medium needs be provided<br>• Vendors supply devices to connect the electronic signals from a device port (typically RS-232C, RS-485, Ethernet) to the antenna<br>• Given the broadband capabilities of the technology, it is possible to use the terminals for additional communication purposes – e.g., voice communications between sites |
| **Regulatory compliance** | • Uses unlicensed spectrum |
| **Staffing needs** | • The antennas are simple to install and require no special skills to align and connect to the monitoring devices<br>• Unlike radio, there is no possibility of electromagnetic interference so less technical skill is required |
| **Accuracy** | • Bit error rates are slightly greater than fiber, but may be better than copper, so unlikely to introduce data artifacts even at the link level.<br>• Digital communication protocols coupled with proper choice of higher-level protocols will transfer data from the field accurately |
| **Completeness** | • Can be interrupted by fog, but relatively insensitive to other weather conditions – rain and snow have little effect on transmissions[28] |
| Real-time | • Transmission speeds generally much greater than required - >100Mbps is common |
| Security | • It is difficult to interfere with FSO transmissions as they are very narrow beam, and user laser light<br>• Could be interrupted by simple physical means to block the light beam |
| Reliability | • Highly reliable except for physical damage to the equipment<br>• Unlikely to be affected by natural disasters or physical human or animal interference provided power is maintained to the terminals (e.g. from a local UPS) and they are not physically disturbed –e.g. by earthquakes that knock the equipment out of alignment |

[28] **What is Free Space Optics (FSO)?** FSO Technology Insight; http://www.freespaceoptics.org/

## Communication protocols

The most widely used set of protocols is the TCP/IP protocol stack. This is the same set of protocols used for the Internet. By selecting this protocol stack, the network designer will have immediate access to the broadest range of communications equipment. In addition, equipment from different manufacturers will very probably inter-operate properly since the protocol stack is so widely used and well understood by equipment manufacturers.

In addition to its use in the contamination network, using the TCP/IP protocol stack will make connections from the WA- CMDTN to the Internet, CMACC, and the WA-IDN transparent and simple.

The designer should note that the TCP/IP stack does not relate to the two lowest layers of the network – the Physical and Media Access (PHY and MAC) layer, and the Data Link Layer (DLL) or Logical Link Control (LLC)layer. These layers use either proprietary or standard protocols suitable for the reliable transport of data over point-to-point links, with higher layers in the TCP/IP stack taking care of the network layer and above.

The commonly used standard protocols in these layers are described by the IEEE 802.xx set of standards. Recently, the 802.11x standards have achieved widespread recognition due to their use in wireless communications, but this is only one protocol subset – another is the various Ethernet protocols[29]. The older X.25/X.21 protocol, a packet switching protocol, was once widely used, but has been largely superseded by the 802.xx and TCP/IP protocols and should not be used for a new installation.

The monitoring equipment device may not present its data in any of these standard forms. Typically, equipment of this type will use an RS-232C, RS-485[30] or RS-449 (RS-422/RS-423) physical and electrical interface[31] to connect to the outside world. Even though RS-232C is a very old standard, and limited to about 50 feet, it is still very widely used despite the improved characteristics of other interfaces. Some key tradeoffs for these standards are shown below:

**Table 11 – Key Characteristics for Common Equipment Interfaces[32]**

| | RS232 | RS423 | RS422 | RS485 |
|---|---|---|---|---|
| **Total Number of Drivers and Receivers on One Line (One driver active** | 1 DRIVER<br>1 RECVR | 1 DRIVER<br>10 RECVR | 1 DRIVER<br>10 RECVRs | 32 DRIVERs<br>32 RECVRs |

[29] The term Ethernet refers to the family of local-area network (LAN) products covered by the IEEE 802.3 standard. Four data rates are currently (2004) defined for operation over optical fiber and twisted-pair cables:

- 10 Mbps—10Base-T Ethernet
- 100 Mbps—Fast Ethernet
- 1000 Mbps and 10,000Mbps—Gigabit Ethernet

[30] "RS485 meets the requirements for a truly multi-point communications network, and the standard specifies up to 32 drivers and 32 receivers on a single (2-wire) bus. With the introduction of "automatic" repeaters and high-impedance drivers / receivers this "limitation" can be extended to hundreds (or even thousands) of nodes on a network. RS485 extends the common mode range for both drivers and receivers in the "tri-state" mode and with power off."; QUICK REFERENCE FOR RS485, RS422, RS232 AND RS423; http://www.rs485.com/rs485spec.html

[31] See QUICK REFERENCE FOR RS485, RS422, RS232 AND RS423; http://www.rs485.com/rs485spec.html for full descriptions

[32] Ibid

| | | | | |
|---|---|---|---|---|
| **at a time for RS485 networks)** | | | | |
| **Maximum Cable Length** | 50 FT. | 4000 FT. | 4000 FT. | 4000 FT. |
| **Maximum Data Rate (40ft. - 4000ft. for RS422/RS485)** | 20kb/s | 100kb/s | 10Mb/s-100Kb/s | 10Mb/s-100Kb/s |

When using these interfaces, a Network Interface Device (NID) of some type will be needed to convert the data leaving (or entering) the monitoring or encryption equipment to (or from) a standard protocol for transmission over the network (see Figure 7 and 0 below).

In general, at this communication layer in the network, the standard protocol of choice is the 802.11xx protocol family (including the Ethernet variants[33]), though more sophisticated NIDs such as routers will translate the data stream all the way to the TCP/IP layers . Older equipment using the RS-232C or the RS-484/RS449 interfaces may present data in the X.25 format. In general, this will need to be translated to one of the more modern standards to be useful.

If the monitoring equipment uses an Ethernet connection for its input and output functions, it will generally be simpler to connect the equipment to the WA-CMDTN. The equipment will need a built-in Ethernet adaptor to provide this capability.

The most modern equipment may use the Firewire or USB standards developed for communications between personal computers and peripheral equipment as the physical and electrical input/output connection. These interface standards will permit interconnection of equipment, but the remote NID will have to translate the data stream to the 802.xx or TCP/IP protocol to be useful in the CMACC.

The diagram below shows, in simplified form, the relationship between the various protocol elements and the equipment used to connect the remote devices to the CMACC:

[33] Using one of the Ethernet (802.3) family protocols has many advantages. A wide range of equipment manufactured by many vendors is available, technical staff are familiar with Ethernet, cost is low due to the wide acceptance and use of the standard, and copper or fiber connection variants are available. The use of a fiber variant reduces problems of interference in remote locations (e.g., interference from lightning), and distance can be essentially unlimited for some of the newer variants, which is useful if a transmitter/receiver device must be located relatively far from the NID or monitoring device.

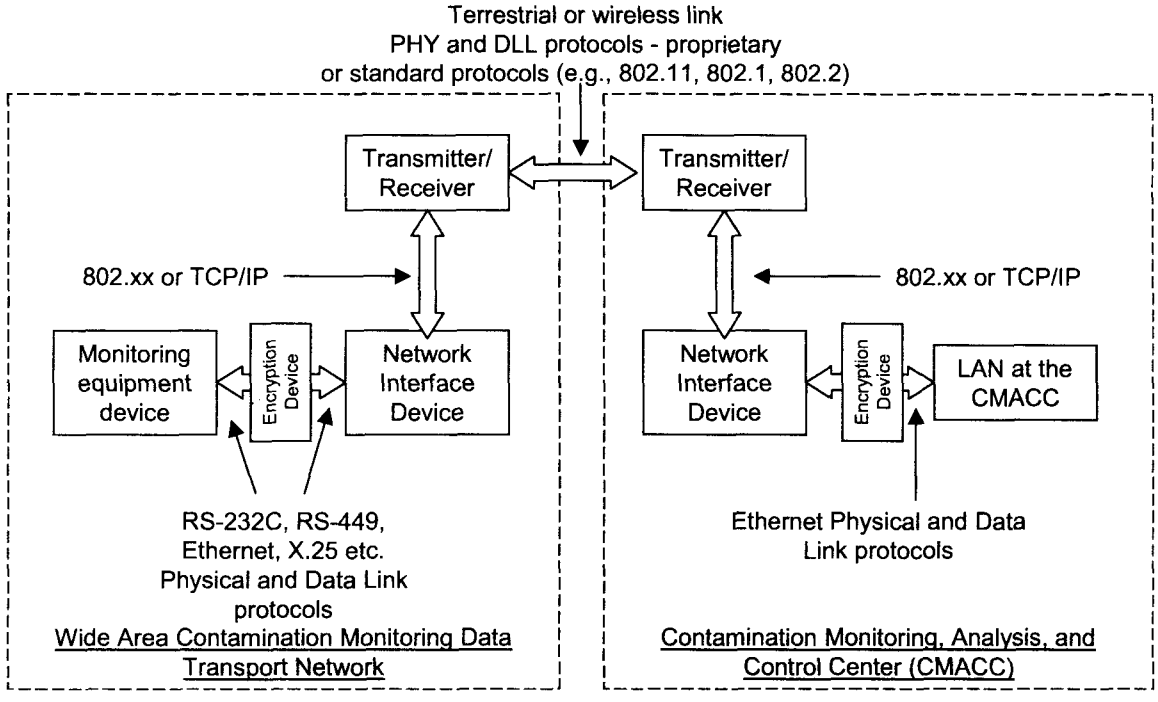



**Figure 7- Simplified view of the Physical and Data Link Layer network protocols**

The Network Interface Devices (NIDs) may be as simple as modems, or as complex as Internet routers or switches. The NIDs may be built in to the monitoring equipment devices or the transmitter/receivers. If not, the network designer will have to supply NIDs in addition to the monitoring equipment. The considerations regarding their selection and use are described in 0 below. The NIDs or the monitoring equipment may include an encryption device, though the latter is unlikely at this time. The encryption device may include the NID function.

It is also possible that the remote transmitter/receiver device can connect directly to an RS-232C interface, for example, thus eliminating the need for a discrete NID or NID function. The transmitter/receiver may not provide a standard output at the CMACC if it does not incorporate a standards-based a NID function. In that case, the NID at the CMACC will have to provide the ability to convert whatever protocol is presented to it at the CMACC end of the transmitter/receiver communication link to the TCP/IP protocol so that the data can be moved onto the CMACC LAN.

These lower level protocols are transparent to the designer, but even at these levels, the use of standard protocols where possible will offer the designer a greater choice of equipment and improved inter-operability between communication devices manufactured by different vendors.

Modems and fiber optic NIDs typically include transmitter/receiver elements that use well-established standards to ensure inter-operability and standardized performance characteristics between different manufacturers even at the lowest protocol levels. Use of standards-based transmitter/receiver equipment is highly recommended.

In many other cases (e.g., microwave, satellite, or photonic systems) the protocols used for communications at the physical level between the transmitters and receivers will be proprietary

to the manufacturer (since both ends of the link are supplied by the manufacturer), and will be translated to a standard protocol at the input and outputs that connect to the NIDs.

In many cases, the NID function will be incorporated at the CMACC end of the transmitter/receiver equipment. The designer need only, therefore, ensure that the transmitter/receivers can connect easily to a standard NID type or a LAN connector. Of course, manufacturers will make claims regarding the reliability and performance of the physical link using their unique protocol, and the designer should evaluate these parameters from a specification sheet, or, better, a field trial.

A comprehensive set of brief descriptions of the most common protocols is found at http://www.cisco.com/en/US/tech/tk713/tech_protocol_families.html.

## Communication equipment

The choice of type transmitter/receiver equipment will be dictated by the transmission technology choices described in the detailed tables in 0. The selection of the equipment therefore involves selecting the desired type of transmission link (copper, fiber, PSTN, radio, microwave, satellite, photonic, etc.) that best meets the specific requirements of the network, and then evaluating and selecting the equipment and vendor that provides the best fit with the requirements.

This section focuses on the specific characteristics of the Network Interface Device, or NID shown in Figure 7. We introduced the concept of a generic Network Interface Device, or NID, to describe the element that connects the monitoring device to the transmitter/receiver, and thus to the links that connect the remote devices to the CMACC.

The remote NID may be physically located in any of four locations. It may be in the monitoring device itself and incorporate a transmitter receiver device (e.g., a modem or Ethernet chip), allowing direct connection to a copper connection (PSTN or dedicated link) or a fiber connection. The NID may be in the transmitter/receiver, connecting the input/output of the monitoring device to the transmitter/receiver physical interface. It may be a separate device – e.g., a modem in a modem rack, or a router that connects the device to the network. Additionally, if encryption devices are used, they may include the NID function. Some encryption devices include a communications element, such as a modem. Others are designed to sit between the data source and the NID. Encryption is discussed in 0.

Typical NIDs are:

- Modems that connect to the PSTN – either built into the monitoring device or as a card that can be added to the monitoring device, or as an externally mounted modem
- A router or packet switch that connects to the monitoring device via a 10 Mbps or 100 MBps Ethernet connection, and to the Internet via a dial-up connection or a broadband connection such as DSL
- A device built in to the transmitter receiver that presents the required interface to the remote monitoring equipment – e.g., an RS-232C interface – at the remote end, and a paired device at the CMACC end that presents the data in a physical and electrical form, using an acceptable protocol, at the CMACC end.

The choice of remote NID, therefore, depends on the interface characteristics of the monitoring or encryption device and transmitter/receiver at each node in the remote network and the type of NID available at the CMACC. The remote NID must be able to communicate with its opposite NID at the CMACC over the transmission link. The NID in the CMACC will pass the data stream to and from the CMACC LAN. As described above, the best choice is a remote NID that converts the data to one of the 802.11 standards (Ethernet or one of the wireless standards such as 802.11x) or even to the TCP/IP protocol. If that is not possible, the protocol conversion will be done at the CMACC.

The NIDs at the CMACC will often be a set of devices in a rack, such as a group of modems, or Ethernet routers. They will connect the incoming and outgoing data streams to the LAN at the CMACC, which we recommend be an IP based LAN.

In addition to the protocol and interface requirements, the NID has limitations on the distance at which it can be located from the monitoring and transmission devices (this is particularly the case when an RS-232C connection is used – the RS-449 and RS-485 interfaces are much less distance and speed limited). The designer must ensure that the NID is placed within the specified maximum distance from the equipment it must connect in order to ensure reliable connections. Of course, the transmission equipment will also be distance limited in most cases, either by the physical length of a terrestrial or air link, or line-of-sight considerations.

These considerations may appear trivial, but, for example, a piece of equipment that is required at the remote site may have been intended for use directly connected to a PC or LIMS (Laboratory Information Management System) in a laboratory, and its interface may not match the NID or transmitter/receiver at the remote site physically, electrically, or in terms of its protocol.

Therefore, in addition to the transmission technology alternatives described in the tables in 0 above, the designer should check the basic interface characteristics of the equipment to use in the WA-CMDTN. The pairs of interfaces must match up to ensure compatibility between monitoring equipment, NIDs, and transmitter/receivers (the same considerations apply to the CMACC). Table 12 lists the common interfaces that are used:

**Table 12 - Equipment Interface Characteristics to Check When Selecting Communications Equipment**

| |
|---|
| Physical interface:<br>• RS-232<br>• RS-449/RS-422-A, RS-423-A<br>• RS-485<br>• Ethernet (802.3 and variants)<br>• Firewire<br>• USB |
| Distance from other equipment permitted by the interface used |
| Required data rates vs. rates permitted by the selected interface if affected by distance from connected equipment |
| Interface protocol compatibility<br>• RS-232 |

| |
|---|
| • RS-449/RS-422-A, RS-423-A<br>• RS-485<br>• Ethernet (802.3 and variants)<br>• Firewire<br>• USB<br>• TCP/IP<br>• 802.xx<br>• X.25 |
| Wide Area Network distance and transmission characteristics<br>• PSTN, Frame relay, etc.<br>• Dedicated copper or fiber links<br>• Radio, microwave, satellite or photonic |

## Encryption Equipment in the WA-CMDTN

Encryption devices and/or software are available that will enhance the security of the wide area network. Encryption may be performed on dedicated links such as a private network link, or over the public networks, such as the PSTN (using dial-up connections), the Internet or frame relay networks. Encryption is especially important on wireless networks, particularly when those are implemented using the ubiquitous and easily intercepted 802.11x protocols. The U.S. federal government's Technical Support Working Group sponsored a Gas Technology Institute (GTI) encryption program for SCADA system communications[34].

The most widely used approach for terrestrial networks uses Virtual Private Network (VPN) technology, especially on IP networks (the Internet, for example). However, there are different varieties of VPN technology, and the designer must ensure that all devices using IP VPN technology use the same, compatible type of VPN technology[35]. The 802.11x networks have a variety of encryption methods, each with advantages and disadvantages.[36] Some vendors or network providers have created proprietary encryption methods.

The encryption may be done by a specialized device dedicated just to the encryption function, or in the software of, for example, a PC connected to the network. Most readers will be familiar with the 128-bit encryption method provided by their PC's browser, for example. Another common example is a router connected to the Internet that includes encryption capability. In any event, both ends of the link must be able to encrypt and decrypt the data streams. Since encryption involves the use of an encryption key, there is generally a device at the host end (the CMACC end, in the case of a Contamination Monitoring Network) that manages the keys. A full discussion of the methods of encryption is beyond the scope of this document.

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[34] See: Protecting SCADA Communications; GTI publication: http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=4reportspubs%5C4_8focus%5Cprotectingscadacommunications.xml and American Gas Association (AGA)/Gas Technology Institute (GTI) SCADA Encryption Web Site AGA Draft 12 - http://www.gtiservices.org/security/.

[35] A useful introduction to IP VPNs is: **Selecting a VPN solution? Think security first;** Linda Christie, M.A.; SearchNetworking, 18 Apr 2001; http://searchnetworking.techtarget.com/originalContent/0,289142,sid7_gci542380,00.html

[36] See: SELECTING AN APPROPRIATE EAP METHOD FOR YOUR WIRELESS LAN; *Jim Burns, Senior Software Engineer, Meetinghouse, Inc.* www.mtghouse.com/MDC_EAP_White_Paper.pdf for a comprehensive review of 802.11x encryption methods.

Once installed, encryption devices or software are transparent to the user, unless a fault occurs. For example, the equipment may become defective, or there may be a synchronization problem with the key management. Therefore, particularly when using specialized equipment dedicated to encryption, it is important to select equipment that has a network management capability, as with all other equipment in the network. This will allow remote fault diagnosis, and possibly allow the device to be restored to operational status without a visit to a remoter site. The encryption device's management system should make key management simple, as potentially dozens or hundreds of encryption devices must be managed.

Since the purpose of encryption is to secure the network, the management system that is used to manage the encryption devices should maintain a log of all activity that affects the encryption devices and the encrypted links. This will create a verifiable paper trail that may be required for policy reasons should any intrusions or malfunctions occur.

## Network management

The Network Management System (NMS) permits the network manager in the Network Operations Center (NOC) to ensure the reliable operation of the network. Typical functions that the NMS allows the network manager to perform and user interfaces that make the task of managing the network easier are listed below

**Table 13 – Network Management System Functions**

| NMS Functional Characteristics | NMS User Interface Functions |
|---|---|
| • View the status of the network elements<br>• Maintain network element address and configuration tables<br>• Manage security of the network<br>• Receive alerts in the event of a malfunction in a network element<br>• Identify the location of a failure or alarm<br>• Reconfigure the network by adjusting various control parameters in the network elements without physically swapping equipment<br>• Restore the network to operational status in the event of a failure<br>• Maintain statistics regarding the network's performance (traffic levels, faults, utilization, etc.)<br>• Maintain an inventory of network equipment by type, location, and other relevant operational parameters<br>• Manage and log network moves, adds, and changes | • Graphical depiction of the network at various levels of abstraction<br>• Real-time depiction of alarms on the network map<br>• The ability to zoom in on a network element using a few mouse clicks to get an immediate on-screen status report<br>• The ability to import or export information from or to other types of software – e.g., database or spreadsheet software |

In an ideal world, one network management system would be able to manage all the elements in a network. However, the equipment in a network typically comes from a variety of vendors, and

many vendors develop dedicated systems designed to manage their own equipment. We call such a dedicated system an Element Management System (EMS).

It is important that when equipment for the network is selected, to select vendors that can supply element management systems that allow their equipment to be managed efficiently from the NOC. In addition, if the network element system can interface with one of the widely used Network Management Systems, this provides the option to create a single, integrated NMS that will allow the network managers detailed, comprehensive, and uniform network management capabilities.

Most EMSs and NMSs today use the Simple Network Management Protocol (SNMP)[37],[38]. This protocol is a network management communication protocol that uses standard methods of communicating between the EMS and the equipment, and between its EMS and an EMS or NMS developed by another vendor. There are now three versions of SNMP. The latest version, SNMP v3, provides increased functionality, especially in the area of network security[39]. If the choice is available, equipment using SNMP v3 should be selected to permit implementation of improved network security.

Each network element that has been designed with the ability to be managed by an NMS that uses the SNMP protocol includes a (software) Management Information Base (MIB) that communicates with the NMS.

There are a large number of such MIBs since each vendor develops the MIBs needed for its own equipment. It is impossible for a vendor of Network Management Systems to include the capability to manage every type of network equipment that exists. However, widely used third-party NMSs such as OpenView (Hewlett Packard) support MIBs developed for much of the equipment developed by major vendors. When such an NMS is used to manage a network that includes equipment having a MIB or MIBs that it recognizes, it can replace or be used in conjunction with the equipment vendor's NMS.

It is not uncommon, therefore, to find several EMSs located side-by-side, running on separate workstations or PCs, in the NOC. This situation has several disadvantages:

- Physically can occupy a great deal of space
- Staff must be trained on more than one EMS
- Trouble shooting may require staff to view several EMS reports or screens simultaneously to determine which element is reporting a problem
- Managing inventory, moves, adds, and changes requires coordination of databases held in more than one system

The advantage of an EMS, it should be stated, that it equipment vendor designs the EMS to work with its equipment to provide the best view of that vendor's equipment. However, network

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[37] http://www.simpleweb.org/tutorials/slides-ppt.html provides a useful set of SNMP tutorials

[38] Another network management approach, developed by the ITU-T (the former CCITT), is the TMN – "Telecommunications Management Network" The concept of a TMN is defined by *Recommendation M.3010*. TMN has a strong relationship to the OSI protocol, developed as a global standards-based alternative to TCP/IP, but much less widely used, especially in the USA.

[39] **SNMP, SNMPv2, SNMPv3, and RMON 1 and 2, 3rd Edition**, author William Stallings, provides a full exposition of the topic

management means more than managing just the equipment (see Table 13). Therefore, a more powerful approach is desirable for multi-vendor networks.

To simplify the management problem in large, multi-vendor networks, a hierarchical approach to network management systems has been developed. Figure 8 shows the generic approach, though it is only in the very largest networks that one encounters the "Manager of Managers."

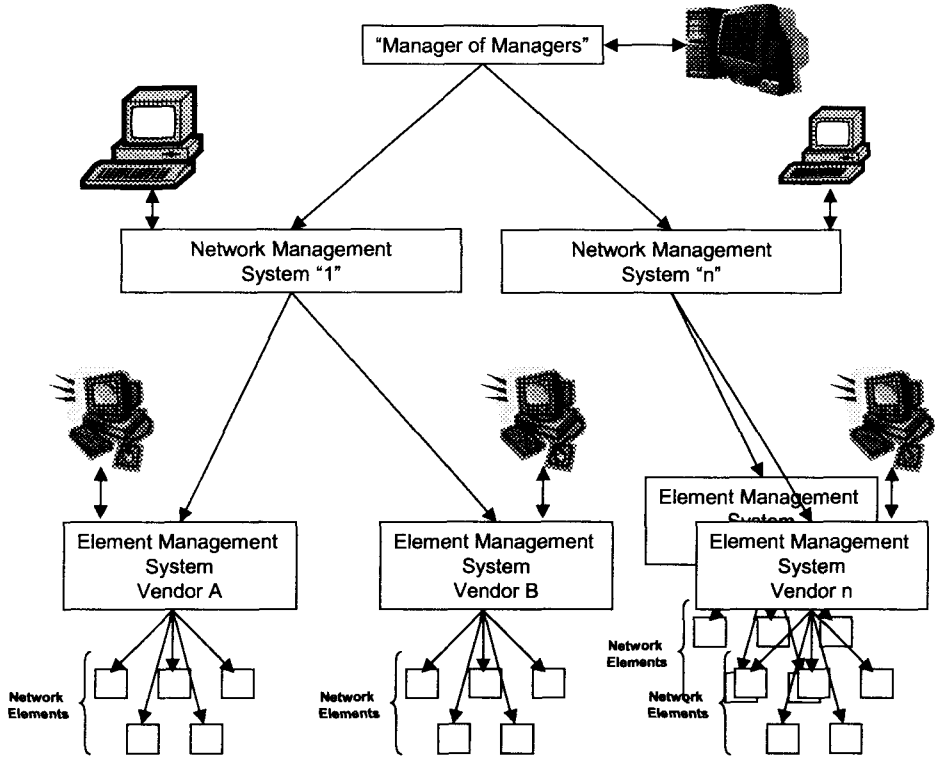


**Figure 8 – The Network Management Hierarchy**

It is unlikely that a powerful third-party NMS would be used to manage a network consisting entirely of equipment from a single vendor (assuming that equipment vendor supplies appropriate MIBs that the third-party NMS can recognize). A third-party NMS can add additional cost and require additional training. If the extra features such third-party systems typically offer provides valuable benefits that the vendor's EMS does not provide, it may be worth the extra investment. (See Table 13 – Network Management System Functions for examples of typical functionality).

## A brief guide to various wireless technologies and spectrum issues

The terms "wireless" and "radio" cover a vast number of proprietary, standard, and quasi-standards technologies, whose common denominator is they do not use a physical medium such as a copper wire or a fiber-optic cable to connect transmitters and receivers. The two terms are often used interchangeably.

The most commonly used systems for SCADA-type systems are radio and microwave. We touch on these briefly (see also Table 7 and Table 8 for greater detail). VSAT systems are used for very long distance communications (Table 9).

## Radio and licensed spectrum

By "radio," we mean systems that transmit (or receiver) signals that are not generally radiated in a specific direction (i.e., the transmitter emits signals through 360° ). This has advantages and disadvantages – for example:

- Advantage - transmission equipment does not have to be aligned, and in many cases does not even require line-of-sight
- Disadvantage – signals are easy to intercept or inject, and can be understood by a third-party unless encryption is used

Radio transmission may be used for voice, data, and video transmission. (See Table 7 for greater detail).

However, apart from the common attribute of not using a physical transmission medium, manufacturers have used many types of communication protocols to improve the quality, range, and reliability of radio communications. Therefore, interoperability between equipment from different manufacturers, even at the level of voice communications, is not assured.

A critical issue for the network designer who wishes to use a radio system is to ensure that the spectrum that the equipment uses is allocated and licensed for this purpose by the FCC. There are frequencies that have historically been allocated for use by fire and public safety communications systems. However, Nextel, the mobile wireless carrier, built its network by purchasing spectrum that uses or overlaps with these frequencies.[40] This causes interference with the public safety communications systems. If the network designer selects equipment subject to such interference, network performance can be impaired.

The FCC is constantly evaluating the use of different frequency bands, and, relevant to this topic, Nextel has offered to pay significant compensatory fees to purchase additional spectrum that would allow it to move off the affected frequencies. This matter has been under review for several years, and a resolution has yet to be reached[41]. If the FCC rules in favor of Nextel's proposal, and it passes unchallenged by other wireless companies, the interference problem should be reduced.

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[40] The public safety interference problem first surfaced in 1999 in Portland, Ore., and Phoenix. It occurred largely because Nextel, the nation's sixth-largest wireless provider, carries its phone calls on frequencies that interweave with those used by fire and public safety communications systems -- the result of its purchases of old radio frequencies at the time it formed its cellular network. Some public safety groups say an unofficial tally indicated between 750 and 1,000 emergency communications [networks] nationally have been blocked or subjected to interference. *Washington Post, April 8, 2004.*

[41] Verizon Wireless, Cingular Wireless and the Cellular Telecommunications & Internet Association vehemently opposed Nextel's plan, calling the spectrum exchange a "giveaway"; *Washington Post, April 8, 2004*

## Wireless and Unlicensed Spectrum

There are a number of frequency bands that can be used without requiring a license from the FCC. These are often used by vendors of the ubiquitous 802.11x systems. The advantages of using these unlicensed bands are:

- No license required – so cost is reduced
- Rollouts are quicker as there is no need to complete the licensing process
- The lower unlicensed frequencies (900 MHz) are not affected by rain
- An enormous variety of equipment is available at low cost – e.g., the 802.11x types

However, the obvious disadvantage is that, since the frequencies are open for use by anyone who chooses to do so, interference is a significant problem.

The FCC designated the ISM and UNII bands for unlicensed use by anyone using approved equipment. Traditionally, the lower bands like the 900 MHz and the 2.4 GHz have been used for wireless LANs. In 1997, the FCC opened up the UNII bands to provide businesses and educational organizations access to inexpensive wireless solutions. Because the amount of spectrum is limited, each band eventually fills up, forcing new users to higher bands[42].

| | |
|---|---|
| **Full Name:** | Industrial, Scientific, and Medical (ISM) Radio Bands; Unlicensed National Information Infrastructure (UNII) Band |
| **Frequency:** | ISM, 900MHz, 2.4 GHz, 5.8 GHz; UNII, 5.2GHz |
| **Distances:** | up to 50 km or 35 mile radius from base station |
| **Throughput:** | 128 Kbit/s to 10 Mbit/s over shared medium |

## Specialized Wireless Solutions – Microwave

Microwave systems are one of the most widely used methods of communicating voice, data, and video over long distance. The equipment manufacturers will ensure that their equipment is compliant with FCC regulations.

The systems produce focused radio beams, which have distance and power advantages. They are also more difficult to intercept or interfere with. A possible geographical limitation (e.g., in hilly areas) is that they are line of sight systems. See Table 8 for greater detail.

## Specialized Wireless Solutions – MMDS

***Multipoint Microwave Distribution System***, also known as ***Multi-channel Multi-point Distribution System*** and *wireless cable*, is a wireless broadband technology for Internet Access[43]. MMDS channels come in 6 MHz bands and run on frequencies between 2.5 GHz and

[42] Source: http://www.lightreading.com/document.asp?site=lightreading&doc_id=1207&page_number=5

[43] http://grouper.ieee.org/groups/802/16/

2.686 GHz licensed exclusively by the Federal Communications Commission. MMDS is a line-of-sight service with a range up to 70 miles. Therefore, it will not work well around mountains, but it could be useful in rural areas, where copper lines are not available.[44] It is a potential, if unusual, alternative to microwave for a utility network

The FCC divided the United States into BTA's (Basic Trading Areas) and auctioned the rights to transmit on the MMDS bands in each of those areas to MMDS service providers. The MMDS band plan is available from the FCC at http://wireless.fcc.gov/auctions/data/bandplans/mdsband.pdf. [45]

## Specialized Wireless Solutions – CDPD (Cellular Digital Packet Data)

CDPD (Cellular Digital Packet Data) is a specification for supporting wireless access to the Internet and other public packet-switched networks over cellular telephone networks. CDPD supports TCP/IP and Connectionless Network Protocol (CLNP). CDPD utilizes the RC4 stream cipher with 40 bit keys for encryption. CDPD is defined in the IS-732 standard[46].

CDPD modems are manufactured by several companies, and supported by a number of major wireless carriers. Data rates are up to 19.2 KB, which is often suitable for monitoring networks. Since the transmissions are carried over a network provided by a wireless communications provider, range is only limited by the extent of the carrier's network. It is likely that this technology will be supplanted by the newer data technologies provided by these carriers.

## Network Elements Selection Guidance in the Contamination Monitoring, Analysis, and Control Center (CMACC)

Most of the discussion of the WA-CMDTN applies also to the choice of network elements at the CMACC, with the obvious difference that the CMACC comprises Local Area Network (LAN) elements, rather than Wide Area Network (WAN) elements.

The network designer must take into account the policy requirements that are identified in the initial planning stages. Activities such as data logging, event logging and escalation, etc., will all be initiated by operators or automatically from the CMACC. The network equipment, including computer equipment such as servers, disks stores, voice, fax and data equipment for communication with decision makers and other external bodies must all be selected to provide the functionality that policy requires.

The network in the CMACC must meet the functional, management and operational objectives described in 0, Functional, Management and Operational Requirements in order to ensure that the network's integrity is preserved.

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[44] Source: http://www.webopedia.com/TERM/M/MMDS.html

[45] Source: http://www.hackfaq.org/wireless-networks/mmds-multichannel-multipoint-distribution-service.shtml

[46] Source: http://www.hackfaq.org/wireless-networks/cdpd-cellular-digital-packet-data.shtml

We briefly examine the technology solutions available for use in the CMACC sub-systems, and provide guidance regarding the options and tradeoffs that are available to the designer:

- Communication links
- Communication protocols
- Communication equipment
- Network management

## Communication links in the CMACC

There is a wide choice of LAN topologies and transmission media available. If the CMACC is physically in one location, typical media choices are copper or fiber media. 802.11x systems are increasingly being deployed, but they are inherently less secure, and should be used with caution.

Since Ethernet allowing transmission speeds of 100 Mbps is commonly available over CAT-5 cabling, this is most likely the technology of choice. It will allow sufficient bandwidth for most LANs used in a network-monitoring environment, where data rates are low, and the quantity of data to be transferred is relatively small.

Unlike the Wide Area Contamination Monitoring Data Network, the CMACC also must make provision for communication with decision makers, emergency teams, maintenance crews, remote laboratory equipment and technicians, etc. who are connected via the WA-IDN. These connections will include voice (telephone, cell phone, radio), data (dedicated connections, internet, dial-up, wireless, etc.), fax, pagers, etc. The connections must be provided so that all required communications links can be supported.

## Security in the CMACC communications links

It is important to note that the connections with the WA-IDN are the most susceptible to intrusion, especially the wireless connections and the Internet access points. Therefore, it is essential that the LAN and equipment connected to it be protected by a firewall. Tight security policies should be enforced in the CMACC and for all devices and users that connect to the CMACC LAN.

Even legitimate users can inadvertently cause damage via remote access (or when they connect a device such as a laptop to the CMACC LAN) – by releasing a virus received in an e-mail message, for example. These users may be connected to the CMACC or Network Operations Center (NOC) via a secured or private communications link, but they may also access the Internet, for example, for personal or research reasons. This opens their computer or PDA to viruses or to use by intruders.

It is essential that all the access points to the CMACC, WA-CMDTN and other facilities from the WA-IDN, the SCADA network, and internal users be protected. The tools that are used are:

- Firewalls
- Virus detection software on the remote computers and the central servers

- Virtual Private Network (VPN) encryption
- Discrete encryption devices at each end of the links
- Rigorous enforcement of password management and other security policies
- Policies to discourage or eliminate the introduction of viruses via removable media – floppy disks, the recently popular USB "keychain" memory devices, ZIP drives, CD-ROMs, etc.
- Policies to control physical access to the CMACC, NOC, communication links and equipment, and remote sites – e.g., by alarming enclosures with a microswitch that indicates when an enclosure is opened, or coded keypads or bio-detection devices to authenticate people's permission to enter a facility or enclosure.

## Communication protocols in the CMACC

The most widely used LAN protocol is the TCP/IP suite, and it is unlikely that there is any reason to select any other protocol. Older installations (e.g., when the CMACC is co-located with the SCADA control room) may use older or proprietary protocols. We recommend that the new network be designed from the ground up to be TCP/IP compliant, as this will enable the use of a far wider range of equipment.

There have been suggestions that the use of non-standard protocols in SCADA networks reduces the threat of intrusion and interference. This is true to some extent, but, since these networks are so widely used, there is a very large base of technically adept people who have in-depth understanding of these protocols. People with this knowledge could penetrate the networks since SCADA networks are increasing connected to the Internet indirectly via local and remote users in the equivalent of a CMACC or NOC. When such a legitimate user accesses the Internet for legitimate purposes while connected to a SCADA network, or has received a virus, they open the SCADA network to attack.

The wider availability of firewall and antivirus products for the TCP/IP world, in our opinion, outweighs the possibility of avoiding attack through reliance on non-standard protocols. Many of the articles listed on Page 342 provide excellent insight and guidance on this matter.

The CMACC must include NIDs (see Figure 7 and section 0) and encryption equipment that use the same data-link layer and encryption protocols as the equivalent devices at the remote monitoring site. These devices are connected to the LAN at the CMACC, and to the transmission equipment, so have the function of protocol conversion between the various physical and data link layer protocols that are present (though largely invisible to the user) on the network.

## Communication equipment in the CMACC

As mentioned above, the CMACC communicates with both the WA-CMDTN and the WA-IDN. It also contains equipment used to log data from the monitoring devices, possibly to process or analyze the data, and the equipment used to communicate the data and provide voice, fax, and pager communications with facilities and personnel outside the utility. Even if the CMACC does not occupy one physical location, it conceptually and logically provides these services.

Therefore, the CMACC includes[47]:

- Transmission equipment used to communicate over the WA-CMDTN and the WA-IDN
- NIDs to permit connections between the equipment in the WA-CMDTN and the WA-IDN to the CMACC LAN
- Encryption equipment to secure communications between the WA-CMDTN and the WA-IDN. If required, this may include encryption of voice and fax systems
- Computers, storage devices, printers, and other office and laboratory equipment used in the collection, storage, analysis and dissemination of the data from the remote monitoring devices that include communications capabilities. This may include entire sub-systems, such as a Laboratory Information management System (LIMS)
- Interfaces to the SCADA network to permit direct transmission of information from the Contamination Monitoring Network to the SCADA equipment (e.g., to permit automatic shutdown in the event of contamination), or to permit the use of all or part of an existing SCADA network to transport Contamination Monitoring Data
- Firewall and anti-virus software to secure the LAN from intruders

Clearly, there may be specialized devices that do not use the TCP/IP protocol to communicate, but are so critical to the monitoring function that they are necessary elements to be included in the equipment that the CMACC LAN communicates with. The designer will need to find an appropriate and specialized solution to incorporate these devices in the CMACC communications system.

In general, however, the designer can choose from many network elements such as routers, switches, modems, wireless devices, photonic devices, servers, storage systems and other computing equipment that have a standard TCP/IP interface built into them that will accept inputs from the analytic, logging, and other equipment in the CMACC. An EMS or NMS can easily monitor many of these kinds of network devices, and the availability of an EMS, NMS, or interface to these types of management system is an essential design criteria when selecting equipment.

Table 3 and Table 4 provide a guide to the functional, operational and management criteria that the designer should consider when selecting the CMACC communications equipment. The considerations of geography, scalability, maintainability, cost effectiveness, regulatory compliance, and staffing needs apply in the CMACC as elsewhere, as do the operational objectives of accuracy, completeness, real-time capabilities, security, and reliability.

## Network management

Generally, the Network Operations Center (NOC) will be located in or near the CMACC. The NMS or various EMSs will manage the LAN and attached equipment found in the CMACC, as they will the communications equipment in the WA-CMDTN and the WA-IDN. The functionality of the EMS and NMS is described in 0 and applies to the LAN in the CMACC as much as to the WA-CMDTN.

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[47] Figure 4- Contamination Monitoring Network Architecture

If encryption is used in the network, the key management function will be located in the NOC. It is important, as described in 0, that the encryption devices or software be easily managed from a central location. Therefore, the encryption management system should be selected for easy of use – for example, it should have a user interface that permits rapid identification of faults, intrusions, and permits logging of events that may be required for regulatory, policy, and maintenance purposes.

The NMS should be able to manage devices that are attached to the CMACC from the WA-IDN, even if intermittently. Examples are laptops used by staff telecommuting by dial-up or over the Internet, PDAs used by maintenance crews that communicate by wireless, dial-up, or Internet connection, equipment in remote laboratories that communicates by these means or over other public or private connections.

These devices should have to communicate through a firewall, and use a VPN to encrypt their communications wherever possible. Usage should be password enabled, and policies to enforce frequent changes and randomization of passwords should be enforced. The network manager should be notified when an employee terminates his or her employment so that their password and access rights can be canceled immediately when they end their employment.

## Network Elements Selection Guidance in the Wide Area Information Dissemination Network(s)

As before, much of the discussion of the WA-CMDTN and the CMACC applies to the Wide Area Information Dissemination Network(s) (WA-IDN). The obvious, and crucial difference, is that much of the communication activity will take place over networks operated by third-parties – for example, local, regional and long distance telecommunication utilities, wireless carriers, ISPs, etc. This increases the vulnerability of the communications to interdiction. It reduces in many cases both the need and the ability to monitor the networks, and moves much of the maintenance burden to the third party or third parties.

Even in the case of the WA-IDN, the network designer must take into account the policy requirements that are identified in the initial planning stages. Thus, the selection of communications methods and the operational requirements should be guided by the policy requirements. Examples would be providing connectivity to meet regulatory or alarm escalation communications.

Activities such as data logging, event logging and escalation will all be initiated by operators or automatically from the CMACC. Some of these activities will result in voice, data, fax, pager, or even video activity that moves over the WA-IDN, generally in response to a failure or suspicious activity on the network detected by the operators in the NOC.

Some activity may be routine – for example, backing up data logs to remote sites, or providing data to a remote laboratory or to a person working remotely (at home, in a remote laboratory, or in the field). Some of this activity will be initiated by the remote user – for example, initiating a communications connection via dial-up in order to download e-mail or data.

This information must reach its intended destination with the same degree of reliability, accuracy and security as in the other two major architectural sub-systems. Therefore, the WA-IDN must meet the functional, management and operational objectives described in 0, Functional, Management and Operational Requirements in order to ensure that the network's integrity is preserved.

We briefly examine the technology solutions available for use in the WA-IDN sub-systems, and provide guidance regarding the options and tradeoffs that are available to the designer:

- Communication links (and data security measures)
- Communication protocols
- Communication equipment
- Network management

## Communication links

We divide this topic into voice and fax, data and remote computing.

### Voice and fax communication links over the WA-IDN

Voice communications will generally be conducted by terrestrial telephony, wireless telephony, and radio ("walkie-talkie"). In some cases, voice will be available over other wireless links, such as microwave or VSAT, for communications with the field or between dispersed operations centers. The primary design issue facing the network designer is the choice of the most reliable and secure solution.

As with other network sub-systems, the best solution to ensure reliability and high availability is to use a redundant set of links. Thus, at least terrestrial and cell-phone communications connection should be available between the CMACC and the critical decision-makers (which may include scientists and emergency response units).

It is best if more than one carrier is used to ensure that redundant communication links are available. If at all possible, the communication links provided by the different carriers should follow different routes to reduce the chance of all communications being disrupted by, for example, a backhoe or maliciously. The choice of carrier should be influenced by their ability to provide route diversity. Communications cables should enter the communications center (the CMACC or NOC) at different points in the building.

In case of an emergency that affects a large number of people, terrestrial and wireless networks can collapse under a sudden spike in the number of users. Therefore, the use of emergency radio handsets can provide a voice communications channel even if the public networks are no longer operational. Unfortunately, not all emergency radio systems interoperate due to frequency or encoding differences. The designer should ensure that radio equipment is compatible with the equipment used in the emergency response services that operate in the area of the utility. Any licenses required must be obtained.

Fax equipment will generally use the terrestrial lines, and the same issues of redundancy should be considered for fax lines if there is a need to include fax capability as part of the emergency response activities (e.g., to create a paper trail, or send plans of facilities to emergency response teams). Faxes can be connected via modems to cell and radio equipment, if needed.

Since most voice and fax communications can be intercepted, scrambling equipment can be used to secure voice and fax communications.

## Selecting and securing data and remote computing communication links over the WA-IDN

The design criteria for selecting private data communication links (microwave, photonic, leased lines, etc.) used in the WA-IDN are not significantly different from those in the WA-CMDTN. The tables in 0, Network Elements Selection Guidance in the Wide Area Contamination Monitoring Transport Network, provide the relevant information.

It is in the use of the public networks for data communications (dial-up over the PSTN, the Internet, frame relay networks) that the primary security problem resides. These are ideal routes for hackers and intruders to gain access to the Contamination Monitoring Network. Such intruders, once inside the network, could disable devices, inject false data, and introduce viruses to disable computing equipment, erase data logs, or even issue false alarms.

If the Contamination Monitoring Network is connected to a SCADA network, both networks must be secured to the same degree in order to prevent vulnerabilities in one network affecting the other. For example, a successful intrusion to a Contamination Monitoring Network could allow the intruder to take over the control of the SCADA network. Alternatively, an intruder who gains access to the SCADA network could disable monitoring alarms on the Contamination Monitoring Network, allowing malicious activity in the SCADA system to go undetected.

To repeat the guidance provided in 0, even legitimate users can inadvertently cause damage via remote access (or when they connect a device such as a laptop to the CMACC LAN) – by releasing a virus received in an e-mail message for example. These users may be connected to the CMACC or NOC via a secured or private communications link, but they may also access the Internet, for example, for personal reasons. This opens their computer or PDA to viruses or use by intruders.

It is essential, therefore, that all the access points to the CMACC and other facilities from the WA-IDN be protected. The tools that are used are:

- Firewalls
- Virus detection software on the remote computers and the central servers
- Virtual Private Network (VPN) encryption
- Discrete encryption devices at each end of the links
- Rigorous enforcement of password management and other security policies
- Policies to discourage or eliminate the introduction of viruses via removable media – floppy disks, the recently popular USB "keychain" memory devices, ZIP drives, etc.

## Data communication protocols

The Physical and Data Link Layer protocols in use in the WA-IDN will be selected by the carriers who provide public networks, or the equipment vendors whose transmission equipment (modems, routers, frame relay, DSL modems, etc) are used. These protocols, and their selection when a choice is possible, are covered in detail in 0 and need not be repeated here.

At the higher level, the protocol of choice will almost always be TCP/IP. It is possible, but unlikely, that a specialized protocol may be needed for a specific piece of equipment, but this will generally be converted to TCP/IP by an appropriate NID and software combination.

The choice of TCP/IP also makes use of the Internet essentially transparent, since that is the protocol used on that network.

The significant drawback of TCP/IP derives from its advantage of being essentially ubiquitous. Since it is so widely used, hacking systems that use TCP/IP for communications is easy unless the links are protected by encryption, firewalls, and other security methods. Therefore, data communication over the WA-IDN should be conducted solely over VPN links, even for dial-up communications, with stringent password protection policies.

A variety of VPN solutions is available from different vendors, and these do not all interoperate. It is necessary, therefore, to standardize on a single vendor, and ensure that the vendor's solution can serve all the needs of the utility. Successful VPN management will also require a network management system, which must be added to any other EMS or NMS installations.

## Communication equipment

The communications equipment used over the WA-IDN will include voice, data, fax, pager, and radio equipment.

The voice equipment will include cell-phones. Since, as mentioned above, it is desirable to have more than one carrier for each type of service, the designer should be cognizant of the fact that equipment from different carriers may not operate on a competitor's network. Unlike the European model, several different cellular methods are in use in the USA. Connections between the different carriers are carried out through (terrestrial) switches. If one of those switches is rendered unusable, it may not be possible to communicate between users on different networks. Therefore, the most robust solution is for critical decision-makers to have one cell phone and one terrestrial phone, or one cell phone from each network provider. (Of course, if the carriers' networks are overwhelmed by a surge in traffic, the fallback, as suggested above, is to use emergency radios and pagers).

If increased voice security is desired, a number of connections can be set up to use voice (and fax) scramblers. This will require the appropriate scrambler/descrambler equipment at each end of the voice connection, and, in some cases, and encryption key management system supplied by the vendor.

Data equipment used will depend on the communication links used. Typically, this equipment will include modems, routers, multiplexers and frame-relay access devices (FRADs). If exceptional security is required, the network designer should consider the use of encryption equipment or software at the remote sites, interfaced with and managed by, similar equipment at the CMACC.

The use of radios and pagers can provide alternative communication links when the public networks are overwhelmed. As mentioned in 0, emergency radio systems do not all interoperate, and it is essential to identify the system in use in the region in which the utility is located so that communications with emergency services can be established. Any licenses required to operate radio equipment must be obtained.

## Network management

The NMS will be useful for managing remote sites or users, but will not, in general, provide information about the condition of the public networks that carry voice, fax, and data communications. (The utility's equipment on either side of the carrier "cloud" can be managed, but the condition of the "cloud" itself is generally not available to the network manager).

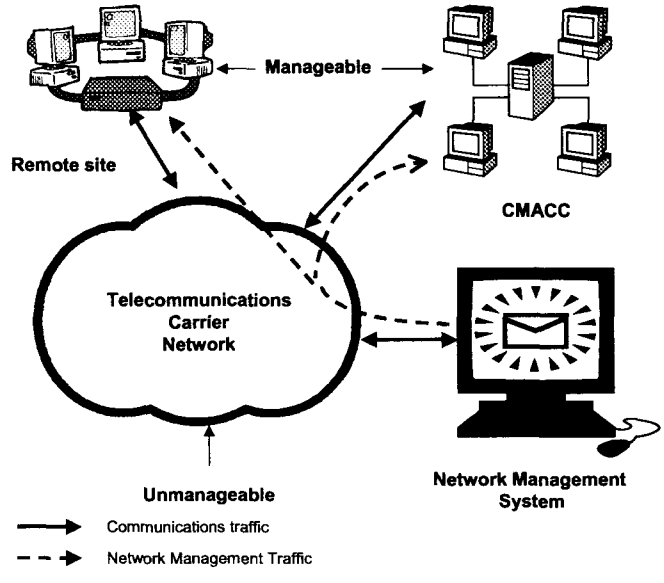


**Figure 9 - Network management over a public network**

This reduces the responsibility of the network manager, but can create a great deal of frustration when trying to identify a communication breakdown between the CMACC and a remote user.

The problem is less difficult when using a "private" network, but even a supposedly "private" network may, in fact, run over the public networks – e.g., a shared frame relay or ATM network, or communications links that connect through a central office switch. Unfortunately, these limitations are very difficult to overcome, and can best be dealt with in the framework of a service contract with the carriers. Some carriers can provide an NMS screen at the utility's site that is linked to the carrier's NMS or NOC. This will allow the utility to monitor, for a fee, the

status of its own links on the carrier's network, and more efficiently manage moves, adds, and changes that require intervention by the carrier,.

The most critical network management aspect, we believe, for the WA-IDN, is the management and enforcement of security policies. Users should only have access when authenticated, and authenticated users should be carefully managed and protected against viruses and misuse of their equipment by third-parties (e.g., gaining access to their equipment via the Internet). Thus, equipment purchased should include the ability to manage user authentication, authorization, password management, automated virus software updating, firewall protection, etc.

## Guidance Language

The designer of a contamination-monitoring network will pay attention both to process and technology aspects of the design.

The process is illustrated below. Note that, although presented in the earlier portions of this paper as a linear process, the diagram below indicates that the design steps are iterative, since the design decisions at one point in the network may influence design decisions in other areas of the network.

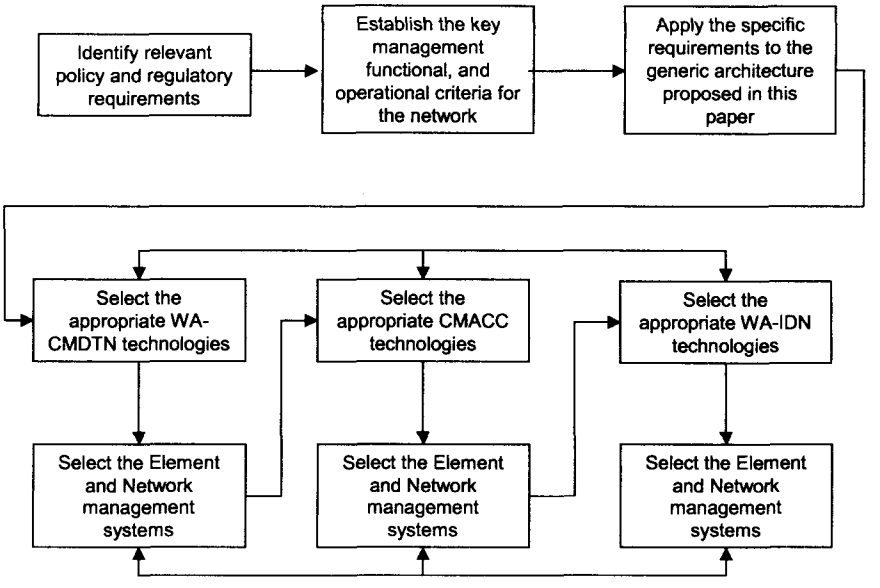


**Figure 10 - Network Design Process**

The early worksteps - identifying policy and regulatory requirements, establishing the proper functional, operational and management requirements - are the most critical. Correctly identifying these aspects of the design will improve the overall design, and reduce the need for any rework.

We have provided specific guidance in each area in the prior sections of this paper. It is worth recapitulating the key questions the designer should examine when starting the design effort:

- What are the overall objectives of the facility, or business, that this network will serve?

- What policies and regulations will affect the design and implementation?
- What are the key management, functional and operational objectives?
- What devices will be attached to the network?
- What information will be transported over the network?
- What are the physical characteristics of the network?
    - Where will the network elements be located?
    - What distances must be covered?
    - What terrain conditions must be accounted for?
    - How will the network equipment obtain power?
- What technologies are available to use in the network, and which are most appropriate for each part of the network?
- How will the network be managed?
- How will the network be secured?
- Who will need access to the network, and who will need to be contacted via the network?

We recapitulate the key points of this paper by providing brief guidance to each of these questions below.

## What are the overall objectives of the facility, or business, that this network will serve?

It is important to identify and interview all the constituencies that will be affected by this network. See Table 1- Relationship between the Communications Network and Other Guidance Topics and Table 2 –Sources the Network Designer Should Interview. They may include:

- Facility owners (or public officials) and managers
- Regulators
- Operational staff
- Research staff
- Scientists and remote laboratory directors who may be involved in analyzing the data emerging from the contamination-monitoring devices
- Emergency response teams

## What policies and regulations will affect the design and implementation?

The designer should acquaint him- or herself with the relevant policies and regulations that govern water utilities. These are likely to change frequently as the country becomes more proficient in establishing protection and monitoring methods for utilities. In addition, valuable guidance and insight is available from the other topic areas in this White Paper (see Table 1- Relationship between the Communications Network and Other Guidance Topics)

## What are the key management, functional and operational objectives?

A series of in-depth interviews with key decision-makers and operational staff should be used to identify these objectives, which can be translated into the technical, functional and operational requirements the designer should meet.

## What devices will be attached to the network?

This is one area in which the network designer has little control, and, in general, must accommodate him- or herself to the technical staff in charge of establishing the monitoring protocol. It is important for the network designer to understand the how each piece of monitoring equipment will connect to the network, what the electrical interface requirements are, what data rates the equipment will generate, and what protocols it can use.

The equipment that the contamination-monitoring staff selects may be available in more than one configuration. The network designer may, therefore, be able to influence the monitoring equipment selection criteria to include, for example, electronic interfaces that are simpler to work with or more standard.

## What information will be transported over the network?

The designer should work with the staff responsible for selecting the monitoring equipment to understand the volumes, frequency, and even the nature (ASCII, binary data) of the data that will be transported over the network. This may influence the choice of communications equipment, the capacity of network links, the selection of an NMS, connectivity choices to data-logging devices, etc.

## What are the physical characteristics of the network

In general, a contamination-monitoring network for a water utility will need to transport data from many remote, often relatively inaccessible, locations, over terrain that may be hilly. The network must work almost faultlessly in the most adverse weather conditions, and even (or especially) if natural disasters or attacks on the facility occur. Three principal questions will influence the selection of network elements, a topic covered in depth in 0, Technology Choices in the Contamination Monitoring Network

### Where will the network elements be located?

Some elements will be located quite close to the CMACC. Others may be located dozens or even hundreds of miles away - for example, at the intake point from a river. The first step, therefore, is to develop a map that indicates the location of each piece of monitoring equipment that must be connected to the network. One or more pieces of network equipment (including power supplies) will be required at each location.

In addition, the map should indicate any existing public or private connectivity solutions that already exist at each location. These solutions may be useful to the network designer.

This investigation should include all three architectural sub-systems (see Figure 4-Contamination Monitoring Network Architecture). This includes network elements connected via public networks - for example, in a remote laboratory, or at the home or office of a key decision-maker.

### What distances must be covered?

The choice of technology will be critically dependent on the distances that must be covered to transport the data from remote locations, or within a utility's campus. There is never one single

network technology that is ideal for all purposes. The designer can select from a wide range of technologies to best match performance and cost criteria.

### What terrain conditions must be accounted for?

Many utilities will require connectivity to contamination-monitoring equipment and decision makers that are located in remote and possibly difficult terrain. These requirements should be mapped, and the designer will then take them into account when selecting specific technologies to provide connectivity at each point in the network.

### How will the network equipment obtain power?

Communications equipment (and the monitoring equipment) usually requires well-regulated, constantly available electric power. Providing power at remote sites can be difficult and expensive. Although it may be possible to supply power from the electric grid, it may be necessary to consider alternative sources

Uninterruptible power supplies (UPS) charged from the grid can maintain operational status for a considerable period of time if power fails (major regional outages of more than 24 hours are not uncommon). Solar powered back-up systems, or UPS systems kept charged by solar-generated power are another alternative. Where the grid is inaccessible, solar powered systems attached to a UPS may be the best or even only solution, even for regular service.

If SCADA equipment exists at the same location, the same power source could be used, with two caveats. The power source must be able to serve the additional load, and, if power to the SCADA system or the contamination monitoring system is attacked in order to disable one or other of the networks, both will be affected.

## What technologies are available to use in the network, and which are most appropriate for each part of the network?

Once the policy, functional, operational and physical characteristics of the network are established, the designer can select the specific solutions for each section of the network. These choices are covered in depth in 0 above, Technology Choices in the Contamination Monitoring Network

## How will the network be managed?

The choice of a network management system (or element management system) is as important as the selection of the network equipment itself. The NMS will be the tool used by the operations staff to ensure that the network is performing as specified, and will act as a first line of defense against tampering with the network in order to permit the introduction of contaminants into the water without detection.

As shown in Figure 10 - Network Design Process, the availability and choice of a network management system, or multiple element management systems, must be made in conjunction with the selection of the network elements themselves.

## How will the network be secured?

There is a wide range of options, ranging from the basic firewall and virus protection approaches, to physical intrusion detection, bio-authentication, and data encryption.

The costs of the various approaches will vary widely, both in the cost of actual system components and licenses, and in terms of staff training and number of staff required to ensure full compliance. Each utility should evaluate its situation to determine a reasonable level of security. However, every network should be protected, at a minimum, by firewalls, virus detection software, and stringent password management policies. All remote access ports should be carefully identified and monitored. Since VPN software is readily available, every link over the WAS-IDN should be encrypted using a VPN solution and management system.

## Who will need access to the network, and who will need to be contacted via the network?

Establishing the potential list of users will be very useful when sizing and costing the network, and selecting among the communications alternatives. The list will include operations and maintenance staff, and, once again, staff at remote laboratories, decision-makers, and emergency response units.

In addition, the list of potential users will provide insight into the requirements for authenticating and permissioning physical and electronic access. The greater the number of users, the lore sophisticated, in general, the authentication and permissioning systems will need to be in order to manage access securely.

# Operations, Maintenance and Upgrades

Terry Engelhardt, Karl King, Katy Craig
Hach Homeland Security Technologies, Loveland Colorado

**April 30, 2004**

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# 1.0 Introduction

Continuous monitors for water distribution systems are needed for two reasons:

Improvement of system operation

Alarm if water quality is compromised as the result of an intentional contamination by a disgruntled employee or terrorist.

The issues surrounding monitors used for security are complex and serious, considering that loss of life on a large scale could happen if the system and/or the people running it fail. Failure can come from common reliability matters, lack of maintenance, as well as from deliberate evasion, subversion or destruction of security measures in place.

Therefore, system operations and maintenance must be considered and planned to ensure the highest possible system reliability and water quality.

Further, it should be assumed that security monitoring of drinking water will advance in technology and practice, and equipment will need to be upgraded over time to incorporate advances.

This paper addresses reliability, maintenance, and system upgrades in the light of security, and general water quality requirements.

# 2.0 Reliability Considerations

Distribution monitoring can provide two types of benefits.

The best possible outcome of installation of an extensive monitoring network for a water distribution system will be improved water quality in the distribution system. By some estimates, 85% or more of the assets of a water utility are invested in the distribution system. Increased monitoring and control of water quality in the distribution system is prudent to protect these assets as well as to improve water quality for the utility's customers

One must fervently hope attack of the distribution system by a subversive group or a disgruntled employee never occurs. The worst-case scenario, would be to prepare for this eventuality – attack on the distribution system to adversely affect water quality causing illness, loss of life and/or loss of public confidence in the safety of the water system.

If one assumes the common use of the equipment is for monitoring and improving water quality, then system reliability standards could be somewhat more relaxed. But it is prudent to assume the worst-case scenario.

Therefore, instruments selected for deployment in this application must have a proven track record of analytical performance, electronic and mechanical reliability, minimal maintenance (cleaning, repair, calibration) and ease of use by persons with minimal formal training in analytical measurements. Failure on one or more of these points will lead to limited system availability and performance, as well as loss of operator confidence.

## 2.1 Acceptable Up-time, Mean Time Off-Line

The monitoring system should be designed for minimal downtime for repair and routine maintenance – replacement of limited life components, replenishment of reagents and calibration. A target for average up-time should be at least 99.9%.

If a monitoring system is off-line for more than 10 minutes, substantial amounts of toxic materials could flow past a site without detection. Consider the consequences if the monitored site is one of the primary transmission mains in the distribution system. That implies a Mean Time Off-Line of not more than 10 minutes. This has significant implications for methods of notification, getting people to the site for repair/replacement, spare part availability and service modes. These new requirements are so different from previous maintenance norms that revolutionary thinking and planning will likely be needed to achieve success.

## 2.2 Scheduled Maintenance

Security monitors must not be allowed to run until they break – preventative maintenance procedures should be considered mandatory. Scheduled maintenance will be a fact of life for such systems, and the operations people must plan for this regardless of the size of the installation.

Such maintenance costs will not be trivial. To minimize these costs, the utility should select instruments that typically require not more than bi-weekly or, ideally, monthly maintenance. If the downtime for maintenance is 0.1% of the time, that translates to 40 minutes per month. Based on instrument selection, the down-time should be not more than 30 minutes. The implications of being off-line for that much time should imply re-thinking the maintenance procedures so that time off-line is minimized. Consideration should be given to hot-swapping components or systems, or having redundant systems so that no down-time is needed.

Consideration should be given to scheduling maintenance at random times rather than in a predictable pattern that might facilitate planning by attackers.

## 2.3 Service Agreements

One option to using in-house scheduled maintenance is to contract with an external service company. Only service companies with technicians trained by the manufacturer should be considered for contract services. This may be advantageous depending on the size and resources of the system, but introduces complications with security. Anyone coming into

contact with the system, whether utility employees or a contractor, should have a background check and perhaps a security clearance.

## 2.4 BITE (Built-In Test Equipment)

It would be useful if a monitor had BITE – Built In Test Equipment to enable on-line testing. BITE or diagnostic information is beneficial because it can decrease the time spent in troubleshooting a failed piece of equipment.

To the extent possible with current technology, instruments should have built-in self-diagnostics to assist maintenance personnel in identifying the probable cause of instrument malfunction. The manufacturer should be required to provide a comprehensive operations manual clearly describing and defining the meaning of the diagnostic codes, probable cause and suggested course of action for remedying an instrument malfunction.

Instruments with predictive diagnostics that can estimate time for service or remaining sensor life would be especially useful so that system downtime can be minimized, or scheduled at times of low use.

## 2.5 Communication Requirements

Data from distribution monitoring devices must be continuously transmitted to a central location that is monitored by operations staff 24 hours per day. Where ever possible instruments selected should be capable of both analog and digital communication. Digital communication should be employed whenever possible. Most modern instruments with digital communication capability will transmit analytical measurement values and also critical diagnostic information about performance of the instruments. Older analog systems provide very limited, if any, ability to communicate instrument diagnostic information.

Whatever hardware and software are selected, they should be designed to use commonly available hardware and software interfaces so that they are compatible with typical HMI (SCADA) systems. System manufacturers must be able to accommodate data transmission over one of the commonly used "BUS" methods (MODBUS, PROFIBUS, etc.).

The need for digital communication may dictate the need to upgrade communication systems to replace older style analog systems. The method of data transmission - radio, satellite systems, hardwired networks - will vary by utility and even at different locations within the same utility.

Whatever means is employed to continuously transmit data, the primary concern should be system reliability. The monitoring system should include local data logging to permit access, analysis and download of data onsite if necessary.

## 2.6 Manufacturer Support

The monitoring equipment manufacturer should be required to provide support for a monitoring device for an adequate length of time.

All instruments supplied for the system must be of current manufacturer's design. In the event that an instrument becomes obsolete, the manufacturer will warrant that repair parts to maintain proper function of the instrument will be available for a minimum of seven years after the date of obsolescence. If the instrument becomes unserviceable before the seven years, the manufacturer should be required to make available a replacement instrument of equal or better analytical and performance specifications. The discount amount, if any, of such replacement instruments should be stipulated at the time of purchase of the original system.

# 3.0 Maintenance Considerations

## 3.1 Supplies and limited life components

**Supplies needed**

An assessment of supply needs must be done to ensure that supplies and expendables are available on a timely basis. That may call for stocking some supplies at the measuring site. However, the utility should avoid stocking replacements for long-life components such as circuit boards, unless recommended by the manufacture, as manufacturers often upgrade designs of such components. Those items should be ordered as needed. It is prudent to stock a two-month supply of limited life components and reagents. As with long-life components, the utility should avoid stocking a large supply of limited life components and especially reagents. Stocking a large supply of reagents creates unnecessary warehousing costs and can lead to degradation and possibly contamination.

**Automatic stocking program**

The instrument supplier should be required to offer an automatic reagent replacement program. Such a program will ensure reagents are in stock when needed as well as to ensure the reagents are fresh. Such plans may simplify re-stocking of reagents and materials that are needed to keep the systems running.

**Disposal considerations**

If reagents or other supplies must be disposed of, plans for disposal services or treatment should be made in advance of the equipment being installed.

## 3.2 Spare Parts

**Short-term**

It is prudent for the utility to stock a two-month inventory of spare parts and limited life components (i.e. lamps, replacement electrode elements, analytical reagents) to effect repair of the instruments for normal maintenance and calibration procedures. . To accommodate more serious maintenance needs, the utility should maintain a service agreement with the instrument supplier to dispatch a factory service technician with all necessary repair parts within 48 hours. Such a service agreement should be considered for all monitoring sites considered 'mission critical.'

**Long-term**

Depending on the system design, it may be prudent to stock spares for items that have long procurement lead times.

For certain critical monitoring sites it may be prudent to install instrument in replicate or have a complete replacement monitoring system available.

A utility should consider mounting one or more monitoring systems in mobile platforms (e.g. a trailer) capable of being deployed on short notice to any location in the distribution system. Such platforms should be self-contained, including an on-board power supply.

## 3.3 Human factors

**Number of people needed**

At minimum, crews of at least two persons should be trained for system operation and maintenance. Having two crews will allow at least one crew to be on call 24/7/365. The total number of crews trained should be that number necessary to respond to all system maintenance needs within 2 hours in any part of the distribution system.

**Security issues**

Utility personnel assigned to operation and maintenance of the monitoring systems shall be senior employees of the utility with a proven track record of reliability. The need for additional security clearances should be addressed on a case-by-case basis based on how critical a particular monitoring location is to security considerations. A less stringent policy may be practical in low risk environments.

In areas where there are a number of significant political targets (government facilities for example) it may be prudent to conduct more extensive background checks of employees. It may also be prudent to require security clearances for manufacturers' service personnel.

The system hardware and software must be designed to anticipate attack. Such attack could be crude, seeking the physical destruction of the equipment. Any monitoring system should report, or be polled on a frequent basis to assure that it is still there and functioning.

Another method of system attack would be to tamper with connections of signals coming into and leaving a monitor. Benign signals could be supplied while a system attack was taking place. Monitoring system hardware and software should be designed

under the assumption that it will be attacked, and be able to recognize and report the condition. If data transmission is interrupted for any reason, the monitoring system should include local data logging to permit onsite access, download and analysis of data if necessary.

**Training**

The utility must train in anticipation that their system will be attacked, and an effective response must be planned and practiced. Operators will need to be trained on the monitoring equipment, and its emergency replacement, such as portable analytical instruments or grab sample programs.

Instrument manufacturers should be required to offer training assistance for operating and maintaining their equipment. In as much as practical, it is prudent to standardize on a single manufacturer's equipment to minimize training needs and to make supply and parts inventory as simple as possible.

**Operational issues**

Municipal water distribution systems have traditionally utilized very little continuous on-line monitoring devices. Monitoring, if any, has been with hand-held portable instruments, or samples have been gathered and transported to a laboratory. Persons conducting this testing may occasionally be water distribution technicians but more typically are water treatment plant or laboratory personnel who are familiar with the instrumentation and test techniques. Hence, few water distribution personnel are familiar with the instruments, proper analytical techniques, sampling techniques, or intricacies of the analytical methods used.

Considering the foregoing, instrumentation placed into the distribution system must be rugged, require little operator intervention and be reliable. They must also be easy to install, service and use since little if any experience in installation, maintenance or use of the instruments is present in the majority of distribution system crews. It is impractical in the long term to utilize laboratory or treatment plant personnel for a wide area distribution-monitoring network.

In the interests of security, personnel should follow procedures that will not compromise system operation or reporting.

During maintenance or repair procedures the maintenance personnel will notify a central control manager of the off-line status

of the system, and the system should be capable of providing automatic notification at the time it is taken off -line for maintenance

During maintenance, the system shall be so configured as to hold all digital and analog signal values that existed when the maintenance was initiated. Maintenance personnel must report to the central control manager when maintenance is complete and the system placed back in service. To assure the system is again communicating to the central control system, the maintenance personnel shall not leave the site until cleared to do so by the central control manager.

If a system will be off-line for any significant length of time, the maintenance staff should notify critical personnel of the system status and implement grab sampling at a frequency established by the utility that is prudent based on the current knowledge or suspected threats to the system and/or the area being monitored by the analytical instrumentation.

Most troubleshooting should be possible with common hand-held diagnostic tools and common hand-tools. When a specialized, proprietary instrument is available for diagnosing common problems, the utility personnel must be trained on its proper use and at least one such device must be owned by the utility.

## 3.4 Budgetary Factors

There are numerous factors to consider. They may be very different for utilities of different size and circumstance, so a number of factors should be considered to find those relevant to a particular site. A broad list of items to consider is given below.

- How many monitoring sites are appropriate in the distribution network? Consider high profile targets, such as federal buildings, as well as areas of greatest concern, such as schools, hospitals, and power utilities. Additionally, consider primary storage locations of water supply, such as tanks and reservoirs, and primary interconnections. It may be useful to think about monitoring in terms of blocks of population, or in square miles, depending upon the system.

- Will the most advanced technology be used at some or all sites?

- What is the lowest cost alternative for a monitoring site, while maintaining the level of surveillance necessary to provide the desired level of activity detection?

- It is prudent to consider the expected working life of the instrumentation, and to budget for replacement instruments and backup instruments accordingly.

- Replacement parts and consumable parts and reagents must be taken into consideration for budgeting purposed.

- Service and maintenance considerations must be included in budgeting. This may include personnel and related expenses, or service contracts.

- Updates to the system to maintain the desired level of surveillance capability should be included in budgeting considerations. Examples may include updated information on potential attack agents, or additional parameters that may be available in the future.

- Communication devices and upgrades to the devices must be considered. This could range from simple upgrades to establishing a major new communication system for the utility.

- Additional training in the event of personnel turn-over, and security/background checks of new personnel.

- In considering the cost of deploying the monitoring network, it would be prudent to consider the cost of doing nothing.
  - What will the cost be in loss of confidence in the utility?
  - What will be the public health cost?
  - What will the cost be in loss of commerce? Water quality concerns play a key role in commerce. When it was thought Sydney, Australia had a serious waterborne disease outbreak (later determined to be laboratory error) just prior to hosting the 2000 Olympics, moving the Olympics to an alternate site was considered.
  - And, in the worst-case scenario, what will be the cost in life lost?

# 4.0 System Upgrades

## 4.1 Hardware

It is understood that technological improvements to instrument design and analytical performance may become available. The manufacturer should be required to notify the utility of the availability of any such improvements. It may be prudent for the utility to enter into an agreement with the manufacturer in advance, so ~~that~~ when upgrades become available, they will be expeditiously implemented.

To the extent possible, new designs, when available shall be backward compatible with existing instrumentation including communications protocols and software interfaces.

## 4.2 Software

Just as with hardware, it is assumed that software will advance and that the system will benefit from software upgrades. If the software has information in the form of agent libraries, decontamination procedures, or treatment, such libraries could be upgraded much like computer anti-virus software.

If such software can be installed in the field, there must be security provisions within the system that will prevent the installation of a null set, or phony set of information.

Algorithms for data analysis should be extensible to accommodate the addition of information from new sensors added to the system.

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