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Executive Summary

Through the assessment of vulnerabilities to drinking water systems, water security experts have identified the distribution system as one of the most vulnerable components in a drinking water utility. This finding was further supported through additional studies and analyses. For example, a Government Accounting Office (GAO) survey of a panel of nationally recognized water security experts identified distribution systems as among the most vulnerable physical components of a drinking water utility due to the large number of access points, ease of access, and the inability to detect contamination in a timely manner due to the absence of integrated and reliable monitoring and surveillance systems (GAO-04-29). Strengthening of key relationships between water utilities and other federal agencies in terms of preparedness, detection, and response activities was another important issue highlighted by the GAO study, and was addressed to some extent through an inter-agency effort, directed by the Homeland Security Council (HSC) of the White House, to assess the threat of drinking water contamination. This effort resulted in a report prepared by the U.S. Environmental Protection Agency (EPA), for the HSC that identified a number of contaminants, which if introduced into a drinking water distribution system could produce consequences upwards of 10,000 fatalities (USEPA, 2004c). This same report concluded that in the absence of a contamination warning system (CWS), many of these contamination incidents would go undetected until weeks following the attack when the first cases of disease would begin to appear in the population, at which time it may be difficult or impossible to find even a trace of contamination in the drinking water distribution system.

Contamination of the drinking water distribution system – whether it is accidental or intentional – can have devastating consequences for public health, critical infrastructure, the economy, and the environment. Drinking water distribution systems may be accidentally contaminated through cross-connections with non-potable water, permeation of contaminated water through pipes in areas of the distribution system subject to low pressures, or chemical reactions or microbial growth within the distribution system pipes. Such unintentional events that result in degradation to distributed water quality may occur with some regularity. Furthermore, intentional contamination, or even the threat of contamination can have significant impacts. Drinking water utilities occasionally receive threats or indications of possible contamination. These contamination threat warnings can be a direct threat or an unusual observation or discovery that indicates the potential for contamination and initiates actions to investigate and potentially respond. However, these threat warnings are not standardized and are difficult to corroborate in the absence of an integrated monitoring and surveillance system and close coordination with response partners including, but not limited to public health, emergency responders, and law enforcement.

In recognition of the contamination threat and the importance of early detection, the Administration issued HSPD 9 – Defense of United States Agriculture and Food. This directive was for EPA and other Agencies, using existing authorities, to build upon and expand current monitoring programs, to:

- ‘develop robust, comprehensive, and fully coordinated surveillance and monitoring systems . . . for . . . water quality that provide early detection and awareness of disease, pest, or poisonous agents,” and
- ‘develop nationwide laboratory networks for . . . water quality that integrate existing Federal and State laboratory resources, are interconnected, and utilize standardized diagnostic protocols and procedures.’

By its authority under section 300i-3 of the Safe Drinking Water Act (42 USC section 1434) and to address the monitoring and surveillance requirements of HSPD 9, EPA intends for WS to build on existing Agency and utility efforts to enhance the ability to detect and respond to contamination threats and incidents through the use of a CWS.

What is a Contamination Warning System?

The key to an effective response to a water contamination threat is minimizing the time between indication of a contamination incident and implementation of effective response actions to minimize further consequences. Implementation of a robust CWS can achieve this objective by providing an earlier indication of a potential contamination incident than would be possible in the absence of a CWS; thus, the core component of the WS program is a CWS. A CWS is a proactive approach to managing threat warnings that uses advanced monitoring technologies/strategies and enhanced surveillance activities to collect, integrate, analyze, and communicate information to provide a timely warning of potential water contamination incidents and initiate response actions to minimize public health and economic impacts. Components of the WS-CWS that should be implemented and evaluated through a pilot demonstration project include the following:

- **Online water quality monitoring.** Online monitors for water quality parameters, such as chlorine residual, total organic carbon, pH, conductivity, turbidity, etc., should be used to establish expected levels for these parameters (a 'baseline'). Anomalous changes from the established water quality baseline should be used as an indicator of potential contamination in the WS-CWS.
- **Sampling and analysis.** Water samples should be collected at a predetermined frequency and analyzed to establish a baseline through the use of an 'unknowns' protocol. This 'unknowns' protocol would target specific, priority contaminants, but may also detect some non-target analytes if the analytical techniques used in the routine monitoring program are sufficiently robust and if the analysts are trained and encouraged to investigate tentatively identified contaminants. In addition, water samples should be collected in response to triggers from water quality monitors or other information streams to identify the potentially unknown contaminants in the sample.
- **Enhanced security monitoring.** Security breaches, witness accounts, and notifications by perpetrators, news media, or law enforcement should be monitored and documented through enhanced security practices. This component of the WS-CWS has the potential to detect a tampering event in progress, potentially preventing the introduction of a harmful contaminant into the drinking water.
- **Consumer complaint surveillance.** Consumer complaints regarding unusual taste, odor, or appearance of the water are often reported to water utilities, which document the reports and conventionally use them to identify and address water quality problems. Occasionally, water quality complaints are reported to local agencies other than the water utility, such as 911 call centers, the health department or a city's general information number. Using an appropriate methodology that compiles and tracks the information provided by consumers, the utility can consider these complaints along with data from other CWS components to identify unusual trends that may be indicative of a contamination incident.
- **Public health surveillance.** Syndromic surveillance conducted by the public health sector, including information such as over-the-counter sales of medication, as well as reports from emergency medical service logs, 911 call centers, and poison control hotlines may serve as a warning of a potential drinking water contamination incident. Information from these sources should be integrated by developing a reliable link between the public health sector and drinking water utilities.

A CWS is not merely a collection of monitors and equipment placed throughout a water system to alert of intrusion or contamination. Fundamentally, it is an exercise in information acquisition and management.

Different information streams should be captured, managed, analyzed, and interpreted in time to recognize potential contamination incidents in time to respond effectively. As discussed in Section 2.0 of this document and further evaluated in *WaterSentinel Contamination Incident Timeline Analysis*, each of these information streams can independently provide some value in terms of more timely initial detection (USEPA, 2005b). However, when these information streams are integrated and used to evaluate a possible contamination incident, the credibility of the incident can be established more quickly and reliably than if any of the information streams were used independently. While the primary purpose of a CWS is to detect contamination incidents, accidental or intentional, implementation of a CWS is expected to result in dual-use benefits for drinking water utilities that should help to ensure sustainability of the system.

Although many utilities are currently implementing some monitoring and surveillance activities, these activities would not be likely to detect a wide range of possible contamination events. For example, while many utilities currently track consumer complaint calls, WS proposes to develop a robust spatially based system that, when integrated with data from public health surveillance, online water quality monitoring, and enhanced security surveillance, should provide specific, reliable, and timely information for decision makers to establish credibility and respond in an effective manner. Beyond each individual component of the WS-CWS, WS should facilitate coordination and planning between the utility and local public health agency to develop a robust consequence management plan that involves the appropriate local officials, law enforcement, emergency responders, etc., to ensure that appropriate actions should occur in response to various triggers/alarms. An advanced and integrated laboratory infrastructure to support baseline monitoring as well as analysis of samples collected in response to triggers from the CWS monitoring and surveillance activities is critical to timely response. In the absence of a reliable and sustainable CWS, a utility's ability to respond to contamination threats and incidents in a timely and appropriate manner is limited.

What is WaterSentinel?

WS is a program developed by EPA in close partnership with drinking water utilities and other key stakeholders in response to HSPD 9. The program involves designing, deploying, and evaluating a model CWS for drinking water security as part of a demonstration project, or pilot. The overall goal of WS is to design and demonstrate an effective system for timely detection and appropriate response to drinking water contamination threats and incidents that would have broad application to the nation's drinking water utilities. The systematic approach to design of the WS-CWS should reduce the time between indication of potential contamination incidents, evaluation of the possible threat, and implementation of consequence management and response actions. More specifically, EPA's objectives for the WS program are to design a CWS that:

- Provides timely detection of contamination;
- Has broad coverage of priority contaminant classes;
- Is the most protective of public health using currently available and well-characterized technologies;
- Is sustainable through benefits to the water utility independent of enhanced water security (dual-use benefits);
- Is implementable, cost-effective, and reliable; and
- Is ultimately applicable to utilities nationally.

To meet these objectives, EPA intends to test a number of broad hypotheses that are critical to understanding the efficacy of a CWS. Through the initial pilot, a research project at a single utility, EPA plans to test the following hypotheses to determine whether the components of a CWS, singularly, collectively, or in some combination, can serve as an effective warning system:

- Water quality parameters (e.g., pH, chlorine residual, total organic carbon, etc.), in conjunction with an event detection system can provide early indication of contamination incidents.
- Consumer complaints can provide warning of contamination with chemicals that have a discernable odor or taste in sufficient time to respond in a manner that reduces consequences.
- Public health surveillance for indicators of disease in the population can provide early indication of drinking water contamination, particularly those contaminants that would not be otherwise detected through utility monitoring and surveillance activities.
- Event detection software (i.e., computer-based algorithms) applied to water quality parameters, consumer complaints, and public health surveillance both singularly and correlatively, can detect statistical anomalies indicative of possible contamination while minimizing the number of false alarms that a utility would otherwise have to deal with.
- Certain vulnerabilities to contamination can be effectively reduced through the focused deployment of security monitoring systems, and such a system can help to resolve false alarms.
- Integration of these different monitoring and surveillance techniques increases the coverage of contaminants, reduces the time to initial detection, and improves the overall reliability of the system
- Site characterization and triggered sampling (e.g., grab samples collected in response to a water quality anomaly, unusual consumer complaints, or an anomaly detected through public health surveillance) for specific high priority contaminants can provide corroboration of a contamination incident.

What are the Key Considerations for the WaterSentinel Contamination Warning System Design?

In the WS-CWS, the design basis can be described in terms of the particular problem that a system is designed to solve or the function the system is designed to perform. It provides a framework for system development and a benchmark against which to evaluate the performance of different design options. For detection systems, the design basis can be described in terms of the incident, or suite of incidents, that a satisfactory system should detect. The design basis for a drinking water CWS is defined as a series of contamination scenarios against which specific design options should be evaluated. A contamination scenario is specified by the location of contaminant introduction, the type of contaminant, and the amount, concentration, and rate of introduction. In addition to the contamination scenarios that define the design basis, a CWS design is subject to other requirements and constraints, such as the ability to detect an event in sufficient time to implement effective response actions. For example, a design option that can consistently detect a contamination scenario should not be acceptable if detection occurs significantly after a response is needed.

Developing a design basis for a contamination warning system is challenging because of the large number of potential contamination scenarios with varying degrees of consequence. The design basis may be substantially narrowed by initially focusing on those contamination scenarios with the highest consequences, particularly those with the potential for a high number of fatalities. However, it is not appropriate to arbitrarily establish a numeric threshold that defines a high-consequence scenario (e.g., 10,000 fatalities) because this can vary from utility to utility depending on the total population in the service area, the population density profiles, configuration of the distribution system, and other factors. A more rational approach is to evaluate and rank the consequences for a large number of potential contamination scenarios, and use those scenarios with the most significant consequences in the design basis (i.e., the relative ranking of scenarios is more useful than an absolute threshold). A system constructed around such a design basis should also detect many lower-consequence scenarios, and, while some scenarios should go undetected, the number of high-consequence scenarios that are not detected should be minimized. The consequences associated with a particular contamination scenario are largely a function of the specific contaminant and the location of contaminant introduction.

Another important consideration in the design of a CWS is the timeline associated with a contamination incident, specifically:

- The time during which consequences (exposures, illnesses, fatalities, pipe contamination, etc.) are experienced in the population,
- The time of initial detection, and
- The time of response actions.

Analysis of different contamination incident timelines can establish whether or not a given design should meet an important design requirement – initial detection in a timeframe that allows for the implementation of response actions that result in a significant reduction in consequences.

The manner in which the integration of multiple monitoring and surveillance strategies, as discussed above, satisfy the design basis is described below and in further detail in Section 2.0.

Contaminant Coverage

Analysis of contaminant properties and detection techniques clearly demonstrates that no single approach should provide timely detection for all contaminants of concern; however, the integrated approach implemented under WS has the potential to provide timely detection of a very high percentage of priority contaminants. The WS contaminant selection process identified contaminants for consideration in the WS pilot, which were ultimately grouped into 12 detection classes based on the manner in which they might be detected through the five WS-CWS monitoring and surveillance components. **Table ES-1** provides a summary of the WS-CWS detection classes (USEPA, 2005c).

Table ES-1. WaterSentinel Contamination Warning System Detection Classes

Contaminant Detection Class	Description
1	Petroleum products
2	Pesticides (chlorine reactive)
3	Inorganic compounds
4	Metals
5	Pesticides (chlorine resistant)
6	Chemical warfare agents
7	Radionuclides
8	Bacterial toxins
9	Plant toxins
10	Pathogens causing diseases with unique symptoms
11	Pathogens causing diseases with common symptoms
12	Persistent chlorinated organic compounds

Spatial Coverage

The monitoring components of the WS-CWS (water quality sensors, sampling and analysis, and enhanced security monitoring) have intrinsic limitations to the spatial coverage that each can achieve. On the other hand, surveillance components of the WS-CWS (consumer complaint and public health surveillance) rely on consumer observations and behavior, and thus provide dense spatial coverage throughout a distribution system. Thus, integration of both monitoring and surveillance systems in the WS-CWS is necessary to achieve a high degree of spatial coverage.

Timeliness of Initial Detection

As demonstrated through analysis of contamination incident timelines that considered approximately 100,000 contamination scenarios involving 10 different contaminants in one real drinking water distribution system, different contaminants are first detected by different monitoring and surveillance techniques (USEPA, 2005b). By integrating multiple data sources, the time of initial detection is reduced across all contaminants, and even those that act very rapidly within the exposed population may be detected in time to implement an effective response. For 6 of the 10 contaminant classes, a strong link between the public health community and the local water utility is critical to early detection and effective response to contamination incidents and for 5 of the 10 contaminant classes, public health surveillance would most likely be used to help establish the credibility of an incident.

Reliability

The multiple monitoring and surveillance techniques used in the WS-CWS extend beyond integration of multiple water quality data streams to other independent information streams including water quality data, consumer calls, public health surveillance, security alarms, results from site characterization and sample analysis. The WS-CWS pilot should provide an unprecedented opportunity to develop the information necessary to better characterize and quantify the value of integrating information from numerous monitoring and surveillance activities to improve our ability to reliably detect contamination incidents, i.e., to minimize the frequency of false alarms. The overall rate of false positive and false negatives for the integrated data streams should be substantially lower than the rates for any one detection strategy. These considerations for reliability of the WS-CWS may also be used to quantify ‘dual-use’ benefits of a CWS, which are related to system sustainability, another key consideration in the design of the WS-CWS.

Sustainability

The integration of multiple monitoring and surveillance strategies already in use at the utility and public health department should improve acceptance of the system, and thus long-term sustainability. The CWS is being designed as a dual-use application that should benefit the utility in day-to-day operations while also providing the capability to detect intentional or accidental contamination incidents.

Table ES-2 describes the manner in which each of the WS-CWS components addresses each of these aspects of the WS design basis. Note that some of these benefits cannot be quantified until the WS pilot is deployed and EPA gains substantial experience; thus the importance of implementing and evaluating the WS-CWS though a pilot program.

Table ES-2. WS-CWS Components and their Contributions to the Approach for WaterSentinel

WS-CWS Component	Capability	Contaminant Coverage	Spatial Coverage	Timeliness	Reliability	Sustainability
Online Water Quality Monitoring	Can indicate the presence of a contaminant that significantly affects one or more monitored parameters that serve as indicators of contamination.	High detection potential for classes 2, 3, 5, 8, 10, and 11; Moderate detection potential for classes 1, 4, 7, 9, and 12.	Function of location, number, and density of monitoring stations	Function of hydraulic travel time from the point of contaminant introduction to the sensor, and the concentration of the contaminant.	Rate of false positive / negative results in this application is largely unknown at this time. May be addressed through event detection systems and consequence management.	Provides utility with a better understanding of water quality variability throughout distribution system and provides an opportunity to optimize distribution system operation.
Sampling and Analysis	Can positively identify the presence of any contaminant in the suite of target analytes and above the MDL.	High detection potential for classes 1, 2, 3, 4, 7, and 12; Moderate detection potential for classes 5, 6, 8, 9, 10, 11.	Function of location, number, and density of sampling stations, as well as sample type (composite vs. grab).	Function of sampling & analysis frequency and the total time required to process the sample and analyze the results.	Function of the reliability of sampling and analysis methods (high for established techniques). Baseline needed for reliable interpretation of results.	Provides utility with an opportunity to exercise sampling and laboratory protocols and may; provide information about previously unknown contaminants that occur in the system.
Enhanced Security Monitoring	Can detect an intrusion that may have provided the opportunity for introduction of *any* contaminant.	Covers all contaminant classes.	Limited to those elements of infrastructure for which physical security can be monitored.	Function of the type of security monitoring system and the time required to evaluate a security breach.	Can be a reliable means of identifying an intrusion, especially when these breaches may involve contamination, such as in storage tanks and clear wells. May be addressed through consequence management.	Provides utility with increased physical infrastructure protection and awareness. Reduces the occurrence of nuisance tampering.
Consumer Complaint Surveillance	Can indicate the presence of a contaminant that significantly affects one or more aesthetic qualities of water.	High detection potential for classes 1 and 2; Moderate detection potential for classes 3 and 4.	Entire service area for contaminants with detectable organoleptic characteristics.	Function of the time from exposures to consumer reporting, complaint categorization, assessment and investigation.	A potentially reliable indicator for contaminants with detectable characteristics if a robust complaint reporting and tracking system is in place.	Provides utility an opportunity to manage consumer information more effectively and can serve as a tool for enhanced consumer confidence.
Public Health Surveillance	Can detect the presence of a symptom or illness in a population which may be the result of the presence of a disease causing agent. May be able to identify the contaminant through clinical diagnosis / testing.	Covers contaminant classes 2 through 11; detection potential varies with type of surveillance.	Comprehensive coverage of a particular city or county, which may include all, or a large portion of, the service area.	Function of the time from the initial exposures, the onset of symptoms, and the point at which public health officials recognize the incident as a potential water-borne illness.	May be a reliable means of identifying the incidence of illness in a population, but communication between drinking water and public health officials is not always quick enough for appropriate response, intervention and remedial actions to take place.	Provides an opportunity for collaboration between utility and local health department(s).

Relating back to the overall objective of WS, **Figure ES-1** demonstrates the potential for the WS-CWS to reduce the impacts of contamination incidents. For 10 contaminant classes, the figure shows the impacts from a high consequence scenario without the WS-CWS (in blue) and with the WS-CWS (in green). In each scenario, WS-CWS has the potential to reduce the public health impacts from 6-100%. For classes 8, 10, and 11, represented by one biotoxin and two biological agents, WS-CWS has the potential to prevent all fatalities assuming availability of sufficient medical resources.

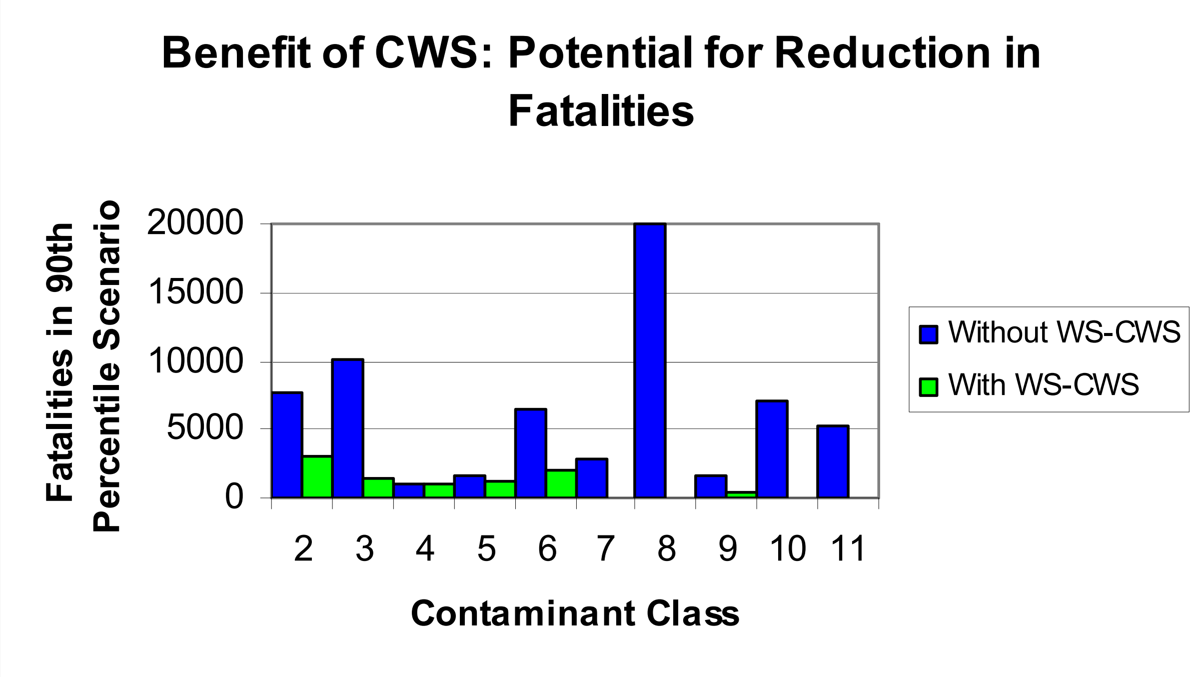

Figure ES-1. Potential Benefit of CWS in Reducing the Number of Fatalities in 10 Contamination Scenarios

The initial method of detection and the time period in which response is effective may differ among the various contaminants. The timeline analysis establishes the timeframes in which utility intervention to reduce further exposure would be effective as well as the timeframe in which public health intervention would be effective. It also highlights the importance of the link between public health services and water utilities, and the importance of rapid utility and public health response strategies.

This design basis forms a framework for system development and a benchmark against which to evaluate the performance of different design options. This document provides more detail regarding the basis for including each of the WS monitoring and surveillance components, and describes the general framework for design and implementation of each component. Initial considerations for evaluation of both the technical design and the overall program are also discussed.

What is the Approach for Implementation of the Initial WaterSentinel Pilot?

The initial WS pilot should serve as a demonstration project for the conceptual design described in detail in Section 2.0 of this document. Using this document as an initial framework, EPA anticipates working with the pilot utility and partner organizations to develop a work plan for implementation of the WS-CWS. EPA plans to provide support to the WS pilot utility and aims to work closely with the utility to design a program that meets its current and projected needs. In addition, EPA intends to work with the utility to develop the necessary laboratory capabilities required to support implementation of the WS program. Once implemented, an evaluation program should assess the effectiveness, costs, and benefits of the pilot and recommend improvements to the WS-CWS, as well as the sustainability and multiple benefits provided by implementation of the WS-CWS. The phases of design and implementation of the initial WS-CWS pilot include the following:

- **Initial Planning.** Includes participation in initial meetings between EPA, the pilot utility, and local partners (as appropriate) to discuss the objectives, technical approach, and general implementation strategy.
- **Assessment.** Review of the pilot utility's current practices, procedures, and capabilities for the technical components of the WS-CWS. This may include an initial request for relevant information as well as an on-site assessment.
- **Gap Analysis and Component-Specific Work Plans.** Based on the assessments conducted in the previous phase, EPA technical staff plan to work with the pilot utility to conduct a gap analysis to determine the appropriate enhancements and modifications to support implementation of the WS-CWS. From this gap analysis, EPA aims to work with the pilot utility to develop component-specific work plans for implementation.
- **Enhancements and Installation.** In accordance with the component-specific work plans, EPA aims to work with the pilot utility to implement enhancements and install the necessary equipment and systems for implementation.
- **Baseline Development.** Establish a baseline for all components of the WS-CWS, including online water quality monitoring, sampling and analysis, enhanced security monitoring, consumer complaint surveillance, and public health surveillance.
- **Full Deployment.** The WS-CWS should be fully operational, information streams should be integrated, and consequence management plans should be fully implemented.
- **Evaluation.** Evaluation of the WS-CWS should occur at established increments throughout the pilot.
- **Refinement.** Based on the evaluation(s), WS-CWS components may require refinements or additional enhancements to ensure proper operation of the system relative to the objectives established in the component-specific work plans.
- **Maintenance.** Following implementation of the WS-CWS and initial enhancements to the system, the pilot utility should maintain the CWS. With the advancement of technology and research, additional cycles of evaluation and refinement should be considered. However, the frequency at which these evaluations occur can likely be decreased over time.

Until the WS-CWS concept has been demonstrated through evaluation and refinement, the system at the pilot utility should function as a research project. As the WS-CWS is refined and enhanced, the system should become protective of public health through the transition from full deployment of the WS-CWS through maintenance by the pilot utility.

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Section 1.0: Introduction

WaterSentinel (WS) is a program developed by the U.S. Environmental Protection Agency (EPA) in close partnership with drinking water utilities and other key stakeholders in response to Homeland Security Presidential Directive 9 (HSPD 9). The program involves designing, deploying, and evaluating a model contamination warning system (CWS) for drinking water security. A CWS is a system that collects information from a variety of sources, including monitoring and surveillance programs, in order to detect contamination events in drinking water early enough to reduce public health or economic consequences. This document presents an overview of the WS program and the CWS concept, including the design and development of the system architecture for the WS program, a framework for making design decisions, and considerations for evaluation of the WS program and the WS-CWS. In addition to guiding the design of the WS-CWS at the initial pilot utility, the approach described in this document can be used to inform other stakeholders and utilities interested in implementing a CWS. This is a living document that should evolve as experience is gained through the implementation of the WS-CWS, and this first version of the document represents the basis for the design of the first pilot.

1.1 Problem Statement

Through the assessment of vulnerabilities to drinking water systems, water security experts have identified the distribution system as one of the most vulnerable nodes in a water utility. This finding was further supported through additional studies and analyses. For example, a Government Accounting Office (GAO) survey of a panel of nationally recognized water security experts who identified distribution systems as among the most vulnerable physical components of a drinking water utility due to the large number of access points, ease of access, and the inability to detect contamination in a timely manner due to the absence of integrated and reliable monitoring and surveillance systems (GAO-04-29). Strengthening of key relationships between water utilities and other agencies in terms of preparedness, detection, and response activities was another important issue highlighted by the GAO study. A report prepared by EPA for the Homeland Security Council of the White House, and under the direction of other federal agencies, identified a number of contaminants, which if introduced into a drinking water distribution system could produce consequences upwards of 10,000 fatalities (USEPA, 2004c). This same report concluded that in the absence of a CWS, many of these contamination incidents would go undetected until weeks following the attack when the first cases of disease begin to appear in the population, at which time it may be difficult or impossible to find even a trace of contamination in the distribution system.

Contamination of the drinking water distribution system – whether it is accidental or intentional – can have devastating consequences for public health, critical infrastructure, the economy, and the environment. Drinking water distribution systems may be accidentally contaminated through cross-connections with non-potable water, permeation through pipes in low pressure areas, or chemical reactions or microbial growth within the pipes. Such unintentional events that result in degradation to distributed water quality may occur with some regularity. Intentional contamination, or even the threat of contamination can have significant impacts. Drinking water utilities occasionally receive threat or indications of possible contamination. These contamination threat warnings can be a direct threat or an unusual observation or discovery that indicates the potential for contamination and initiates actions to investigate and potentially respond. However, these threat warnings are not standardized and are difficult to corroborate in the absence of an integrated monitoring and surveillance system and close coordination with response partners including, but not limited to public health, emergency responders, and law enforcement.

In recognition of the contamination threat and the importance of early detection, the Administration issued HSPD 9 – Defense of United States Agriculture and Food. This directive was for EPA and other Agencies, using existing authorities, to build upon and expand current monitoring programs, to:

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- 'develop nationwide laboratory networks for . . . water quality that integrate existing Federal and State laboratory resources, are interconnected, and utilize standardized diagnostic protocols and procedures.'

By its authority under section 300i-3 of the Safe Drinking Water Act (42 USC section 1434) and to address the monitoring and surveillance requirements of HSPD 9, EPA intends for WS to build on existing Agency and utility efforts to enhance the ability to detect and respond to contamination threats and incidents through the use of a CWS. In June 2004, EPA and the American Water Works Association (AWWA) established a group of utilities to participate in the Threat Ensemble Vulnerability Assessment research program, and effort focused on the use of hydraulic modeling tools to better characterize the consequences of contamination and use that information in the design of a CWS. Further refinement of the CWS model occurred in close partnership with drinking water utilities and other key stakeholders. The AWWA established an informal 'Utility Users' Group' in October 2003 as a forum for utilities to exchange experiences in dealing with water security and contamination issues and discuss approaches for detection and response. At a subsequent meeting in January 2005, this group focused on issues related specifically to the design and implementation of a CWS (AWWA, 2005). In addition to this larger effort organized by AWWA, a group of California water utilities that provided critical input to the development of EPA's Response Protocol Toolbox (USEPA, 2004a) also convened a series of workshops to focus on the conceptual design for a CWS and identify considerations for implementation of a CWS that would be sustainable by meeting security objectives while also providing multiple benefits to routine operations and system performance. The approach for the design of the WS-CWS described in this document is an extension of the concepts identified and informed by these and other utility and stakeholder efforts.

1.1.1 Overview of Contamination Warning Systems

A CWS is a proactive approach to managing threat warnings that uses advanced monitoring technologies/strategies and enhanced surveillance activities to collect, integrate, analyze, and communicate information to provide a timely warning of potential water contamination incidents and initiate response actions to minimize public health and economic impacts. Components of the WS-CWS include the following:

- **Online water quality monitoring.** Online monitors for water quality parameters, such as chlorine residual, total organic carbon, pH, conductivity, turbidity, etc., should be used to establish expected levels for these parameters (a 'baseline'). Anomalous changes from the established water quality baseline should be used as an indicator of potential contamination in the WS-CWS.
- **Sampling and analysis.** Water samples should be collected at a predetermined frequency and analyzed to establish a baseline through the use of an 'unknowns' protocol. This 'unknowns' protocol would target specific, priority contaminants, but may also detect some non-target analytes if the analytical techniques used in the routine monitoring program are sufficiently robust and if the analysts are trained and encouraged to investigate tentatively identified contaminants. In addition, water samples should be collected in response to triggers from water quality monitors or other information streams to identify the potentially unknown contaminants in the sample.

- **Enhanced security monitoring.** Security breaches, witness accounts, and notifications by perpetrators, news media, or law enforcement should be monitored and documented through enhanced security practices. This component of the WS-CWS has the potential to detect a tampering event in progress, potentially preventing the introduction of a harmful contaminant into the water.
- **Consumer complaint surveillance.** Consumer complaints regarding unusual taste, odor, or appearance of the water are often reported to water utilities, which document the reports and conventionally use them to identify and address water quality problems. Occasionally, water quality complaints are reported to local agencies other than the water utility, such as 911 call centers, the health department or a city's general information number. Using an appropriate methodology that compiles and tracks the information provided by consumers, the utility can consider these complaints along with data from other CWS components to identify unusual trends that may be indicative of a contamination incident.
- **Public health surveillance.** Syndromic surveillance conducted by the public health sector, including information such as over-the-counter sales of medication, as well as reports from emergency medical service (EMS) logs, 911 call centers, and poison control hotlines may serve as a warning of a potential drinking water contamination incident. Information from these sources should be integrated by developing a reliable link between the public health sector and drinking water utilities.

The key to an effective response to a water contamination threat is minimizing the time between indication of a contamination incident and implementation of effective response actions. Implementation of a robust CWS can achieve this objective by providing an earlier indication of a potential contamination incident than would be possible in the absence of a CWS; thus, the core component of the WS program is a CWS. A CWS is not merely a collection of monitors and equipment placed throughout a water system to alert of intrusion or contamination. Fundamentally, it is an exercise in information acquisition and management. Different information streams should be captured, managed, analyzed, and interpreted in time to recognize potential contamination incidents in time to respond effectively. While the primary purpose of a CWS is to detect contamination incidents, accidental or intentional, implementation of a CWS is expected to result in dual-use benefits for drinking water utilities that should help to ensure sustainability of the system.

Although many utilities undertake monitoring and surveillance activities, they are not likely to detect a wide range of possible contamination events. For example, while some utilities currently track consumer complaint calls, WS proposes to develop a robust spatially based system that, when integrated with data from public health surveillance, online water quality monitoring, and enhanced security surveillance, should provide specific, reliable, and timely information for decision makers to implement response plans. Beyond each individual component of the WS-CWS, WS should integrate information from both the utility and local public health agency and provide a robust consequence management plan that involves the appropriate local officials, law enforcement, etc., to ensure that appropriate actions should occur in response to various triggers/alarms. In the absence of a reliable and sustainable CWS, a utility's ability to respond to contamination threats and incidents in a timely and appropriate manner is limited.

1.1.2 WaterSentinel Objectives

The overall goal of WS is to design and demonstrate an effective system for timely detection and appropriate response to drinking water contamination threats and incidents that would have broad application to the nation's drinking water utilities. The systematic approach to design of the WS-CWS should reduce the time between indication of potential contamination incidents, evaluation of the possible threat, and implementation of consequence management and response actions. More specifically, EPA's objectives for the WS program are to design a CWS that:

- Provides timely detection of contamination;
- Has broad coverage of priority contaminant classes;
- Is the most protective of public health using currently available and well-characterized technologies;
- Is sustainable through benefits to the water utility independent of enhanced water security (dual-use benefits);
- Is implementable, cost-effective, and reliable; and
- Is ultimately applicable to utilities nationally.

To meet these objectives, EPA intends to test a number of broad hypotheses that are critical to understanding the efficacy of a CWS. Through the initial pilot, EPA plans to test the following hypotheses to determine whether the components of a CWS, singularly, collectively, or in some combination, can serve as an effective warning system:

- Water quality parameters (e.g., pH, chlorine residual, total organic carbon, etc.), in conjunction with an event detection system can provide early indication of contamination incidents
- Public health surveillance for indicators of disease in the population can provide early indication of drinking water contamination
- Consumer complaints can provide warning of contamination with chemicals that have a discernable odor or taste in sufficient time to respond in a manner that reduces consequences.
- Event detection software (i.e., computer-based algorithms) applied to water quality parameters, consumer complaints, and public health surveillance both singularly and correlatively, can detect statistical anomalies indicative of possible contamination while minimizing the number of false alarms that a utility would otherwise have to deal with
- Certain vulnerabilities to contamination can be effectively reduced through the focused deployment of security monitoring systems that provide access control and detection capabilities.
- Integration of these different monitoring and surveillance techniques increases the coverage of contaminants, reduces the time to initial detection, and improves the overall reliability of the system
- Site characterization and triggered sampling (e.g., grab samples collected in response to an anomaly in water quality, consumer complaints, or public health surveillance) for specific high priority contaminants can provide corroboration of a contamination event

The conceptual approach for the integration of these information streams as part of the WS-CWS is described in Section 1.2. A detailed discussion of the design basis for the WS system architecture as it relates to the objectives and hypotheses described above is discussed in Section 2.0.

1.2 Overview of WaterSentinel

The WS concept of operations (ConOps) describes all of the operational activities to be used by a water utility and public health agency to detect and respond to a contamination incident through the WS-CWS. The WS ConOps provides the broad context from routine monitoring and surveillance activities to recovery from an actual contamination incident. **Figure 1-1** illustrates the basic ConOps for the WS-CWS.

WS System Architecture

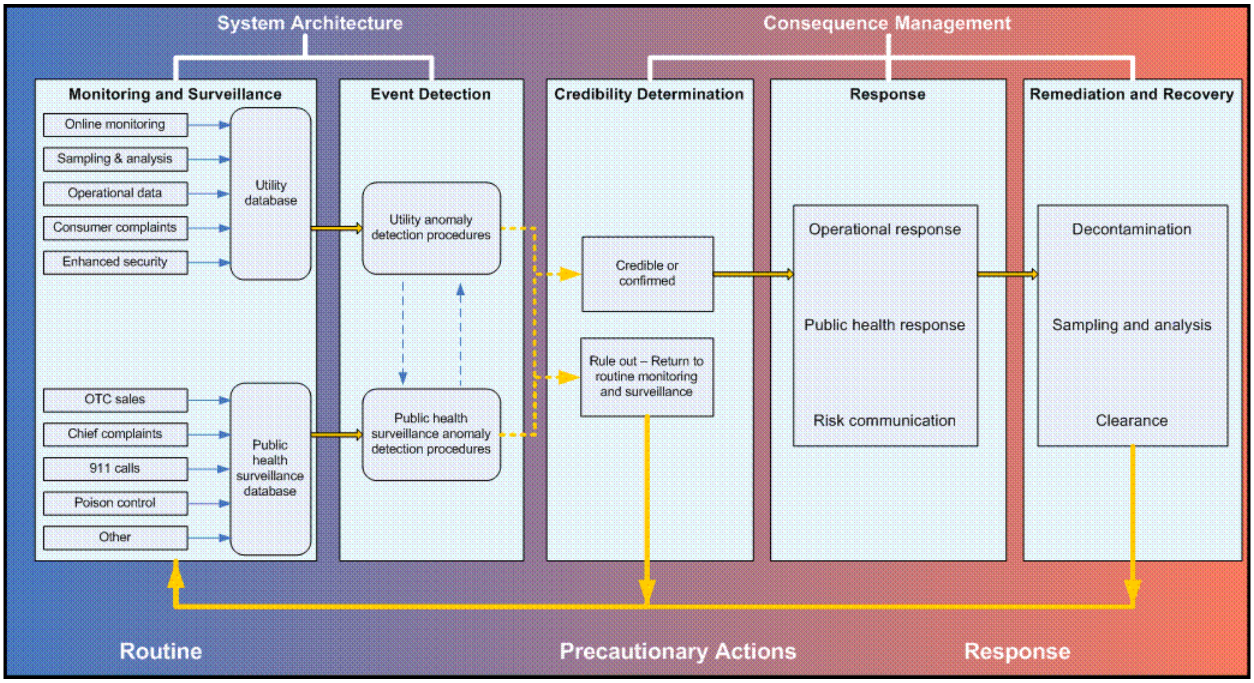


Figure 1-1. Overview of WS Concept of Operations

Sections 1.2.1 through 1.2.3 briefly describe the elements of the WS ConOps and basic operation of the WS-CWS.

1.2.1 Monitoring and Surveillance

WS-CWS monitoring and surveillance activities rely on an established set of information streams to detect contamination events. As shown in Figure 1-2, these information streams are primarily managed by either the drinking water utility or the public health department. In order for WS to be successful and sustainable, a close relationship between the utility and the local public health department should be developed and maintained to address exchange of data, coordination, and notification.

1.2.2 Event Detection

The fundamental challenge in relying on a variety of information streams as an indication of a contamination incident is establishing a means of distinguishing anomalous patterns in these data from an established baseline. In the WS-CWS model, event detection is a process to analyze signals from monitoring and surveillance activities to identify anomalies that are indicative of a possible contamination incident. Event detection algorithms could identify a pattern of unusual water quality, a cluster of unusual consumer complaints, or unusual symptoms picked up by a public health surveillance program. When incorporated as part of an event detection system, these algorithms can be used to identify and ‘learn from’ changes in data patterns that are indicative of drinking water contamination. In short, the purpose of the event detection algorithms is to reduce the false positive rate without missing potential events (i.e., without incurring false negatives). Additional information on available event detection algorithms, software, and tools can be found in *Overview of Event Detection Systems for WaterSentinel* (USEPA, 2005f).

1.2.3 Consequence Management

Based on lessons learned from deployment of BioWatch, an early-warning system designed to detect the release of biological agents in the air through a comprehensive protocol of monitoring and laboratory analysis, EPA recognizes that consequence management plans should be in place before any monitoring and surveillance activities begin. As part of the WS-CWS ConOps, consequence management consists of a series of actions taken after a potential incident is identified to establish credibility, minimize public health and economic impacts, and ultimately return to normal operations. The consequence management guidance developed as part of the WS pilot should build on the concepts and approach described in EPA's *Response Protocol Toolbox (RPTB)*. The RPTB provides a framework to guide the response to contamination threats and incidents and establishes the foundation for the primary steps, or phases, for consequence management as part of the WS-CWS. Sections 1.2.3.1 through 1.2.3.3 describe the general approach for WS-CWS consequence management. A detailed discussion of EPA's approach for WS consequence management is discussed in *WaterSentinel Consequence Management Strategy* (USEPA, 2005i).

1.2.3.1 Credibility Determination

Once monitoring and surveillance activities detect a possible contamination incident, a series of steps should be taken to determine the credibility of the incident through the process of credibility determination as discussed in Module 2: Contamination Threat Management Guide of EPA's *Response Protocol Toolbox.* Based on this analysis, a decision should be made to return to normal operations or determine that the incident is 'credible' and implement appropriate response actions. Through the WS-CWS, the credibility determination process can be enhanced through integration of data from multiple information streams to corroborate a 'possible' incident and provide additional information to decision-makers in a timely manner. It is critical that a systematic approach for assessing credibility in response to contamination threat warnings is used to ensure that all available information is analyzed in a timely and efficient manner to minimize both false alarms and over-response to a trigger that has not been determined to be 'credible.'

1.2.3.2 Response

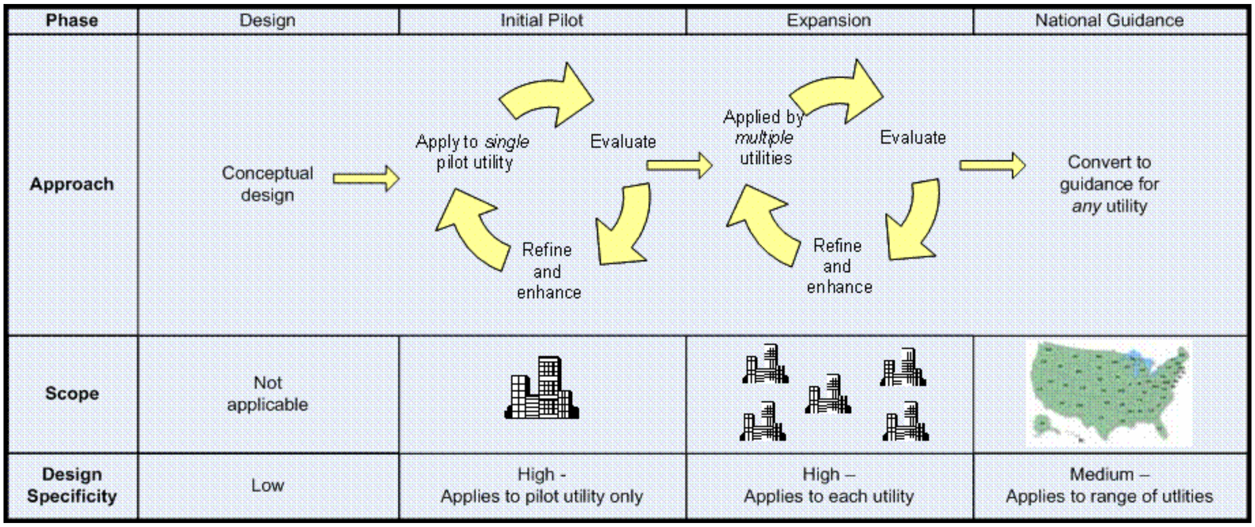
Response actions are initiated upon detection of a 'possible' contamination event and continue through determination of credibility and confirmation of a contamination threat. As described in Section 1.2.3.1, an initial trigger indicating 'possible' contamination could come from single or multiple monitoring and surveillance information streams. Indication of 'possible' contamination should prompt the water utility to conduct follow up actions such as site characterization, triggered sampling, and analysis for 'unknowns' as part of credibility determination, potentially resulting in notifications to public health and local response partners and implementation of precautionary response actions to reduce consequences should the event later be deemed 'credible.' As the information from the initial response actions (such as site characterization and 'unknowns' analysis and/or additional information from monitoring and surveillance streams) is collected from or coordinated with the water utility, additional response actions should be considered and implemented as the credibility of the incident is assessed. This process of continuous information collection followed by assessment and action should be performed by the water utility and others from the local, State, or Federal levels of various agencies to respond to the event, mitigate the consequences, provide internal and external notifications, bring in additional resources for response and analysis, and manage all related emergency response requirements associated with the specifics of the event. Rapid response actions should be critical to the success of the CWS. These response actions should be fully described in the *WS Consequence Management Plan* prior to implementation of the CWS.

1.2.3.3 Remediation and Recovery

The goal of remediation and recovery is to return the water supply system to service as quickly as possible while protecting public health and minimizing disruption to normal life (or business continuity). During the remediation and recovery stage, the immediate urgency of the situation has passed, and the magnitude of the remedial action requires careful planning and implementation. While rapid recovery of the system is crucial, it is equally important to follow a systematic process that establishes remedial goals acceptable to all stakeholders, implements the remedial process in an effective and responsible manner, and demonstrates that the remedial action was successful.

1.3 Approach to Implementation

In the design of the WS-CWS, EPA aims to partner with drinking water utilities, key water sector stakeholders, technical experts, representatives from public health departments, law enforcement, State and other Federal agencies to implement the WS-CWS pilot and evaluate first-generation CWS components that initially address a representative subset of priority contaminants and improve a utility's ability to respond to any contamination threat or incident. In addition, the WS-CWS should yield operational benefits for non-security related water quality issues and enhance collaboration/integration of water utility and local health department operations. Through a partnership with these organizations, EPA plans to use the results of the WS pilot to develop a sustainable model for a CWS that can be implemented by utilities throughout the nation. **Figure 1-2** presents an overview of the approach for design, initial pilot, expansion, and development of national guidance under the WS program.



Phase	Design	Initial Pilot	Expansion	National Guidance
Approach	Conceptual design	Apply to *single* pilot utility Evaluate Refine and enhance	Applied by *multiple* utilities Evaluate Refine and enhance	Convert to guidance for *any* utility
Scope	Not applicable			
Design Specificity	Low	High - Applies to pilot utility only	High – Applies to each utility	Medium – Applies to range of utlities

Figure 1-2. Overview of the WS Program

Following the enhancements and modifications to the initial WS-CWS design, EPA plans to engage in an extensive outreach effort to promote the water sector's understanding and adoption of CWSs. This effort should allow EPA, the utilities, and partner organizations to begin to establish a more protective program (i.e., a program that could include more contaminants, more cities, more sensors, and overall greater reliability) once the concept of the WS-CWS has been demonstrated through the initial pilot. As the adoption and evaluation of CWS expands, the level of sophistication should evolve as well to include more contaminants, an expanded laboratory network, a higher degree of data integration, and enhanced detection technologies.

Throughout all phases of the WS program, EPA plans to continue to conduct supporting research to enhance the monitoring and surveillance strategies available to be used in the WS-CWS. Research priorities include the following:

- Evaluation and development of methods for sampling and analysis
- Evaluation of water quality monitors and new and emerging technologies for contamination warning
- Evaluation of data collection and transmission techniques
- Refinement and enhancement of modeling and data analysis tools
- Characterization of contaminant properties and risks to human health, infrastructure, and the economy
- WS program evaluation

The initial WS pilot should serve as a demonstration project for the conceptual design described in detail in Section 2.0 of this document. Using this document as an initial framework, EPA anticipates working with the pilot utility and partner organizations to develop a work plan for implementation of the WS-CWS. EPA plans to provide support to the WS pilot utility and work closely with the utility to design a program that meets its current and projected needs. In addition, EPA plans to work with the utility to develop the necessary laboratory capabilities required to support implementation of the WS program. Once implemented, an evaluation program should assess the effectiveness, costs, and benefits of the pilot and recommend improvements to the WS-CWS, as well as the sustainability and multiple benefits provided by the program. The phases of design and implementation of the initial WS-CWS pilot include the following:

- **Initial Meetings.** Includes participation in initial meetings between EPA, the pilot utility, and local partners (as appropriate) to discuss the objectives, technical approach, and general implementation strategy.
- **Assessment.** Review of the pilot utility's current practices, procedures, and capabilities for the technical components of the WS-CWS. This may include an initial request for relevant information as well as an on-site assessment.
- **Gap Analysis and Component-Specific Work Plans.** Based on the assessments conducted in the previous phase, EPA technical staff plan to work with the pilot utility to conduct a gap analysis to determine the appropriate enhancements and modifications to support implementation of the WS-CWS. From this gap analysis, EPA anticipates working with the pilot utility to develop component-specific work plans for implementation.
- **Enhancements and Installation.** In accordance with the component-specific work plans, EPA plans to work with the pilot utility to implement enhancements and install the necessary equipment and systems for implementation.
- **Baseline Development.** Establish a baseline for all components of the WS-CWS, including online water quality monitoring, sampling and analysis, enhanced security monitoring, consumer complaint surveillance, and public health surveillance.
- **Full Deployment.** The WS-CWS should be fully operational and information streams should be integrated.
- **Evaluation.** Evaluation of the WS-CWS should occur at established increments throughout the pilot.
- **Refinement.** Based on the evaluation(s), WS-CWS components may require refinements or additional enhancements to ensure proper operation of the system relative to the objectives established in the component-specific work plans.
- **Maintenance.** Following implementation of the WS-CWS and initial enhancements to the system, the pilot utility should maintain the CWS. With the advancement of technology and

research, additional cycles of evaluation and refinement should be considered. However, the frequency at which these evaluations occur can likely be decreased over time.

1.4 Document Organization

The remaining sections of this document describe the following aspects of WS system architecture:

- **Section 2.0: WaterSentinel Contamination Warning System Design Basis.** This section provides a detailed description of the WS design basis, CWS components, and cost considerations.
- **Section 3.0: Online Water Quality Monitoring.** This section describes the rationale for inclusion of online water quality monitoring as a component in the CWS and presents a framework for how this component should be implemented as part of the WS pilot.
- **Section 4.0: Sampling and Analysis.** This section describes the rationale for inclusion of sampling and analysis as a component in the CWS and presents a framework for how this component should be implemented as part of the WS pilot.
- **Section 5.0: Enhanced Security Monitoring.** This section describes the rationale for inclusion of enhanced security monitoring as a component in the CWS and presents a framework for how this component should be implemented as part of the WS pilot.
- **Section 6.0: Consumer Complaint Surveillance.** This section describes the rationale for inclusion of consumer complaint surveillance as a component in the CWS and presents a framework for how this component should be implemented as part of the WS pilot.
- **Section 7.0: Public Health Surveillance**. This section describes the rationale for inclusion of public health surveillance as a component in the CWS and presents a framework for how this component should be implemented as part of the WS pilot.
- **Section 8.0: Information Integration and Data Management.** This section presents an overview of the approach to integration of information and management of data from all CWS components.
- **Section 9.0: Approach to Evaluation.** This section describes how the WS-CWS and overall pilot program should be evaluated with regard to performance, costs, benefits, and sustainability.
- **Section 10.0: References and Resources.** This section provides a bibliography of the references cited in this document and provides a brief summary of other documents related to the WS program.
- **Appendix A: Acronyms**
- **Appendix B: Glossary**
- **Appendix C: Overview of Related Projects**

Section 2.0: WaterSentinel Contamination Warning System Design Basis

System architecture is the conceptual design for the WS-CWS, and describes the monitoring and surveillance techniques that should be integrated to detect potential drinking water contamination incidents. This section describes the results of EPA's analyses and technical considerations that lead to the proposed WS-CWS design basis for the WS-CWS. Factors considered in developing the design basis include a description of the contaminant threat and identification of high impact contamination scenarios, the manner by which different classes of contaminants might be detected, the time at which different detection strategies might provide an initial indication of contamination, and design considerations related to reliability and sustainability.

In system design, the design basis can be described in terms of the particular problem that a system is designed to solve or the function the system is designed to perform. It provides a framework for system development and a benchmark against which to evaluate the performance of different design options. For detection systems, the design basis can be described in terms of the incident, or suite of incidents, that a satisfactory system should detect. The design basis for a drinking water CWS is defined as a series of contamination scenarios against which specific design options should be evaluated. A contamination scenario is specified by the location of contaminant introduction, the type of contaminant, and the amount, concentration, and rate of introduction. In addition to the contamination scenarios that define the design basis, a CWS design is subject to other requirements and constraints, such as the ability to detect an event in sufficient time to implement effective response actions. For example, a design option that can consistently detect a contamination scenario should not be acceptable if detection occurs significantly after a response is needed.

Developing a design basis for a contamination warning system is challenging because of the large number of potential contamination scenarios with varying degrees of consequence. The design basis may be substantially narrowed by initially focusing on those contamination scenarios with the highest consequences, particularly those with the potential for a high number of fatalities. However, it is not appropriate to arbitrarily establish a numeric threshold that defines a high-consequence scenario (e.g., 10,000 fatalities) because this can vary from utility to utility depending on the total population in the service area, the population density profiles, configuration of the distribution system, and other factors. A more rational approach is to evaluate and rank the consequences for a large number of potential contamination scenarios, and use those scenarios with the most significant consequences in the design basis (i.e., the relative ranking of scenarios is more useful than an absolute threshold). A system constructed around such a design basis should also detect many lower-consequence scenarios, and, while some scenarios may go undetected, the number of high-consequence scenarios that are not detected may be minimized. The consequences associated with a particular contamination scenario are largely a function of the specific contaminant and the location of contaminant introduction. The manner in which these two parameters are considered in the design basis is discussed in Section 2.1 and 2.2.

Another important consideration in the design of a CWS is the timeline associated with a contamination incident, specifically:

- The time during which consequences (exposures, illnesses, fatalities, pipe contamination, etc.) are experienced in the population,
- The time of initial detection, and
- The time of response actions.

Analysis of different contamination incident timelines can establish whether or not a given design will meet an important design requirement – initial detection in a timeframe that allows for the implementation of response actions that result in a significant reduction in consequences. Integration of the results of the contamination incident timeline analysis into the CWS design is discussed in Section 2.3.

Additional considerations in the design of a CWS include reliability and sustainability, which are discussed in Section 2.4.

2.1 Contaminant Detection Classes

There are a large number of contaminants that could cause serious harm if introduced into the drinking water distribution system. Previous prioritization efforts resulted in a list of 80 contaminants that are of particular concern with respect to intentional water contamination. This ‘priority list’ was the starting point for the WS contaminant selection process through which 33 contaminants were identified for consideration during implementation of the initial WS pilot (USEPA, 2005c). These 33 contaminants, were grouped into 12 classes based on their potential for detection through each of the following monitoring and surveillance strategies:

- Utility monitoring and surveillance activities:
    - Online water quality monitoring for free chlorine residual, TOC, and/or conductivity
    - Laboratory analysis for the specific contaminant
    - Field testing for the specific contaminant
    - Consumer complaint surveillance
- Public health surveillance:
    - Emergency room (ER) visits, 911 calls, or emergency medical services (EMS) logs
    - Clinical diagnosis
    - Other forms of public health surveillance including over-the-counter (OTC) sales of pharmaceuticals, absenteeism, clinical laboratory orders, etc.

The water quality parameters listed under the first bullet where used in the development of the contaminant detection classes because they have been shown to be the most reliable indicators of contamination for the widest number of contaminants, particularly free chlorine residual and total organic carbon (TOC) concentration (USEPA, 2005h). However, additional water quality parameters may be used such as pH, redox potential, and turbidity, among others.

The detection potential for each of these monitoring and surveillance techniques was assessed for each of the 33 contaminants using contaminant-specific information (USEPA, 2005c), and ranked as high, moderate, or low according to the criteria listed in **Table 2-1**.

Table 2-1. Ranking Criteria for the Various CWS Components

Monitoring or Surveillance Technique	Detection Potential		
	High	Moderate	Low
Online Water Quality Monitoring	**Change in two or more parameters**	**Change in only one parameter**	**No change in water quality**
Laboratory Analysis	**Availability of a validated lab method**	**Availability of a non-validated lab method**	**No method available**
Field Testing	**Availability of a validated field test**	**Availability of a non-validated field test**	**No field test available**
Consumer Complaints	**Detectable odor in water at lethal concentrations**	**Detectable taste in water at lethal concentrations**	**No odor or taste**
ED Visits, 911 Calls, EMS Logs	**Onset of severe symptoms within one hour**	**Onset of severe symptoms within four hours**	**Gradual onset of symptoms**
Clinical Diagnosis	**Unique and/or severe symptoms**	**Symptoms typical of common ailments**	**No symptoms readily evident**
Other Forms of Public Health Surveillance	**Onset of reportable symptoms**	**Onset of non-reportable symptoms**	**No symptoms readily evident**

For changes in water quality, it was generally assumed that a detectable change in chlorine residual, TOC, or conductivity would occur at contaminant concentrations well below lethal levels for most contaminants. This assumption is supported by numerous studies that showed substantial change in water quality at concentrations well below the concentration that would be lethal to half of the population exposed to that concentration (USEPA, 2005h). For consumer complaints, information about the organoleptic properties of a contaminant was used to establish detection by this surveillance technique. While the nature of the odor or taste was well documented, the threshold concentrations typically were not. However, available threshold data for volatile and semi-volatile chemicals indicates odor thresholds at the parts per billion or parts per trillion level. Given that many toxic chemicals are lethal at concentrations in the range of parts per million, it was assumed that contaminants with a documented taste or odor would be detected at concentrations at or below the lethal concentration.

For the purpose of ranking the detection potential for the 33 baseline contaminants, the three public health surveillance techniques listed in Table 2-1 were considered collectively. However, the relative time in which the information is available as well as the reliability and specificity of information received through public health surveillance varies based on the contaminant, the illness it produces, as well as other factors. While onset of reportable symptoms is rated as ‘high’ for other forms of public health surveillance (e.g., OTC sales, absenteeism, clinical laboratory orders, etc.) in Table 2-1, if this was the only means of detection through public health surveillance, the contaminant was ranked as having a low detection potential via that technique due to the decreased reliability, specificity, or timeliness of this information. For example, even if a contaminant produces reportable symptoms, without corroborating data from another public health source such as 911 calls or clinical diagnosis, the contaminant was considered as having a low detection potential because of the delayed timeframe and/or decreased reliability and specificity of this information.

Groups of contaminants that can be detected by similar monitoring and surveillance strategies were evident from this analysis, and clustering of the 33 WS baseline contaminants was used to define 12 *contaminant detection classes* summarized in **Table 2-2**.

Table 2-2. Detection Potential for Each of the 12 Contaminant Detection Classes

Source of Information	Monitoring or Surveillance Technique	Contaminant Detection Class											
		1	2	3	4	5	6	7	8	9	10	11	12
Drinking Water Utility	Online Water Quality Monitoring	**M**	**H**	**H**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**H**	**M**
	Laboratory Analysis	**H**	**H**	**H**	**H**	**M**	**M**	**H**	**M**	**M**	**M**	**M**	**H**
	Field Testing	**H**	**H**	**H**	**H**	**L**	**M**	**M**	**M**	**M**	**M**	**M**	**L**
	Consumer Calls	**H**	**H**	**M**	**M**	**L**	**L**	**L**	**L**	**L**	**L**	**L**	**L**
Public Health	SS: 911, EMS, or ED Visits	NA	**H**	**H**	**H**	**H**	**H**	**M**	**M**	**M**	**L**	**L**	**L**
	SS: Clinical Diagnosis	NA	NA	NA	NA	NA	NA	**H**	**H**	**H**	**H**	**M**	**L**
	SS: Other*	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**H**	**L**

H: High potential for detection via the specified technique
M: Moderate potential for detection via the specified technique
L: Low potential for detection via the specified technique
NA: Technique not applicable for the listed contaminant class
SS: Syndromic surveillance
*Other types of syndromic surveillance include OTC sales, laboratory orders, etc.

While derived from a list of 33 contaminants, these 12 classes are comprehensive for the 'priority list' contaminants because the classes are representative of all contaminants on that list (USEPA, 2005c). Using these contaminant detection classes is particularly useful from a design perspective because they allow the WS-CWS to be designed from a small number of contaminants that represent the various detection classes, while still providing coverage of a large number of contaminants, including—and beyond—those on the 'priority list.' Thus, these contaminant detection classes form a critical element of the design basis for the WS-CWS.

2.2 High Impact Contamination Scenarios

A drinking water distribution system in even a moderately sized city can consist of thousands of miles of pipe and tens of thousands of access points. At a minimum, each of these access points, or nodes, can represent a potential location of contaminant introduction, and in the absence of specific threat information, one may consider all nodes to be equally likely points of contaminant introduction (Murray et al., 2004). However, the consequences of an attack can vary significantly at different nodes. Using hydraulic distribution system, fate and transport, exposure and disease transmission models, the consequences associated with contamination attacks at each accessible node can be estimated.

To evaluate the consequences associated with different distribution system nodes, attacks were simulated at all nodes using one contaminant with the contaminant volume, concentration, and injection rate held constant so that only the insertion point varied. The nodes were then ranked according to the relative magnitude of the consequences associated with an attack at that node. The results of this analysis are graphically depicted in **Figure 2-1** as a cumulative distribution function (CDF). The CDF shows the probability (y-axis) that a contamination incident at a particular node would result in consequences at or below the corresponding value on the x-axis, as shown in Figure 2-1. This particular CDF shows that there is a relatively low probability (~20%) of a random attack producing consequences impacting more than 1,000 people. Stated another way, attacks at roughly 80% of the nodes will produce consequences affecting less than 1,000 people. This is significant given that the most severe attack could result in consequences for close to 3,000 people. This information can be used in the design basis to focus efforts on the relatively small percentage of nodes that produce the highest consequences.

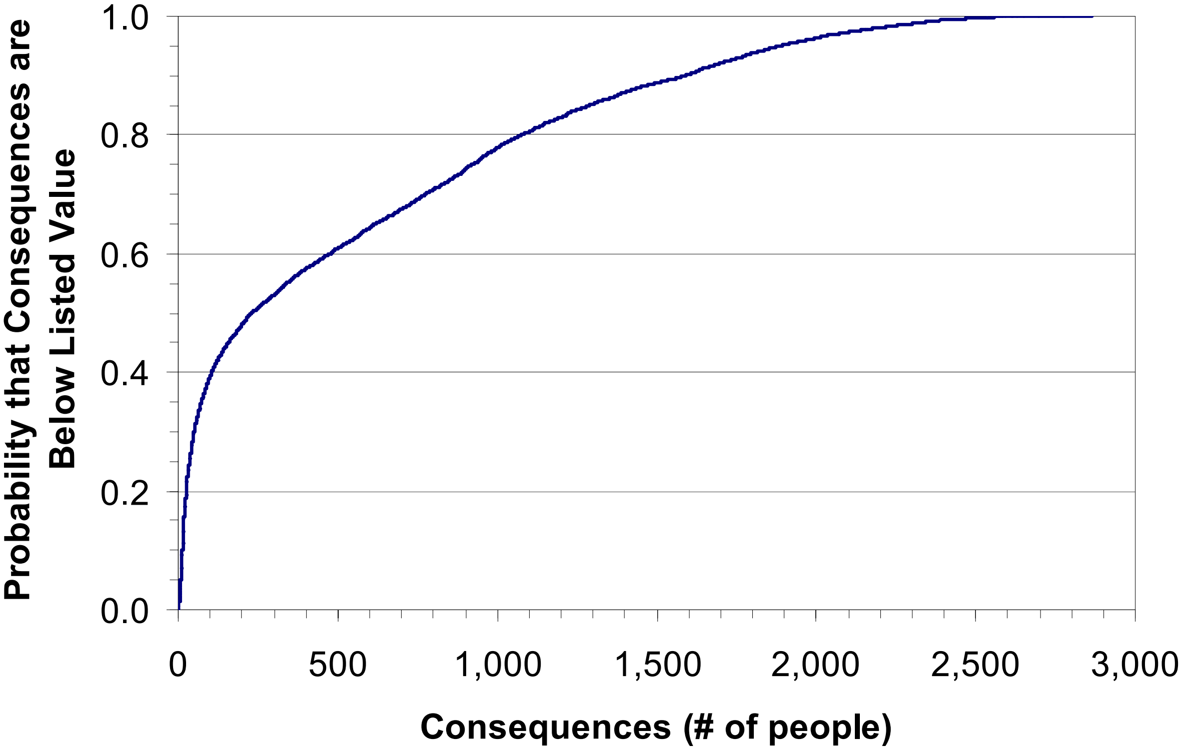


Figure 2-1. Cumulative Distribution Function of Consequences for all Possible Insertion Points in a Distribution System using one Specific Contaminant

The consequences shown in Figure 2-1 could represent several different endpoints, such as number of exposures, number of illnesses, number of fatalities, area of the distribution system contaminated, miles of pipe contaminated, number of people without potable water, or the overall economic damage resulting from contamination. Regardless of the metric used to quantify consequences, this approach can be used to identify the nodes at which contaminant introduction results in the highest consequences for a given system. However, the relative ranking of nodes would vary as a function of the metric used to quantify the consequences of the attack; thus the measure used to quantify consequences in this analysis should be selected thoughtfully.

While the results discussed in this section are specific to one distribution system and one contaminant, similar results have been obtained for several different systems and all contaminant classes listed in Table 2-2. A consequence assessment, such as the one presented here, can aid in the identification of nodes where the introduction of a specific contaminant would produce the most significant consequences in a particular distribution system. While it is desirable to design a system with the potential for detection of contamination at any node, it is critical that the system be able to detect those incidents with the potential to yield the highest consequence. Thus, the ‘high-consequence’ nodes identified through a consequence assessment are a key element of the design basis for a CWS.

2.3 Contamination Incident Timeline

A key requirement of the WS-CWS is to provide initial detection in a timeframe that allows for the implementation of response actions that result in a significant reduction in consequences. This aspect of the WS-CWS design was evaluated through a timeline analysis, the details of which are provided in *WaterSentinel Contamination Incident Timeline Analysis* (USEPA, 2005b). This document describes the methods and assumptions underlying the timeline analyses, and therefore provides critical insight for understanding the results from these analyses. In summary, contamination incident timelines were generated for 10 of the contaminant detection classes listed in Table 2-2 in order to understand how the contamination events would impact the consumer population over time, the time and method of initial detection, and the benefit provided by the integrating multiple detection strategies. Using a suite of modeling tools, contamination scenarios were simulated at each possible point of contaminant introduction in a specific drinking water distribution system. The conclusions of this analysis were used to evaluate the WS-CWS design against the requirement for timely detection.

The results of the entire ensemble of timelines (approximately 10,000 scenarios per contaminant, for a total of 100,000 scenarios) were statistically evaluated for each contaminant class to characterize the general trends in the propagation of consequences and the time of detection through various monitoring and surveillance strategies. **Table 2-3** presents a statistical summary of the time to the various consequence and detection events including the median and 25th to 75th percentile range, as calculated from the complete ensemble of scenarios. Analysis of the time to the first 1% of potential fatalities shows a very narrow distribution, with the 25th, 50th, and 75th percentiles being equal in most cases. This is due to the fact that the timing of the first fatalities is largely a function of the contaminant attributes, such as the time to onset of symptoms. This also explains the range in the median times to the first fatalities across the different contaminant classes. Fast-acting chemicals, such as those included in classes 2 through 6 result in fatalities shortly after exposure, while the pathogens (classes 10 and 11) have latency periods of several days to longer than a week. The time to 50% of exposures is much more consistent across the different contaminant classes, with median values ranging from 5 to 8 hours. Exposures are largely influenced by system hydraulics and demand patterns, and thus the timing of exposures is less a function of the contaminant, and more a function of the scale of the incident. The latter point is illustrated by the large inter-quartile range of times to 50% of potential exposures, which range from 1 to 20 hours. In general, the larger the consequences, the more time it takes to reach 50% of the potential exposures, for the simple reason that it takes more time for the contaminated water to reach the larger number of people that will ultimately be exposed. This is further evidenced by the relatively short times for contaminants that produced relatively low numbers of exposures over all scenarios (e.g., classes 4, 5, and 9), compared to those that produced high consequences and generally had longer times.

Table 2-3. Statistical Summary of Consequence and Detection Times over all Possible Scenarios for Each Contaminant Detection Class

Class	Median[1] Time to Consequence or Detection Event (hours)					
	1% Potential Fatalities	**50% Potential Exposures**	**Online WQ Sensors**	**Consumer Calls**	**PHS 911/ED/EMS**	**PHS Syndromic**
2	**3** (3 to 3)	**8** (1 to 16)	**8** (5 to 13)	**7** (6 to 10)	**7** (7 to 8)	**N/A**
3	**8** (8 to 9)	**8** (2 to 18)	**8** (5 to 12)	**7** (6 to 10)	**7** (7 to 8)	**N/A**
4	**3** (3 to 3)	**5** (1 to 8)	**9** (6 to 15)	**7** (5 to 10)	**7** (7 to 7)	**N/A**
5	**3** (3 to 3)	**6** (1 to 10)	**9** (6 to 13)	**N/A**	**7** (7 to 7)	**N/A**
6	**3** (3 to 3)	**7** (1 to 14)	**8** (5 to 12)	**N/A**	**7** (7 to 7)	**N/A**
7	**27** (27 to 27)	**6** (1 to 12)	**8** (5 to 12)	**N/A**	**10** (10 to 11)	**37** (37 to 38)
8	**49** (49 to 50)	**8** (1 to 19)	**7** (5 to 11)	**N/A**	**30** (30 to 30)	**59** (59 to 60)
9	**19** (19 to 19)	**5** (1 to 10)	**9** (6 to 13)	**N/A**	**17** (16 to 19)	**43** (43 to 44)
10	**361** (361 to 362)	**8** (1 to 20)	**9** (6 to 15)	**N/A**	**N/A**	**133** (133 to 134)
11	**337** (337 to 337)	**8** (1 to 18)	**8** (5 to 15)	**N/A**	**N/A**	**207** (205 to 210)

1. The median or 50th percentile is shown in bold, while the 25th to 75th percentile range is shown in parentheses.

For proper interpretation of the statistical analysis, it is important to understand that not all of the contamination incidents simulated were detected by a given monitoring strategy. Some of the scenarios resulted in no exposures or fell below the detection threshold and therefore were not detected. For each contaminant class, online monitoring detected between 33-45% of all class 2-11 scenarios; 911 calls detected 77-80% of class 2-9 scenarios; customer complaints detected between 64-70% of class 2-4 scenarios; public health surveillance (clinical) detected 50-79% of class 7-11 scenarios; and public health surveillance (syndromic) detected 51-54% of class 10-11 scenarios. It is important to note that the scenarios not detected were generally those with few exposures. Furthermore, the time available to detect and respond to a low consequence scenario is remarkably short as discussed previously. However, it is important to consider that the WS-CWS is being designed primarily to detect high consequence incidents, as will be illustrated through specific scenarios, rather than statistical summaries, later in this section.

The times to initial detection reported in Table 2-3 illustrate important trends in detection through the various monitoring and surveillance strategies. Online monitoring exhibited the largest inter-quartile range (as a percentage of the median value) of detection times, largely due to the limited number of monitoring stations that could reasonably be deployed in a distribution system. Scenarios in which a contaminant is inserted at a location far from the closest monitor should take several hours to detect, while contamination inserted immediately upstream of the monitor should be detected within minutes. Furthermore, the time to initial detection through online monitoring is generally independent of the contaminant class, although some contaminants should be more readily detected at lower concentrations than others (and some, like class 6, require specialized instrumentation). Additionally, detection through online monitoring is independent of the number of people exposed – it can detect an incident before anyone is exposed but can also miss a large incident with numerous exposures if there are no monitoring stations in the vicinity of the incident.

Contaminants with a discernable taste or odor are likely to be detected through consumer calls (classes 1, 2, 3, and 4). Detection through consumer calls is directly related to exposures, and there are a minimum number of exposures that should occur before the utility should be alerted to the problem (68 exposures based on the assumptions of this analysis). For this reason, small-scale incidents should take longer to detect through consumer calls, or may not be detected at all. However, incidents with even a modest number of exposures (i.e., more than 100) should be detected very quickly through this surveillance technique, with the most significant time delay attributable to the time that it takes consumers to call the utility and the time that it takes the utility to process the calls and recognize a potential problem.

Chemicals and biotoxins that produce very severe or sudden symptoms (classes 2 through 6) or symptoms of a unique nature (classes 7 through 9) are likely to be detected through public health surveillance of 911 calls, ER visits, or EMS logs. Similar to consumer complaints, detection through this surveillance technique is directly related to the number of symptomatic people. Due to the severity of symptoms associated with most of these contaminants, even a relatively small incident is likely to be detected through this surveillance method. For fast-acting chemicals, the most significant time delay for detection through this technique is the time that it takes for public health to recognize the potential problem followed by the delay in alerting the utility to the potential problem. For other contaminants, such as the biotoxins, the time lag between exposure and onset of symptoms is the most significant delay in detection.

Pathogens that produce serious diseases with a gradual onset of symptoms (classes 10 and 11) are likely to be detected through public health surveillance of clinical cases of a specific disease or surveillance of general health indicators in the population. As shown in Table 2-3, detection through this form of public health surveillance occurs much later than detection through online monitoring. Comparison of these times with the times to 50% of potential exposures clearly indicates that detection through this technique comes too late to prevent exposures; however, it may provide ample time for medical intervention to minimize the number of fatalities.

In general, the detection sequences for contaminant classes 1 through 9 can vary from one scenario to another. For example, in one case it may be public health (PH)-911 – Consumer Calls – Online Monitors. In another scenario for the same contaminant, it may be Online Monitors – Consumer Calls – PH-911. This indicates that information from multiple data streams should be available in a similar timeframe for most of the contaminants in these classes. However, classes for which public health surveillance (clinical or general) is applicable, there would generally be two detection opportunities: 1) rapid detection through online monitoring, or possibly 911 calls, in time to limit exposures through utility response actions and 2) delayed detection through public health surveillance (clinical or syndromic) that comes too late to prevent exposures, but which could inform medical response actions and minimize the number of fatalities or severe illnesses.

In addition to the statistical summary presented above, one specific scenario per contaminant was analyzed in greater detail to illustrate the timing of detection and response actions. The scenario selected was that resulting in the 90th percentile consequences (i.e., only 10% of the scenarios have consequences more severe than this example scenario). The timeline summary presented in **Table 2-4** lists three critical points in the timeline for the 90th percentile scenario:

- The time that ‘possible’ water contamination was detected through one of the WS-CWS components, and the means of initial detection. Following the detection of ‘possible’ contamination, it is assumed that the utility should begin collecting additional information in an effort to establish whether or not the incident is ‘credible.’
- The time that the contamination incident was determined to be ‘credible’ and the information that provided the basis for this determination. Once an incident has been deemed ‘credible’ it is assumed that response actions are implemented to prevent further exposures and fatalities.
- The consequences that would be prevented, in terms of exposures and fatalities, if effective response actions were implemented 15 hours after credibility was established.

The time (ΔT) to each critical event in the timeline is reported relative to the start of contaminant insertion, which is the time shortly before exposures begin.

Table 2-4. Timeline Summary for the 90th Percentile Scenarios for each Contaminant Detection Class

Class	'Possible' Contamination		'Credible' Contamination		Consequences Prevented	
	Means of initial detection	ΔT[1]	Basis for Determination	ΔT[1]	Exposures	Fatalities
2	Consumer calls	4:30	PH surveillance – 911 calls	5:30	54%	61%
3	Consumer calls	7:00	PH surveillance – 911 calls	7:30	61%	85%
4	Online monitoring – cond.	2:00	PH surveillance – 911 calls	5:30	4%	6%
5	PH surveillance – 911 calls	7:30	Online monitoring – TOC	13:00	30%	32%
6	PH surveillance – 911 calls	12:30	Online monitoring – GC/MS	14:00	63%	68%
7	Online monitoring – cond.	21:00	PH surveillance – 911 calls	24:00	22%	99%
8	Online monitoring – Cl_2	6:00	Site characterization	9:00	45%	100%
9	Online monitoring – TOC	12:00	Site characterization	14:30	27%	79%
10	Online monitoring – Cl_2	25:00	'Unknowns' analysis - PCR	37:00	55%	100%
11	Online monitoring – Cl_2	3:00	'Unknowns' analysis - PCR	14:00	27%	100%

1. ΔT is the time in hours and minutes (hh:mm) that the incident was deemed 'possible' or 'credible' relative to the start of contaminant insertion.

These results for the 90th percentile scenarios generally reinforce the trends observed in the overall statistical analysis. Initial detection and subsequent credibility determination for contaminant classes 1 through 7 should generally occur rapidly through some combination of consumer calls, 911 calls, or online monitoring, as applicable to the specific contaminant. There is a relatively short time delay between initial detection and determination that the threat is 'credible' (½ to 5½ hours) for all of these contaminants due to comparable times in which information from these various detection strategies becomes available. The ability to quickly establish credibility in these scenarios provides sufficient time for response actions to prevent over 50% of potential exposures and fatalities in most cases. The scenario for contaminant class 4 is an exception in that response actions were implemented too late to prevent a significant percentage of consequences. Similarly, a relatively small percentage of exposures were prevented for classes 5 and 7. One reason for this is the relatively low number of exposures compared with the other scenarios (5 to 10 times fewer exposures), and as discussed previously, low consequence incidents are more difficult to detect in sufficient time to respond in a manner that limits consequences.

Classes 8 and 9, representing the biotoxins on the WS baseline contaminant list, and classes 10 and 11, representing the pathogens on the WS baseline list, are all initially detected through online monitoring of chlorine residual and TOC. These initial detection times vary based on the relative location of the sensor to the point of contaminant insertion, and over just these 4 scenarios range from 3 to 25 hours. For the class 8 and 9 contaminants, credibility is established a few hours after initial detection through the use of field tests implemented during site characterization. For the class 10 and 11 contaminants, credibility can not be established until the results of polymerase chain reaction (PCR) analysis, part of the 'unknowns' analysis are available. The field tests available for pathogens are not sufficiently sensitive to detect them at concentrations of concern in drinking water.

Contaminant classes 2 through 6 represent fast-acting chemicals with a very short time between exposure and serious health consequences. Thus, for these contaminants the only response actions that would minimize consequences are those that limit exposures, such as issuance of a 'do not use' notice, several hours before the majority of potential exposures occur. After this point, there is little that can be done to minimize the public health consequences. Similarly, rapid response to infrastructure threats, such as classes 1 and 12, are necessary to minimize the spread of the contaminant, and thus the effort required for remediation and recovery.

Classes 8 through 11 represent contaminants with a latency period for which medical treatment is available. There are two opportunities for response for these contaminants. The first occurs if initial detection and credibility determination occur quickly enough to limit exposures. The specific scenarios summarized in Table 2-4 for these contaminant classes follow this model, with initial detection occurring soon enough to allow for effective response actions to minimize exposures. However, if this first opportunity is missed, there is a second opportunity for detection through public health surveillance, as shown in Table 2-3. While this occurs too late to prevent any exposures, it could provide sufficient time to implement medical response actions to limit the number of serious health consequences and fatalities.

The results of the timeline analysis demonstrate different detection sequences (i.e., the relative time that the various WS-CWS components provide information about potential contamination) associated with each contaminant detection class. **Figure 2-2** presents a simple graphical summary of the relative timing of consequences for different contaminant categories and detection by WS-CWS components.

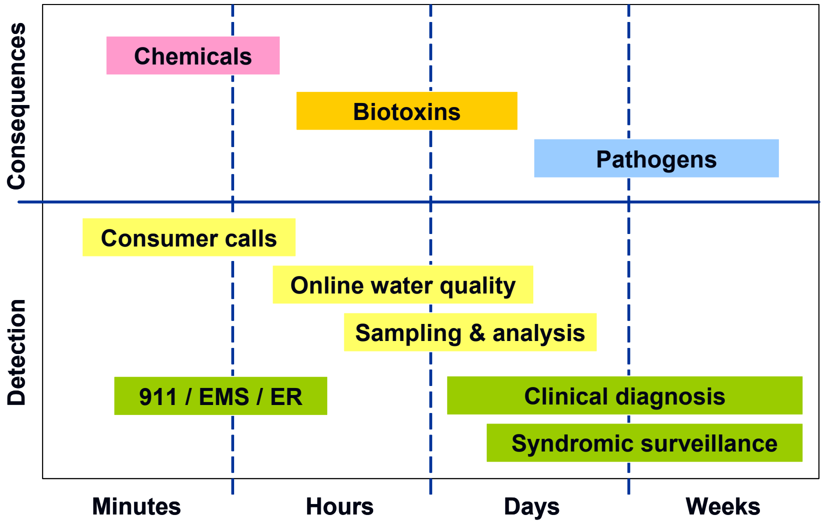


Figure 2-2. Relative Timing of Consequences and Detection

In summary, the contamination incident timeline analysis considered approximately 100,000 contamination scenarios involving 10 different contaminants in one real drinking water distribution system. Based on a preliminary analysis of the contamination incident timelines, all classes that should be considered in the WS pilot can be detected in a time period that allows for effective response to reduce consequences, but only through the use of multiple monitoring and surveillance strategies included in the WS-CWS design. Furthermore, the statistical analysis of the timelines has established the likely detection sequence, as well as the time available to prevent exposures and treat those who have been exposed. It also demonstrates the importance of reducing response times for all contaminant classes and quantitatively estimates the public health benefits of reducing response times (and conversely, the public health costs of delaying response). However, the timeline analysis also points to several challenges that should need to be addressed in the design and implementation of a successful CWS:

- Low consequence incidents are difficult to detect in sufficient time to minimize exposures, although this limitation is offset to some extent by the fact that the incident is of lower consequence.
- Consumer calls and public health surveillance of 911 calls and ER visits can provide timely detection of a fast-acting chemical or toxin, but only if the data can be effectively mined and quickly communicated to the utility.
- Online water quality sensors may be the only means of early detection of contaminants such as pathogens and biotoxins, but only if the event detection system used with the water quality sensors performs well at detecting true contamination incidents while minimizing false alarms.

- Site characterization and ‘unknowns’ analysis are important for corroborating ‘possible’ contamination under many scenarios, but further refinement and validation of these tools are necessary to be able to use them with confidence.
- Public health surveillance of clinical cases and general symptomatic information is a potential means of detecting a potential public health crisis, but not in sufficient time to limit exposures to contaminated water resulting from a short-term contamination incident. Furthermore, communications between public health and the utility need to be optimized to quickly recognize a potential link to drinking water.

2.4 Additional Design Considerations

The previous subsections have described principal considerations in the development of a design basis for a contamination warning system, namely high consequence locations of contaminant introduction, high consequence contaminants and the means by which they might be detected, and the relative time in which contamination might be detected through different monitoring and surveillance techniques. This section describes two other important design considerations: reliability and sustainability.

2.4.1 System Reliability

For a CWS, reliability can be considered from at least two perspectives. The first is system operation, that is, factors such as CWS component downtime and maintenance requirements. The second is system performance, defined as the ability of the system to provide information that leads decision makers to successfully infer that contamination has or has not occurred. While both aspects of reliability are important, the latter is more pertinent to the conceptual design of a system because it relates to the ‘information reliability’ of a system that is largely based on the acquisition/interpretation/management of information. Thus, this section will focus on system performance.

System performance can be characterized in terms of the probability of detecting an intentional contamination incident, which is expected to occur infrequently, relative to the probability of a false alarm (i.e., a false-positive). For hazardous conditions that occur, the probability that an environmental indicator (e.g. public health surveillance, water quality monitoring, etc) will identify a contamination incident can be calculated through the use of Bayesian inference (Hrudey and Rizak, 2004). Given the low probability of a contamination incident, the probability that any one data stream will identify a contamination incident will itself be low. However, the information available from the multiple WS-CWS components can increase the probability of accurately detecting an anomalous condition in the water system. While the quantitative improvement in probability of correctly identifying contamination can vary significantly depending on the characteristics of the various information streams, the qualitative benefit of using multiple data streams should remain. A more complete discussion of this approach and its implications is found elsewhere (Magnuson, et. al., in preparation).

To illustrate the improvement in system performance achieved by integrating multiple data streams, the following simple example considers two water quality parameters that should be included in the WS-CWS design: chlorine and total organic carbon (TOC). For the purpose of this analysis, it is assumed that a contamination incident should decrease chlorine residual and increase TOC levels. Assuming that the two sensors are co-located, they measure the same parcel of water, thus eliminating any confounding factors associated with spatial variability. It is also assumed that the responses from each of the two sensors are independent of one another in the absence of a water quality change, and that, in the case of a water quality change, that the response of one sensor is independent of the other. **Table 2-5** provides example event detection characteristics for the chlorine sensor and TOC analyzer. The actual event detection characteristics would have to be experimentally determined and may vary with the magnitude of the sensor response.

Table 2-5. Probability of Sensors Responding

	Chlorine Sensor	TOC Sensor
Probability of sensor producing true positive response	0.99	0.95
Probability of sensor producing false positive response	0.05	0.01

Figure 2-3 provides an illustration of chlorine and TOC sensor response data with significant deviations from the baseline. The figure also illustrates the calculated posterior probability of an event, calculated with one sensor or a combination of both sensors. It was assumed that the event only occurs 1 time in a 1000. When the individual sensors are both detecting a change (t=8), the calculated posterior probability from the chlorine sensor data and the TOC sensor data is 0.02 and 0.09, respectively. When both sensors are detecting a change (t=8), the calculated posterior probability increases to 0.65. Another observation in Figure 2-2 is that when one sensor is responding and the other is not, the posterior probability calculated from combining the data is in between the probabilities calculated for the individual sensors (t=3,4). If neither sensor is detecting a change, combining the information decreases the calculated posterior probability of an event.

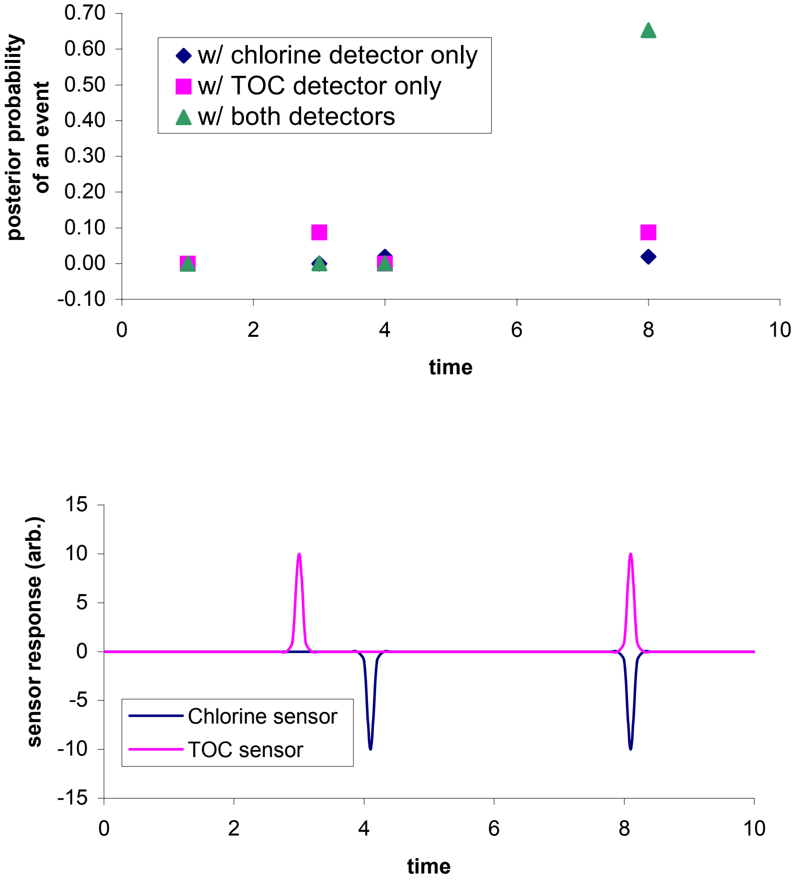


Figure 2-3. Comparison of the Posterior Probability of an Event Using Data from Individual and Multiple Water Quality Sensors

While one of the ultimate objectives of WaterSentinel is to better characterize the actual probabilities of contamination detection through monitoring and surveillance, this example illustrates that integration of multiple data streams can dramatically improve system performance and overall reliability for detecting contamination incidents. The multiple monitoring and surveillance techniques used in the WS-CWS extend beyond integration of multiple water quality data streams to other independent information streams including water quality data, consumer calls, public health surveillance, security alarms, results from site characterization and sample analysis. The WS-CWS pilot should provide an unprecedented opportunity to develop the information necessary to better characterize and quantify the value of integrating information from numerous monitoring and surveillance activities to improve our ability to reliably detect contamination incidents, i.e. to minimize the frequency of false alarms.

In addition, the approach described in this section may be beneficial in quantitatively elucidating the ‘dual-use’ benefits of CWS, which are related to system sustainability, which is more completely discussed below. Namely, the type of events which could be viewed as ‘dual-use’ may occur more frequently that intentional contamination. Using estimates for the occurrence of these non-security related water quality events, which could be available from water utility operation records, probabilistic calculations can be performed to inform decisions regarding the implementation of various monitoring and surveillance strategies with dual-use application. For example, the probabilities of detection could be compared for different online sensors that respond accurately 85% and 95% of the time, respectively. Based on the occurrence rate of the ‘dual-use’ event being considered, it is possible that the calculated probability of detection of this event by the two sensors is similar. If the first sensor only costs 1/10 of the second, clear savings may be realized, while maintaining a similar level of ‘dual-use’ benefit. Such considerations are important to the long-term sustainability of the system as utilities make decisions regarding the investment of limited resources in various CWS components. Other considerations related to sustainability are discussed in the following subsection.

2.4.2 System Sustainability

Sustainability of a CWS considers factors that influence the ability of an entity, such as a drinking water utility, to operate and maintain the CWS over an extended period of time and in the face of competing priorities that could siphon resources away from the program. In most cases, the analysis of sustainability for a CWS should entail a cost-benefit analysis. An order-of-magnitude cost estimate for the development and implementation of the WS-CWS pilot at one utility in 2006 is presented in Section 2.5.

Benefits of the WS-CWS can be characterized as primary or secondary. Primary benefits should be related to the early detection of, and response to, a contamination incident, and might be quantified in terms of consequences avoided due to the implementation of the CWS. The primary benefits of the system can be estimated through modeling, but should ultimately need to be assessed during evaluation of the WS pilots.

Additional benefits consider ‘dual-use’ application of the system, potentially including:

- Detection of cross-connections and other distribution system water quality problems.
- Enhanced knowledge of distribution system water quality leading to improved operations (e.g., more consistent disinfection residual levels, improved corrosion control, early warning about nitrification episodes, means to evaluate the efficacy of flushing programs, etc.)
- Identification of problem valves (closed, partially closed, inoperable).
- Improved relationship with public health, including mutual sharing of information and alerts.
- Improved coordination with local, state, and federal response organizations.
- Consequence management plans applicable to any water quality emergency.
- Improved consumer complaint tracking and response.

- Integration of disjointed information resources and systems.
- Improved laboratory capability and application of methods developed for WS to routine water quality monitoring programs.
- Established relationships with reference and confirmatory labs.

2.5 Preliminary Cost Analysis for the WaterSentinel Contamination Warning System

An important aspect of sustainability for a CWS at any water utility is the cost of implementation and maintenance. While the specific costs associated with implementation of the WS-CWS should be based on the utility-specific system architecture, an order-of-magnitude cost analysis was conducted to provide an initial assessment of costs associated with various approaches for system design and varying degrees of utility capability. *Preliminary Cost Analysis for WaterSentinel Contamination Warning System* presents a detailed description of the preliminary cost analysis (USEPA, 2005g). One of the objectives of the WS pilot is to develop more detailed and accurate cost estimates for the deployment and operation of a CWS.

Costs were estimated for the Fiscal Year 2006 (FY06) WS pilot project and focused specifically on establishing and/or enhancing those WS-CWS components that were exclusive to the WS program and that would be incurred to deploy and operate the WS-CWS. Costs for activities that would support the WS program and other programs, and costs that would be incurred only in the event of a credible incident were not included. These included Agency programmatic costs; costs related to laboratory network infrastructure; data management infrastructure; analysis of triggered or response samples; and consequence management in the event of an incident.

Each WS-CWS component was analyzed, and costs were estimated for ‘low,’ ‘moderate,’ and ‘high’ categories based on component-specific variations in terms of levels of existing utility capability. **Table 2-6** summarizes the definitions of these cost categories for each of the WS-CWS components.

Table 2-6. Definition of Cost Categories for WS-CWS Components

WS-CWS Component	High-Cost Category	Moderate-Cost Category	Low-Cost Category
Online Water Quality Monitoring	**The utility has a hydraulic and water quality network model that, through the application of tracer studies and water quality monitoring program, requires significant modification and refinement to adequately represent distribution system hydraulics prior to designing a sensor network through approaches such as TEVA.**	**The utility has a hydraulic and water quality network model that, through the application of tracer studies and water quality monitoring program, has been sufficiently developed to adequately represent distribution system hydraulics prior to designing a sensor network through approaches such as TEVA.**	**The utility has a hydraulic and water quality network model that has already been verified through their own tracer studies and water quality monitoring program ensuring a network model that adequately represents distribution system hydraulics and is suitable for designing a sensor network through approaches such as TEVA.**
Sampling and Analysis	**Analysis of all baseline monitoring samples for both chemicals and pathogens are performed by a contract laboratory. Baseline samples are collected on a monthly basis.**	**Analysis of all baseline monitoring samples for chemicals performed by utility laboratory; for analysis of pathogens a contract laboratory should be used. Baseline samples collected on a monthly basis.**	**Analysis of all baseline monitoring samples performed by utility laboratory; samples collected on a monthly basis.**

WS-CWS Component	High-Cost Category	Moderate-Cost Category	Low-Cost Category
Consumer Complaint Surveillance	**Manual tracking of consumer complaints within a utility.**	**Semi-automated tracking of consumer complaints within a utility.**	**Existing, automated tracking of consumer complaints within a utility.**
Enhanced Security Monitoring	**Significant enhancements to existing physical security monitoring including installation of monitoring equipment at 20 field locations and 20 water quality monitoring stations.**	**Moderate enhancements to existing physical security monitoring including installation of monitoring equipment at 10 field locations and 10 water quality monitoring stations.**	**Minimal enhancements to existing physical security monitoring stations including installation of monitoring equipment at 1 field location and 9 water quality monitoring stations.**
Public Health Surveillance	**No existing syndromic surveillance at local health department(s).**	**Existing syndromic surveillance at local health department(s), but there is no existing mechanism for integration of water quality data.**	**Utility is participating in National Homeland Security Research Center (NHSRC) public health surveillance research project to integrate water quality and public health data.**

Table 2-7 summarizes the results of the costing exercise for each WS-CWS component. For all WS-CWS components, the cost analysis included estimates for preliminary assessments and modifications to facilitate integration of the component as part of the WS-CWS; costs associated with installations and enhancements to existing systems, hardware, and operations; costs associated with utility labor and operation and maintenance; data management and analysis; and estimated EPA support.

Table 2-7. Preliminary WS-CWS Component Cost Estimate

WS-CWS Component	High-Cost Category	Moderate-Cost Category	Low-Cost Category
Online water quality monitoring	$ 4,200,000	$ 2,500,000	$ 1,400,000
Sampling and analysis	$ 1,200,000	$ 700,000	$ 500,000
Consumer complaint surveillance	$ 1,100,000	$ 500,000	$ 200,000
Enhanced security monitoring	$ 4,400,000	$ 2,300,000	$ 700,000
Public health surveillance	$ 1,500,000	$ 800,000	$ 400,000

Additional considerations for the preliminary cost analysis are summarized below for each of the WS-CWS components.

2.5.1 Online Water Quality Monitoring

As presented in Table 2-6, the state of the utility's hydraulic model was a driving factor in the assessment of estimated costs associated with online water quality monitoring. The cost analysis included estimated costs for model refinement and calibration as defined in the cost categories in Table 2-6 as well as costs associated with conducting tracer studies, and applying TEVA or other approaches to determine monitoring station locations. Based on preliminary results available from TEVA, an estimate of 30 monitoring stations within the distribution system was used. The actual number of monitoring stations deployed to achieve a certain level of coverage should vary by utility. Estimated costs for each monitoring station included the following components:

- **Capital costs:** Include estimated costs associated with the multi-probe sensor, filter apparatus (for routine or triggered sampling), composite sampler (for routine or triggered sampling), installation, supervisory control and data acquisition (SCADA) connection, and capital infrastructure improvements. Capital equipment costs were based on estimates developed for EPA's Test and Evaluation (T&E) facility for YSI Sonde and Hach Astro TOC (USEPA, 2005j).

- **Operation and Maintenance (O&M) costs:** Include estimated costs associated with the maintenance of hardware and software for each monitoring station based on estimates developed for EPA's T&E facility for YSI Sonde and Hach Astro TOC (USEPA, 2005j).
- **Labor costs:** Include estimated costs associated with reagent preparation, calibration, travel, and maintenance based on estimates developed for EPA's T&E facility for YSI Sonde and Hach Astro TOC (USEPA, 2005j).

2.5.2 Sampling and Analysis

As in the estimate for online monitoring, the cost analysis for the sampling and analysis component of the WS-CWS assumed 30 sampling sites within the distribution system based on preliminary results available from TEVA. However, the number of sampling sites should vary for each utility implementing a CWS. Considerations for selection of sampling locations and development of a baseline monitoring program are discussed in Section 4.2. Analytical costs were based on commercial laboratory estimates for the contaminants or contaminant classes of concern. For chemical contaminants, it was assumed that up to an additional two or three contaminants could be identified for little to no additional analytical cost. For pathogens, select agent costs were based on estimates provided by the Laboratory Response Network (LRN) for environmental sample analysis by LRN labs performing analyses for commercial customers during the anthrax attacks in fall 2001. It should be noted that additional investment needed to implement in-house capability at the utility laboratory is substantial, but utility specific. Laboratory infrastructure needs would be evaluated in terms of sustainability of the CWS at a given utility and would need to be consistent with the utility's long-term business case.

For the purpose of this estimate, analytical costs per sampling station included the following:

- **Pathogens:** Six bacteria, four of which are also select agents
- **Chemicals, radionuclides, and biotoxins:** Cyanides (1 contaminants), Arsenic compounds (1 contaminant), Metals (2 contaminants), Fluoride compounds (1 contaminant), Herbicides (1 contaminant), Petroleum products/hydrocarbons (2 contaminants), Organophosphorus compounds (7 contaminants), Rodenticides (1 contaminant), Carbamates (4 contaminants), PCBs (1), Radionuclides (3 contaminants), Biotoxins (3 contaminants)

2.5.3 Enhanced Security Monitoring

Many drinking water utilities have implemented or are in the process of implementing physical security enhancements based on vulnerability assessments conducted as a requirement under the *Bioterrorism Preparedness and Response Act of 2002* (BTACT, 2002). As such, costs associated with implementation of this component should generally focus on integration of physical security information with other CWS components and perhaps enhanced security monitoring at a small number of locations.

2.5.4 Consumer Complaint Surveillance

Approaches for recording, tracking, and managing consumer complaints vary from city to city. Upgrades to consumer complaint surveillance software and data management tools along with establishment of integrated call centers were driving factors in costs associated with implementation of this component of the WS-CWS. Additional considerations for implementation of consumer complaint surveillance are discussed in Section 6.1.

2.5.5 Public Health Surveillance

Integration of public health surveillance as a component of the WS-CWS requires the utility to coordinate with the local health department(s) and may require the utility to provide support to the health department(s) in terms of capital costs, labor, or both. This cost analysis assumed that there will be an electronic exchange of water quality and health data through a syndromic surveillance system. For the initial WS pilot, EPA plans to work with the pilot utility and local health department(s) to determine the most effective means to exchange information given existing systems, existing protocols, and staffing resources. Section 7.2 discusses alternate options and considerations for implementation of this component of the WS-CWS.

The results of this preliminary cost analysis suggest the following in terms of design of the WS-CWS:

- Leveraging of existing EPA programs (e.g., TEVA) and water security efforts (e.g., enhanced security monitoring as a result of vulnerability assessments) provides a significant advantage in terms of both the cost associated with implementation of the WS-CWS at the pilot utility and the time required to implement the WS-CWS components.
- While multiple design options may be considered for implementation of each WS-CWS component, the cost of implementation and sustainability of these options should be considered in order to meet the objectives of the WS program as identified in Section 1.

While this costing exercise provides a useful tool for evaluation of design options based on existing utility capability, it is not meant to be a definitive analysis of costs associated with implementation of the WS-CWS, but an initial estimate. These costs should be tracked and refined through implementation of the WS-CWS pilot to assist in the cost-benefit analysis and evaluation of the WS-CWS design and the WS program.

2.6 Summary of WaterSentinel CWS Design Basis

For the WS-CWS, the design basis is defined as a series of contamination scenarios against which specific design options should be evaluated. The WS design basis considers possible locations of contaminant introduction, various contaminant classes, different methods of detection, timing of detection, reliability, and sustainability. The design of the WS-CWS consists of several monitoring and surveillance strategies including: water quality monitoring, sampling and analysis, enhanced security monitoring, consumer complaint surveillance, and public health surveillance. The manner in which this integrated approach to contaminant warning satisfies the design basis is described by the following:

- **Contaminant Coverage:** Analysis of contaminant properties and detection techniques clearly demonstrates that no single approach would provide timely detection for all contaminants of concern; however, the integrated approach implemented under WS has the potential to provide timely detection of a very high percentage of priority contaminants.
- **Spatial Coverage:** The monitoring components of the WS-CWS (water quality sensors, sampling and analysis, and enhanced security monitoring) have intrinsic limitations to the spatial coverage that each can achieve. On the other hand, surveillance components of the WS-CWS (consumer complaint and public health surveillance) rely on consumer observations and behavior, and thus provide dense spatial coverage throughout a distribution system. Thus, integration of both monitoring and surveillance systems in the WS-CWS is necessary to achieve a high degree of spatial coverage.
- **Timeliness of Initial Detection:** Different contaminants are **first** detected by different monitoring and surveillance techniques. Thus, by integrating multiple data sources, the time of initial detection is reduced across all contaminants, and even those that act very rapidly within the exposed population may be detected in time to implement an effective response.
- **Reliability:** All monitoring and surveillance techniques should produce false positive and false negative results, which decreases reliability of detection. However, integration of multiple data streams can dramatically improve the reliability of the overall system because the overall rate of

false positive and false negatives for the integrated data streams should be substantially lower than the rates for any one detection strategy.
- **Sustainability:** The integration of multiple monitoring and surveillance strategies already in use at the utility and public health department would improve acceptance of the system, and thus long-term sustainability. The CWS is being designed as a dual-use application that should benefit the utility in day-to-day operations while also providing the capability to detect intentional or accidental contamination incidents.

Table 2-8 describes the manner in which each of the WS-CWS components addresses each of these aspects of the WS design basis. Note that some of these benefits cannot be quantified until the WS pilot is deployed and EPA gains substantial experience; thus the importance of implementing and evaluating the WS-CWS through a pilot program.

The design basis presented in this section leads to the multi-pronged approach developed for the WS-CWS, as summarized in Section 1.0. It also forms a framework for system development and a benchmark against which to evaluate the performance of different design options. The following sections provide more detail regarding the basis for including each of the WS monitoring and surveillance components, and describe the general framework for design and implementation of each component.

Table 2-8. WS-CWS Components and their Contributions to the Approach for WaterSentinel

WS-CWS Component	Capability	Contaminant Coverage	Spatial Coverage	Timeliness	Reliability	Sustainability
Online Water Quality Monitoring	**Can indicate the presence of a contaminant that significantly affects one or more monitored parameters that serve as indicators of contamination.**	**High detection potential for classes 2, 3, 5, 8, 10, and 11; Moderate detection potential for classes 1, 4, 7, 9, and 12.**	**Function of location, number, and density of monitoring stations**	**Function of hydraulic travel time from the point of contaminant introduction to the sensor, and the concentration of the contaminant.**	**Rate of false positive / negative results in this application is largely unknown at this time. May be addressed through event detection systems and consequence management.**	**Provides utility with a better understanding of water quality variability throughout distribution system and provides an opportunity to optimize distribution system operation.**
Sampling and Analysis	**Can positively identify the presence of any contaminant in the suite of target analytes and above the MDL.**	**High detection potential for classes 1, 2, 3, 4, 7, and 12; Moderate detection potential for classes 5, 6, 8, 9, 10, 11.**	**Function of location, number, and density of sampling stations, as well as sample type (composite vs. grab).**	**Function of sampling & analysis frequency and the total time required to process the sample and analyze the results.**	**Function of the reliability of sampling and analysis methods (high for established techniques). Baseline needed for reliable interpretation of results.**	**Provides utility with an opportunity to exercise sampling and laboratory protocols and may; provide information about previously unknown contaminants that occur in the system.**
Enhanced Security Monitoring	**Can detect an intrusion that may have provided the opportunity for introduction of *any* contaminant.**	**Covers all contaminant classes.**	**Limited to those elements of infrastructure for which physical security can be monitored.**	**Function of the type of security monitoring system and the time required to evaluate a security breach.**	**Can be a reliable means of identifying an intrusion, especially when these breaches may involve contamination, such as in storage tanks and clear wells. May be addressed through consequence management.**	**Provides utility with increased physical infrastructure protection and awareness. Reduces the occurrence of nuisance tampering.**
Consumer Complaint Surveillance	**Can indicate the presence of a contaminant that significantly affects one or more aesthetic qualities of water.**	**High detection potential for classes 1 and 2; Moderate detection potential for classes 3 and 4.**	**Entire service area for contaminants with detectable organoleptic characteristics.**	**Function of the time from exposures to consumer reporting, complaint categorization, assessment and investigation.**	**A potentially reliable indicator for contaminants with detectable characteristics if a robust complaint reporting and tracking system is in place.**	**Provides utility an opportunity to manage consumer information more effectively and can serve as a tool for enhanced consumer confidence.**
Public Health Surveillance	**Can detect the presence of a symptom or illness in a population which may be the result of the presence of a disease causing agent. May be able to identify the contaminant through clinical diagnosis / testing.**	**Covers contaminant classes 2 through 11; detection potential varies with type of surveillance.**	**Comprehensive coverage of a particular city or county, which may include all, or a large portion of, the service area.**	**Function of the time from the initial exposures, the onset of symptoms, and the point at which public health officials recognize the incident as a potential water-borne illness.**	**May be a reliable means of identifying the incidence of illness in a population, but communication between drinking water and public health officials is not always quick enough for appropriate response, intervention and remedial actions to take place.**	**Provides an opportunity for collaboration between utility and local health department(s).**

Section 3.0: Online Water Quality Monitoring

Online water quality monitoring has been used as a tool in the drinking water treatment industry for objectives such as process control and maintenance of acceptable finished water quality. For example, turbidity has been used as a process control tool for conventional filtration plants for decades. Chlorine residual analyzers are used in the treatment plant to ensure that disinfection requirements are met. pH is monitored to make sure that corrosion control measures are effective. Recently TOC has been used in many utilities to quantify removal of organic matter through various treatment processes and to optimize strategies to minimize the formation of organic disinfection byproducts. Given the familiarity of utility operators with these water quality parameters, and the obvious potential for dual-use application, online water quality monitoring has been considered as a potential means of detecting contamination incidents in the distribution system. However, water quality monitoring in the distribution system has been limited to date, and the application of this tool in the context of a CWS is largely untested.

Nonetheless, online water quality monitoring appears to be one of the more promising approaches for detecting contamination incidents that is currently available, as demonstrated through research conducted over the past few years. Thus, online water quality monitoring is included as a component of the WS-CWS due to its demonstrated potential to rapidly detect contamination through changes in several commonly used water quality parameters. These changes may result from the aqueous chemistry of the contaminant (e.g., dissolution of an organic compound may result in an increase in the TOC concentration) or from reactions with the disinfectant residual (e.g., oxidation of the contaminant consumes the free chlorine residual). While there are limited empirical data regarding the impact of many contaminants of concern on conventional water quality parameters, there has been a substantial amount of research over the past few years demonstrating that many contaminants of concern, including several WS baseline contaminants, can produce measurable changes in conventional water quality parameters. Furthermore, many of these contaminants have been shown to impact water quality at concentrations well below reported lethal dose concentrations. A summary of the results from some of the more comprehensive water quality studies is presented in *Online Water Quality Monitoring as an Indicator of Drinking Water Contamination* (USEPA, 2005h).

Guidance on the design of online contamination warning systems has been provided in ASCE's *Interim Voluntary Guidelines for Designing an Online Contaminant Monitoring System* (Pikus, 2004), which synthesizes many publications on the subject, including: King, et al. (2004), Hargesheimer et al. (2002), Grayman et al. (2001), and Gullick (2001). This section considers the published body of work on the subject, but goes beyond these recommendations to develop a detailed and comprehensive approach to the design of the online monitoring component of the WS-CWS. Specifically, this section describes the basis for the selection of water quality parameters and sensors, the design of various sensor stations, the systematic design of the sensor network, the approach to management and analysis of data from an online water quality monitoring network, and the framework for evaluation of the monitoring network.

3.1 Water Quality Sensors

Sections 3.1.1 –3.1.2 provide an overview of consideration for selection of water quality parameters and selection of water quality sensors in the context of the WS-CWS.

3.1.1 Selection of Water Quality Parameters

As discussed in Section 2.0, one or more conventional water quality parameters have been shown to change with the presence of representative contaminants from 11 of the 12 contaminant detection classes, as illustrated in **Figure 3-1**.

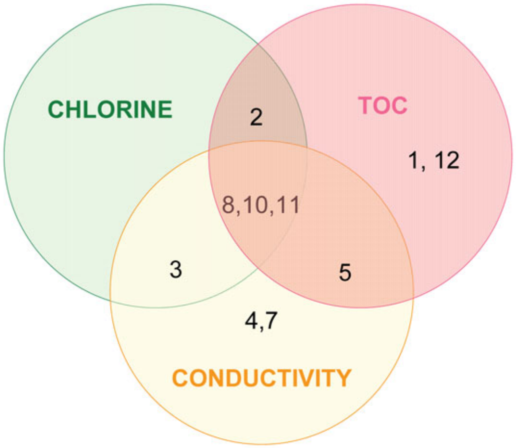


Figure 3-1. Contaminant Class Detection by Type of Water Quality Sensor

The assessment of water quality response to the WS Baseline Contaminants indicates that chorine residual and TOC are potentially the most useful indicators of contamination, with the potential to detect 28 of the 33 WS Baseline Contaminants. In general, the results of these studies illustrate that free chlorine is the most sensitive indicator of contamination, showing significant changes from baseline values at concentrations often one to two orders of magnitude below lethal concentrations. Specifically, many contaminants were detected at concentrations around 1 mg/L, while the corresponding lethal concentration might range from 10 to 100 mg/L. These studies also indicate that TOC is a particularly useful parameter for detecting the presence of many organic compounds, with a sensitivity ranging from a few tenths of a mg/L to more than 1 mg/L, depending on baseline levels and variability. Even at the upper end of this range, most organic contaminants should trigger a change in TOC concentration at levels below the lethal concentration.

Other water quality parameters, although not as reliable as indicators of contamination as chlorine and TOC, may still provide supporting information about potential contamination. Oxidation reduction potential (ORP) should generally behave similarly to chlorine residual, and can be used to corroborate an observed change in the chlorine residual. ORP may also serve a more prominent role in systems that use a chloramine disinfectant residual since certain oxidation reactions can occur without consuming chloramines. Conductivity and pH are both important to aqueous chemistry and may be useful in understanding observed changes in other parameters, such as free chlorine residual. Studies have generally shown that turbidity is an erratic and unreliable primary indictor of contamination; however, as with pH and conductivity, it may be useful in understanding changes in other measured parameters.

Based on this assessment, the recommended water quality parameters for inclusion in the online monitoring component of WaterSentinel include chlorine residual and TOC as primary indicators of contamination, and ORP, pH, conductivity, and turbidity as secondary parameter that may help in the interpretation of a water quality trigger. In addition, other parameters or sensors may be deployed depending on the interests of the pilot utility. The core suite of water quality parameters that may be evaluated under the WaterSentinel pilot are: free chlorine residual, TOC, pH, conductivity, ORP, and turbidity. The following subsection provides guidance in the selection and design of sensors.

3.1.2 *Selection of Water Quality Sensors*

The sensors that can continuously monitor water quality in distribution systems fall into two configurations:

- In-line monitors where the equipment is tapped directly into the water main and monitors water quality under distribution system pressure.
- Online monitors where a slip stream from the water main is continuously analyzed by the equipment. Presently, online monitors have a longer track record than inline monitors because online monitors have been in use at source waters and water treatment plants for decades.

The different configurations may consist as single instruments or as suites of instruments including:

- Sensors. These consist of water quality specific analysis that utilize membrane or electrode specific technology and do not require additional reagents. These sensors can be purchased individually or as a multi-probe sonde.
- Analyzers. These equipment types require reagents and analytical process, performed automatically, to analyze for the specified water quality parameter (e.g., TOC, HACH DPD chlorine units).
- Sensors on a chip. These sensors utilize chip-technology and typically measure a suite of contaminants on a very small footprint. The more advanced chips are currently undergoing development and/or testing and do not have the track record of online instruments. These chips can be used in-line or online.

The sensors used in the WS-CWS should primarily be online sensors and analyzers. However, in-line sensors and chip technologies may be considered if the products have undergone a sufficient level of validation and demonstrated robust and reliable operation in a field setting.

Chlorine Residual Sensors and Analyzers

Free or total chlorine residual is monitored by the vast majority of water systems and procedures for monitoring them are well established. Because many chemical and biological contaminants react with chlorine, a significant drop in chlorine residual could indicate the presence of contaminants. The biggest challenge associated with the use of online chlorine measurements as an indicator of contamination is the identification of an anomaly from a variable chlorine residual baseline.

There are many methods used to measure chlorine: wet chemistry (e.g., N,N-diethyl-*p*-phenylenediamine or DPD), amperometric, and polarographic (with or without membrane), and thus chlorine instruments come in a variety of configurations, including all listed above. Their performance and maintenance requirements vary, and some require reagents (King et al., 2004).

Total Organic Carbon (TOC) Analyzers

Water utilities may monitor TOC for a variety of reasons, including regulatory requirements related to enhanced coagulation and control of disinfection byproducts. As discussed in Section 3.1.1, TOC can be a valuable element in the online monitoring component of a CWS, particularly for detecting the presence of organic compounds (such as petrochemicals, solvents, pesticides, and growth media associated with pathogens). TOC concentrations in distributed water are typically stable and predictable, assuming that there is no mixing of water from different plants or wells with different TOC concentrations in the distribution system. This should make it easier to recognize deviations from a stable baseline that could be indicative of contamination with an organic substance.

Due to the cost and maintenance requirements of TOC instruments, they are not typically used in drinking water distribution systems. Due to the small market, few vendors offer online TOC analyzers. However, there are a small number of reliable, online instruments that should be considered for use in the WS-CWS pilot. Some require carrier gases (that are supplied from gas cylinders) and frequent replacement of reagents. However, at least one instrument manufacture offers an analyzer that does not require a carrier gas and has substantially lower maintenance requirements than conventional TOC instruments.

Conductivity Sensors

Electrical conductivity is a surrogate measure for the amount of total dissolved solids (TDS) present in the water. Inorganic anions (e.g., chloride, nitrate, sulfate, and phosphate) and cations (e.g., sodium, magnesium, calcium, iron, and aluminum) typically increase the conductivity of the water. On the other hand, neutral organic compounds are not good conductors, and tend to reduce conductivity. As was the case with TOC, conductivity levels in finished water remain fairly stable throughout a distribution system, assuming that there is no mixing of multiple sources and there are no major corrosion problems.

Sensors designed for finished drinking water are typically mid-range (100 to 2,000 uS/cm at 25 °C). Conductivity sensors are reliable, accurate, and simple to use and maintain. If the given application site has problems with coatings, there are non-contacting conductivity sensors that can be used. (King et al., 2004)

pH Sensors

One of the most commonly monitored parameters in a water system is pH. The distribution system pH is typically controlled at the water treatment plant to reduce corrosion and to comply with the Lead and Copper Rule, and thus does not show significant variations in a distribution system. Sometimes, however, biological activity can introduce some variations in the pH of the water. Similarly, degasification (for example, loss of carbon dioxide at tanks with a free surface) or precipitation of a solid (for example, calcium carbonate) and other chemical, physical, and biological reactions may cause the pH of a water sample to change appreciably soon after sample collection (Wagner et al., 2000). Depending on the alkalinity of the water, pH changes over 0.5 pH unit should alert operators to a potential problem (Burns et al., 2003).

The electrometric pH measurement method, using a hydrogen-ion electrode, commonly is used for continuous pH monitoring. A correctly calibrated pH sensor can accurately measure pH to ± 0.1 pH units; however, the sensor can be scratched, broken, or fouled easily. Because pH sensors are designed as ion selective electrodes, they typical do not require reagents beyond routine maintenance (e.g., replacement of the electrolyte). Detailed instructions for the calibration and measurement of pH are provided by instrument manufacturers (Wagner et al., 2000).

ORP sensors

Oxidation reduction (or redox) potential (ORP) instruments measure the potential required to transfer electrons from the oxidants (i.e., reducing agents) to the reductants (i.e., oxidizing agents). This potential is related to the relative concentrations of the oxidants and reductants in the water. In general, water without disinfectants is considered ‘neutral’ relative to its ORP value. However, the addition of most chemicals or biological contaminants changes the ORP of water. For example, chlorine, either in the form of free chlorine or hypochlorites, is a potent oxidizing agent (reductant), changing the ORP of water. As a result, ORP indirectly can measures the chlorine residual in water. However, there is no reliable conversion from ORP in millivolts to chlorine concentration because pH, temperature, other reductants and oxidants in water also affect the ORP value. In moving from an oxidizing to a reducing condition, the ORP typically drops several hundred millivolts. ORP instruments are very sensitive in detecting small (parts per billion) concentration changes, and thus useful as an alarm surrogate parameter. In alarm applications, the exact trigger level is usually not critical.

ORP instruments are typically pH instruments operating in a millivolt mode, with the measuring electrode being an inert metal such as platinum or gold. Sensors are typically not calibrated, and ORP standard solutions are used primarily for verification of electrode response rather than calibration. ORP sensors are simple and require no reagents. However, the electrodes can be damaged by some metals in the water and can also be covered with inorganic or organic films that affect the values of ORP measured by the instruments. This can complicate the utility of ORP as a parameter. Routine cleaning and calibration is required to compensate for electrode degradation, and the electrode should be replaced every year or two on a regular basis depending on the application (King et al. 2004).

Online experience is necessary at startup to establish the particular operating range and trigger level for an application. The best practice to determine a trigger level for control is to use a test for chlorine concentration as a reference.

Turbidity sensors

Turbidity is a measure of a sample's relative clarity, and indirectly a measure of suspended particles. Turbidity measurements are thus useful because waterborne disease-causing organisms such as bacteria, viruses, *Giardia* and *Cryptosporidium* often attach themselves to particles in water. Because suspended particulates can protect attached organisms from disinfection, turbidity sometimes can be an important surrogate parameter of contamination. Furthermore, contaminants that do not dissolve in water or that react with carbonates in water to form precipitates will increase turbidity. Similarly, it is also possible for some contaminants to kill and slough off biofilms in the pipes increasing turbidity (King, et al. 2004).

Turbidity instruments transmit a beam of light through a water sample in a cylindrical quartz turbidity cell, and measure the amount of light scattered at right angles to the beam using a photoelectric sensor. There are a number of units in which turbidity can be measured, the most common one being Nephelometric Turbidity Units (NTU). Particle size, concentration of suspended solids as well as dissolved solids can affect this parameter.

Turbidity instruments of different designs do not yield identical or equivalent results. As a result, turbidity measured using instruments with different optical designs can differ by factors of two or more for the same sample, even with identically calibrated instruments. Thus, raw data from different instruments should not be considered directly interchangeable.

In addition to water characteristics, sensor damage due to biological growth or scratches on the optical surface of the instrument tends to produce either a negative bias when light beams are blocked or a positive bias if scratches increase the scatter of the sensor's light beam.

Sensor Selection

Considerations for the selection of online water quality sensors have been the topic of several recently published reports and studies (ASCE, 2004; King et al, 2004; ISO, 2003; Hargesheimer et al, 2002 manual). Some of these documents present considerations for sensor selection as part of a CWS, whereas most focus on traditional applications of these devices. In general, considerations for installation and most instrument characteristics are independent of any specific application of the online sensors. However, the performance characteristics, as listed below, may be more rigorous for the application of online sensors in a CWS. General characteristics of online sensors that should be considered in the selection process are described below.

- Physical Characteristics
    - <u>Dimensions</u>. Overly large assemblies may not fit in the space available, or may be troublesome during installation or removal.

  - Weight. If sensor will be inserted into a flowing line, the weight of the assembly should be considered during installation, maintenance and service.
  - Enclosure ratings. Instrument enclosures should, at a minimum, be designed for National Electrical Manufacturers Association (NEMA) for indoor installation. To the extent possible, corrosion resistant materials should be utilized for instrument enclosures, plumbing connections and mounting back planes.
  - Connection to water source. Suites of instruments should be clustered to permit use of a single water input and single drain manifold. It is prudent to have a single sample manifold connected to a single sample tap so that all instruments are receiving the same sample.
  - 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 and sensors powered by backup batteries should not take excessive power.
  - Electrical isolation and connections. Ground loop currents can lead to erroneous readings, so there should be electrical isolation between the sensors and any electrical devices that receive their signals (recorders, SCADA systems, programmable logic controllers (PLCs), modems, remote terminal units (RTUs), etc.) Electrical connections should be water tight and corrosion resistant.
  - Data transmission and storage. A single connection for data transmission is desirable. Both analog and digital data transmission options are permissible, but preference should be given to instruments and sites where digital communication is possible. Onsite storage of data should be minimized.
  - Pressure and flow ratings. Nominal line pressure rarely exceeds 100 pound per square inch (PSI), but pressures to over 200 PSI are not uncommon. 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.
  - Tolerance to flow and pressure variations. Water hammer can produce pressures far above 200 PSI with resultant damage to inline sensors. Sensor mountings are also at risk to high pressures, with catastrophic or dangerous results. Sensor packages should include instrumentation to monitor local pressure conditions. Both mechanical pressure reducers and barometric loops are frequently used to provide a sample in the proper pressure range.
  - Instrument materials that may be affected by oxidants, such as free chlorine. Drinking water is not highly corrosive but can contain significant amounts of chlorine that may damage some plastics and metals, such as steel. With chlorine residual a primary indicator in a CWS, and ORP a secondary indicator, instrument materials should be unaffected by oxidants.
  - Instrument materials that may be affected by humidity. While instrument enclosures should be resistant to water intrusion, instrument materials should also be able to withstand exposure to ambient humidity during routine maintenance.

- Performance Characteristics
  - Repeatability. Repeatability should 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.
  - Drift. Sensors may be mounted in areas where temperature varies considerably. Temperature drift specifications for zero and span should be known.
  - Signal memory. Signal memory defines how long a signal can be generated in time before repeating the signal
  - Warm-up time. This could be significant when power to the sensors is interrupted. Sensors that require long periods to return to normal operation should be avoided.
  - Supply voltage effects. Often overlooked; sensors should be robust with respect to accuracy under varying supply voltage.

  - Response time. Fast response time is generally not needed in monitoring applications, but response times greater than 2 minutes should be avoided.
  - Polling frequency. This is the frequency the SCADA or the Control Room will poll remote instruments for data, and the recommended frequency should be 2 minutes or less.
  - Data backup. Individual instruments should have data backup capabilities, in case of a communication failure, operators can then collect the data from the instrument's data logger directly.
  - Temperature range. A range of 0 to 70 degrees Centigrade should be adequate, although temperatures would rarely exceed 50 degrees Centigrade at most sites.
  - Interference from electrical equipment in the area. Sensors may be mounted in proximity to pumps and other electrically actuated equipment. The sensors should not be susceptible to interference from those devices.

- Operational Characteristics
  - Installation requirements. Typical sites will have limited room and power for installation activities. Pre-assembly of sensor packages can speed installation, paying close attention to limitations of the access point to the site (i.e., manholes). Dimensions, weight and the power/water needs of the sensors should match the conditions at each site.
  - Maintenance and calibration requirements. Ideally instruments should require minimal operator intervention and service. It is reasonable to expect that the instruments should be looked at once or twice a month, but require active maintenance only monthly.
  - Technical skill level required for operation. Instruments will likely be operated by persons with limited analytical training. Thus, to the greatest extent practical, the instruments should be plug-and-play with simple menu-driven operation and set-up.
  - Compatible cleaning methods and solutions. Sensors should be cleaned during maintenance. Cleaning methods and solutions should be clearly identified, noting if the cleaning solution for one type of sensor is not suitable, or incompatible with, any of the other sensors at that location.
  - Availability and quality of reagents. When required, reagents should be available from the manufacturer, who can assure their quality.

3.1.3 Sensor Station Design

Figure 3-2 illustrates a typical configuration for a sensor station, and includes the typical elements that are recommended for inclusion in the design of a sensor station for the WS-CWS:

- Slip stream line tapped into the distribution system pipe. This line is typically 3/8 inch in diameter and should be fitted with a valve and regulator to control the flow and pressure into the instrument. The tap should extend to the center of the distribution system pipe to deliver a representative stream of water to the sensor. In addition, a backflow prevention device is recommended to prevent reverse flow through the sensor and back into the distribution system pipe.
- Strainer or filter to remove any particulates that might clog the solenoid valve.
- Solenoid valve that is energized when an alarm occurs, or when an operator triggers it, and collects a sample for further analysis.
- Sample container (100 L) to hold the water sample when the solenoid valve is energized.
- Smaller lines that first go to the rotometers and then go to the instruments: these could typically be ¼ in. in diameter. For a suite of instruments, one could go to the TOC analyzer while the other(s) could go to the remaining instruments (or multi-parameter sensor).
- Rotometers to measure the flow to each sensor.

- Uninterrupted Power Supply (UPS). If the sensors are powered by electricity, then a 120 v AC UPS is recommended, which will provide temporary power to the sensors for 1-2 hours if electrical power is lost.
- Sensors, individual or as a multi-probe sonde. Three tiers of sensor stations are considered: 1) the full complement of water quality parameters: TOC, chlorine residual, conductivity, pH, ORP, and turbidity; 2) all of the previously listed water quality parameters except TOC; and 3) online chlorine analyzers only. Additional parameters may be considered at the discretion of the pilot utility.
- Event detection system. Some sensor platforms include an event detection system that has been integrated with a suite of sensors which process the data at the site of the sensor station. In other configurations, multiple sensor stations send data to a single, centralized event detection system.
- Discharge lines for the sensor effluent that direct the water to a drain if necessary.
- Reagents, gas cylinders, and other consumables as required.

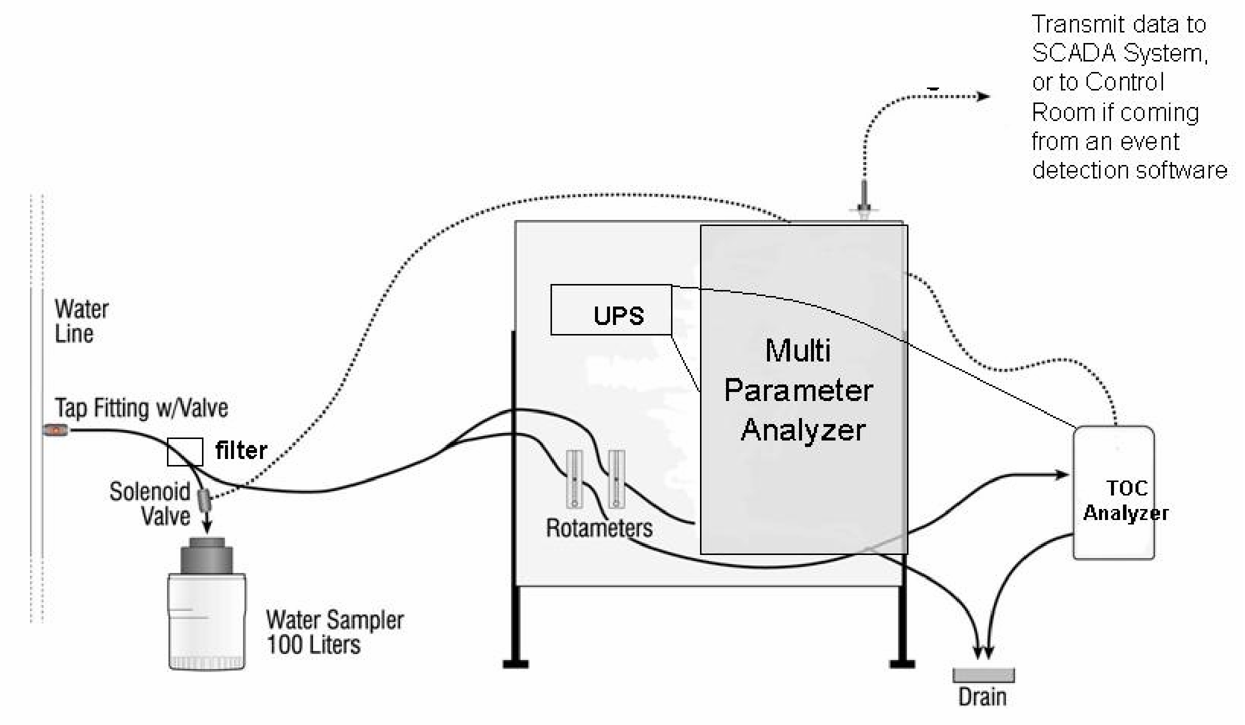


Figure 3-2. Schematic of an Example Water Quality Sensor Station

3.2 Sensor Network Design

Sensor network design is a systematic process for determining the location and number of sensor stations deployed in a CWS. The design should directly impact two important aspects of system performance: the time of detection and the spatial coverage of the system. The time detection relative to the start of the incident is a function of:

1) the travel time between the point of contaminant introduction and the first downstream sensor station;
2) the delay between sensor measurements (seconds to minutes); assuming the sensors are sensitive enough to detect a water quality change due to a contaminant, as discussed in Section 3.1.

3) the time required to transfer the data to the central data acquisition system (seconds to minutes); and
4) the time necessary to evaluate the data, along with other information, and conclude that the unusual water quality data is a threat warning.

The most significant time delays are associated with the first and fourth steps, and the former is largely dependant on the design of the sensor network.

The spatial coverage provided by a sensor network could be viewed from the perspective of geographical coverage of the service area; however, as discussed in Section 2.1, the majority of scenarios (i.e., locations of contaminant insertion) result in relatively low consequences, and only a small fraction of the scenarios result in the most serious consequences. Thus, maximizing spatial coverage may not provide optimal protection for consumers. Given this observation, a better approach may be to optimize the sensor network design to an objective that more closely relates to public health protection. Various methods have been developed to determine optimal sensor locations, see (Berry et al, 2003, Watson et al, 2004, Ostfeld et al, 2004; Uber et al, 2004) These methods are based on optimizing the sensor network design for a single objective from the following list:

- Minimizing the number of persons exposed to a lethal or infectious dose.
- Minimizing the time of detection.
- Minimizing the extent of the contamination in the pipe network.
- Minimizing the cost of placing sensors.
- Maximizing the spatial coverage of each sensor

Of the existing methods, the optimization approach developed by Watson et al. is the most preferable because it: (1) has been proven to find the exact optimal solution for each objective, (2) is flexible enough to accommodate any one of the above objectives, and (3) is solvable for even very large distribution systems. This method is described in more detail below.

Application of this method to date has shown that if a sensor network design is based on minimizing the health impacts to the population, the design also performs well(though not optimally) in most of the other objectives. It is also clear that with any reasonable number of sensor stations (i.e., less than 50), there may be events that may not be detected by a sensor network; however, in general these events should tend to have small impacts.

Typically utilities have addressed spatial coverage of the sensor networks by using intuitive methods. When using intuitive methods the selection of sensor locations is primarily based on 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. Although intuitive methods are convenient, they do not place the sensors in locations that might benefit the utilities most. Academicians have addressed this issue either by developing optimization/mathematical programming methods (sometimes incorporating hydraulic/water quality network models) or by using multiple simulations of hydraulic/water quality network models (as is the case with TEVA).

In the use of the optimization methods, the objectives have typically been:

- Minimizing the expected fraction of the population at risk
- Minimizing the quantity of contaminated water at a concentration higher than a minimum hazard level for a given number of sampling sites
- Minimizing the detection time for a given number of sensors (or budget)
- Minimizing the detection time before a certain quantity of contaminants is consumed
- Minimizing the number of sensors (or budget) for a specified time interval of detection

The purpose of this section is to outline the process that will be used to design the online water quality sensor network, in particular, the number and locations of water quality sensors. Water quality sensors should be a critical component of WaterSentinel and by optimizing the number and locations of sensors at the pilot utility, the overall performance of the CWS can be maximized. The sensor network should be designed to support the overall goal of WaterSentinel: to detect contamination events in time to reduce the potential public health and economic consequences.

The EPA has collaborated with researchers at Sandia National Laboratories and the University of Cincinnati to develop software tools for determining the best locations for sensors throughout distribution systems. The first step of this work was to formulate the sensor network design problem mathematically as an optimization problem in which the sensor placement objective is to minimize the time of detection, the number of people exposed, the spatial extent of contamination, and maximize the number of events detected (Berry et al, 2003, 2005; Watson et al, 2004). Additional constraints can be added to the optimization problem; for instance bounds can be set on the overall costs of sensors, the total number of sensors, or the locations that are suitable for sensor placement. Algorithms and software tools were developed to solve the optimization problem and are referred to hereafter as Sensor Placement Optimization Tools.

The proposed approach to sensor network design is largely independent of the specific sensor technologies that should be used. The approach includes:

1. Identifying potential sensor locations
2. Categorizing costs of locating sensors at those locations
3. Defining the objectives and constraints for sensor location
4. Using an optimization tool to select optimal sensor locations
5. Determining the number of sensors needed
6. Refining the final sensor design

Identifying Potential Sensor Locations

The main requirements for locating sensors at a particular are summarized in (ASCE, 2004) and summarized below:

- Available Utilities (water, electricity, sewer, communication)
    - Water: availability of water for use at the monitoring station
    - Electricity: power for monitoring equipment and communications, availability of uninterrupted water supply or battery power if there is an interruption in electricity.
    - Drain or Sewer: to dispose of any waste stream generated by the instruments
    - Communications: to transmit data via phone lines, wireless, fiber optics, radio, etc.
- Physical characteristics and considerations
    - Space Availability: to mount the instruments and related equipment
    - Mounting Scheme: the feasibility of instruments be mounted on a common backplane
    - Accessibility for Maintenance: sensors should be located where access is safe and easy. Sites requiring confined space entry or other special requirements should be avoided
    - Temperature Ratings of Instruments: for both sample temperature and ambient temperature, should be appropriate for the installation environment.
    - Sunlight: Direct sunlight should be avoided as it may cause degradation of many plastic materials and reagents.
    - Humidity: condensing humidity should be avoided.
    - Sample Pressure: High and low pressure, frequent pressure fluctuations, or water hammer may adversely affect instrument performance. Pressure reducers could be used to maintain the sample in the proper pressure range.

- Hydraulic Conditions: it is important that that sensor stations be located at locations where the water in the system is well mixed and thus representative of the water in that section of the distribution system. If turbulent flow may interfere with sensor performance, this may be addressed through the design of the sample port and slip stream piping that delivers water to the sensor (e.g., if entrained air causes problems with sensor performance, a bubble trap can be installed in the slip stream).
- Physical Security: at the site of sensor station installation to guard against unauthorized access or tampering. The site should be reasonably secure to prevent tampering with the instrumentation, introduction of contaminants, falsification of instrument data, and disruption of the power supply or data communications.

Most drinking water utilities can identify many locations satisfying the above requirements, such as pumping stations, tanks, valves, or other utility-owned infrastructure. Furthermore, many additional locations may meet the above requirements, or could be easily and inexpensively adapted for sensor station locations. Sites owned by other utility services, such as publicly owned treatment works, collection stations, storage facilities, etc. likely meet all the requirements for locating sensor stations. In addition, many publicly-owned sites could be easily adapted, such as fire stations, police stations, schools, city and/or county buildings, etc. By including these sites, the list of potential sites for sensor stations numbers in the hundreds for the WaterSentinel pilot utility. Finally, most consumer service connections would also have most of the requirements for sensor placement, with the exception of an existing data transmission mechanism. There may be legal issues with locating sensors in private homes or businesses; nevertheless, the benefit of using some of these locations may far outweigh the difficulties. An example of a water distribution system with potential sensor locations is shown in **Figure 3-3**.

In addition to the above physical characteristics of potential sites, there will be other considerations that may constrain sensor station locations, such as the normal variability of the water quality baseline. Even with regular maintenance and calibration of the sensors, there may be some locations in the distribution system in which the water quality is so variable that potential contamination incidents cannot be distinguished from background variability. Therefore, the list of potential sensor locations should be restricted to locations that are able to maintain relatively stable water quality. For example, locations near storage tanks may have significant variability in chlorine levels as tanks cycle between draining and filling. However, such predictable variability might be accounted for in some event detection systems.

Simulations of distribution system chlorine residual levels using hydraulic/water quality models, or empirical data generated from field studies, can help to identify locations with stable, predictable chlorine residuals. These points can be assumed to have low variability in other water quality parameters for the purpose of sensor placement. This process may remove a large number of potential sensor locations, but for the WaterSentinel pilot utility, at least one-thousand possible sensor locations should remain.

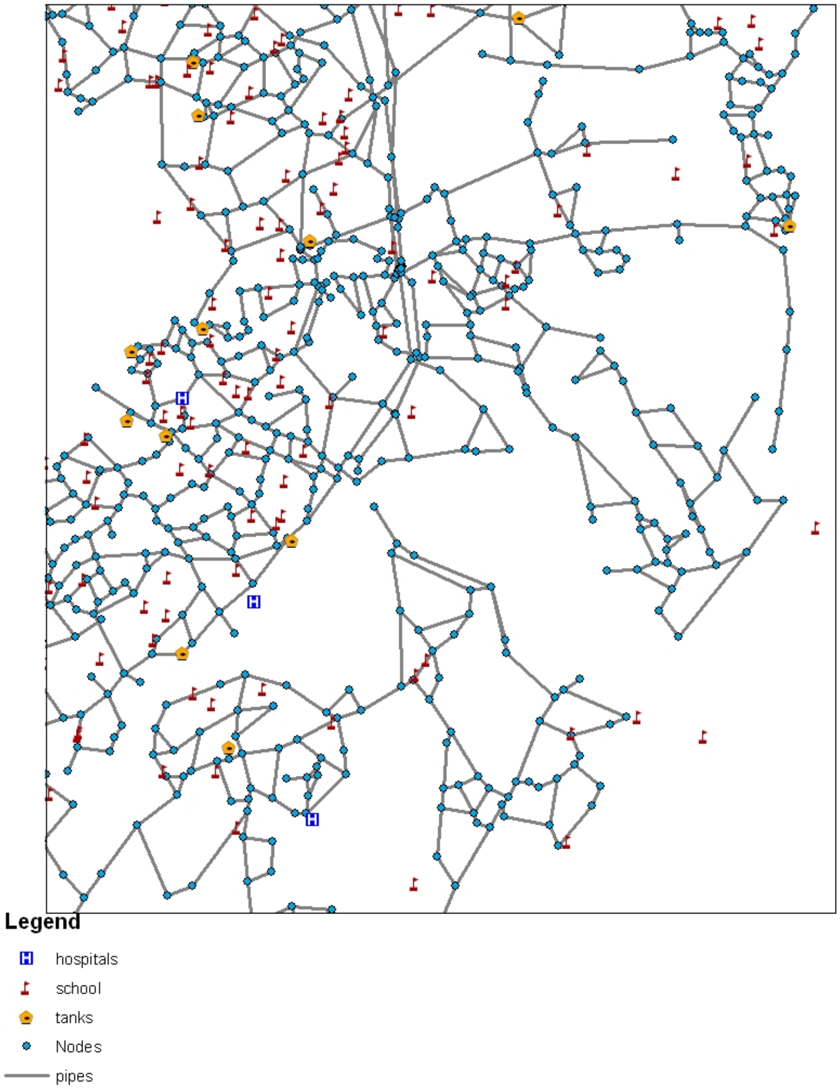


Figure 3-3: Example Water Distribution System with Potential Sensor Locations

Categorizing Sensor Location Costs

Potential sensor locations can be divided into five categories based on the costs of installation. EPA plans to work with the WaterSentinel pilot utility to determine which locations fall into each category:

- Cost category 1: Sites that already have water quality sensors.
- Cost category 2: Utility or public-owned sites that meet the site requirements listed above, except perhaps a data transmission capability which can be inexpensive to add.
- Cost category 3: Privately owned sites that meet the site requirements, except perhaps a data transmission capability which is inexpensive to add. These sites may have an additional cost associated with gaining access to the space.
- Cost category 4: Sites that lack one or more of the following: easy access, sewer, electricity, or physical security. These sites may be significantly more expensive to adapt for sensors.
- Cost category 5: Forbidden sites. Certain locations in a network may not be appropriate sites for water quality sensors, no matter the cost of placement. In the optimization model, these sites

should be assigned an infinite cost. It may be difficult for a water utility to enumerate all of the forbidden (infinite cost) locations, but current sensor placement capabilities allow a utility to specify some if it wishes.

Defining the objectives and constraints for sensor placement

There are many possible objectives to consider for sensor placement, including the following.

1. Minimizing the public health impacts.
2. Minimizing the time to detection.
3. Minimizing the extent of contamination.
4. Maximizing the number of events detected.

In order to measure these impacts, a set of contamination scenarios should be defined and simulated, and the resulting objective values should be measured for each potential sensor site. The optimization methods need to know, for example, the impact of a potential attack at location $\boldsymbol{x}$, given that the plume from this attack first encounters a sensor at location $\boldsymbol{y}$. For public health impacts, this requires simulation of the fate and transport of a contaminant in the drinking water system, assumptions about the consumption patterns of the population, estimates of the spatial and temporal distribution of the people that have been exposed, calculations of the number of people that become ill according to contaminant-specific dose-response curves, and predictions of the time evolution of health impacts.

The goal of optimization software, for example, may be to select sensor locations which should minimize the average number of people that become ill from ingestion of the contaminant, considering a large ensemble of attack scenarios. Additional constraints could be added to this goal; for example, to require that the worst case population affected is bounded from above by some constant, or that the average extent of contamination is below some specified number of pipe-feet. The sensor placement software tool is flexible enough to allow for such considerations and many more. The general plan for the WaterSentinel pilot is presented below, though it is recognized that there should be significant interactions with the pilot utility before a final decision is made.

The Sensor Placement Optimization Tool has been described in numerous publications (Berry et al, 2003, 2004, 2005; Watson et al, 2004). The tool can find sensor placement solutions for each of the above objectives that have been proven to be the exact optimal solutions, (Watson et al, 2004). The tool is flexible enough to allow for exploring the trade-offs of selecting one objective compared to another. A future version of the tool may allow for the simultaneous optimization of several objectives. A future version may also include additional objectives; for example, minimizing the impacts of worst case attacks, which is profoundly more difficult to solve than the existing objectives.

Sensor Placement Methodology for the WaterSentinel Pilot

The sensor placement process for the WaterSentinel pilot should use an incremental approach, providing a sequence of sensor layouts, the merits of which can be compared and contrasted. The process should begin by designing the sensor network under ideal conditions using many simplifying assumptions. Then, assumptions should be removed one by one in order to make the results more meaningful. At each iteration, the performance of the given sensor placement should be compared quantitatively and visually with previous steps in order to understand what has been gained or lost with each assumption. The steps will include:

- Idealized sensor placement
- Determining the number of sensors by requiring upper bounds on costs and/or the total number of sensors (see **Figure 3-4**)
- Constraining the set of potential locations to those with low variability in water quality
- Incorporating realistic response delays

- Considering additional high consequence contaminants
- Refining the sensor design based on field studies and interactions with pilot utility

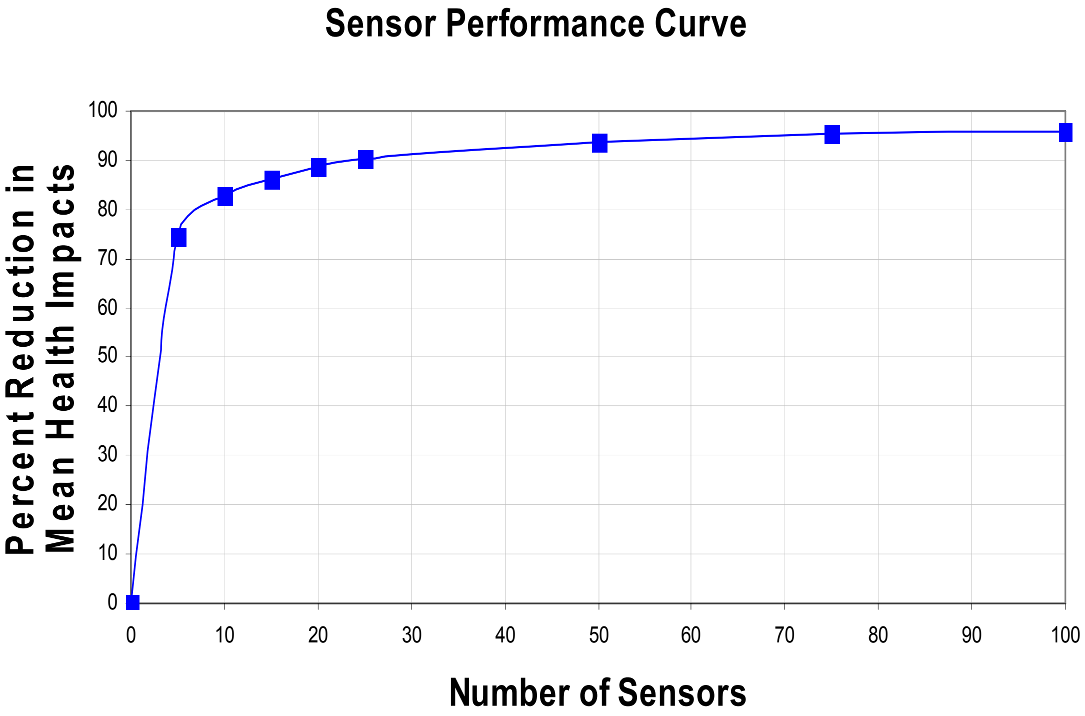


Figure 3-4. Sensor Network Design Trade-Off Curve

3.3 Data Management, Analysis, and Interpretation

Considerations for the management, analysis and interpretation of data from online water quality monitoring are described in this section. Additional information pertaining to the integration of this information as part of the WS-CWS is discussed in Section 8.0.

3.3.1 Data Management

A data management system should be capable of delivering data from CWS sensors to a data collection system for analysis, storage, and notification of designated responders. The overall data management system should include the following elements:

- Local Data Logging: Field located water quality instruments each generate a signal which is directly related to the measured parameter. At each field location, each analyzer's signal should be stored in a data logger as protection against loss of data elsewhere in the management stream. Some instruments include built-in data logging capability. For other instruments, a dedicated data logger should be provided. Typically, numerous signals may be stored by a single data logger, so one unit should be sufficient for each sensor station location.

- Data Concentration: Instrument signals (analog or digital signals) should also be inputted into a data concentrator**,** which is a device that collects all local instrument signals and prepares them for transmission to a central data management system. A data concentrator may be programmable logic controller (PLC), a remote terminal unit (RTU*)* or remote input-output (RIO) device.

A PLC will typically convert the raw signal from the analyzer to engineering units (mg/l, ppm, pH, etc.) before passing them on to the transmitting device. An RIO device typically does not convert the raw signals, so this should be done elsewhere in the data stream. An RTU may convert the raw data or not, and frequently includes a data logger function, so this device may serve two purposes in the data management architecture. Analyzers which have the capability to deliver a digital signal may internally convert the raw signal before it is passed to the data concentrator.

Data concentrators may perform signal evaluation tasks such as comparison of measured values against set alarm limits to activate automated samplers, isolate or redirect water flows, or other purposes.

- Data Transmission: Water parameter measurements should be transmitted from the remote sensing location to a central communications interface at a data warehousing and analysis location. Common communications methods used include licensed and unlicensed radio, frame relay, digital subscriber line (DSL), cellular telephone digital data service, and cable television digital data service. Often several of these will be in use from different remote locations for a single utility. Each of these transmission methods will require a communications device (radio, modem, or other similar device) at both the remote instrument location and at the central data management facility.

- Data Processing: At the central data management facility, the measured signals should be converted to engineering units, if not already done at the data concentrator. The signals are then delivered to a data warehousing system. This system includes the data storage hardware and software, and a data storage network which provides interconnection between all data storage and retrieval computers and interfaces.
  The data may initially be received by a dedicated purpose system, such as the utility's SCADA data historian, but it may then be made available to a special purpose CWS data management system. The special purpose system can provide services such as broad trend analysis of data from many remote sensors, incorporation of geographical information system (GIS) data, comparison of measurements to trends, analysis against known mitigating factors such as planned maintenance activities, among others. While a special purpose system would be very useful for a fully operational CWS, it may be overly complex or expensive for some utilities. In that case, existing information systems, such as a SCADA system and associated data historian, may be programmed to provide many of the functions of the special purpose system.

While providing the necessary functions of transporting and managing the data, each of the above described elements introduces vulnerabilities that should be accounted for and minimized.

In order to select the specific data management elements to be used in a CWS, the following should be considered in selecting data management elements:

- Evaluate whether an existing remote monitoring and control system, SCADA, has the capacity to provide transmission and data handling services.
  - Evaluation of existing radio transmission pathways would include not only the available capacity (available bandwidth) of the radio link, but also whether the radio link can be established from the CWS field locations.

  - Evaluation of availability of telephone or other communication services at the field location.
  - Communication method effectiveness, reliability, and maintainability.
- Determine whether the CWS data management system can interface directly with the data warehouse at the central facility, or whether the CWS data should be routed to the SCADA data management system, and then made available to the CWS data system.
- Requirements for providing maintainability by the utility staff and minimizing cost of ownership.
- Vulnerabilities introduced and methods required for minimizing and mitigating those vulnerabilities.
- Use of the SCADA and historical data collection storage and retrieval hardware and software for CWS data management for a limited capability system.

3.3.2 Analysis and Interpretation

Since water quality sensors are only monitoring for potential indicators of contamination, rather than for the contaminants themselves, interpretation of the water quality results is necessary to determine whether or not the water has been potentially contaminated. Thus, the success of the online water quality monitoring component of the WS-CWS for detecting anomalies that may be indicative of contamination without generating an unmanageable number of false alarms depends on the performance of the water quality event detection system. The tools and software currently available for event detection are discussed in *Event Detection for Drinking Water Contamination Warning Systems* (USEPA, 2005f). The reliability of these event detection systems can be further enhanced through integration data streams from multiple water quality sensors as well as information from system operations and maintenance. A water quality event detection system has not yet been selected for the WaterSentinel pilot, and it is likely that several available systems will be evaluated over the course of the pilot, with the process for initial system selection described in USEPA, 2005f.

Furthermore, ongoing research is developing a database of ‘water quality responses’ for specific contaminants (USEPA, 2005h). These profiles should support the analysis of online water quality data and help to distinguish alarms associated with possible contamination from other anomalies. Once the ‘water quality response’ for a large number of contaminants have been thoroughly tested and documented, such information can support the characterization of an incident, credibility determination, and response decisions.

Following the identification of a water quality anomaly, the next step in data analysis is the integration of the water quality data with additional CWS data streams. A complete CWS system should include data analysis and interpretation tools that integrate many data types (online water quality data, field and lab test data, consumer call information, and public health surveillance data) to improve the overall reliability and coverage of the system. This higher level of data integration and analysis is discussed in Section 8.0.

3.4 Framework for Evaluation

The evaluation of the online sensor network of the WS-CWS should utilize both laboratory and field-scale studies. In general, the field-scale studies should consist of tracer tests, hydraulic and water quality monitoring, and provide the majority of the information used to evaluate the design and performance of the online sensor network. The following sub-sections describe the portions of the WS-CWS to be evaluated and provide a brief description of the approach to be utilized.

3.4.1 Network Model Confidence

The sensor placement tools described in Section 3.2 rely on the accuracy of the hydraulic network model provided by the pilot utility. The ability to evaluate the vulnerability of a distribution system and develop adequate sensor locations requires a reasonable representation of the actual dynamics within the distribution system. These dynamics, in large part, need to adequately describe transport throughout the distribution system. To that end, there needs to be confidence that the network model represents the actual behavior within a distribution system. To develop model confidence, tracer tests (using an inorganic salt measured as conductivity) and hydraulic and water quality monitoring programs should be developed to collect information regarding the dynamics within a distribution system. The data collected should be a combination of hydraulic and water quality measures obtained from the utility's SCADA system, grab sampling program, and continuous monitors placed at remote locations throughout the distribution system. Bench-scale experiments should be performed to evaluate the water chemistry within the bulk fluid (e.g., chlorine decay) to establish a baseline of decay for use with a distribution system network model. These data, coupled with the available distribution system network model, should be used to evaluate model confidence (Boccelli et al, 2004). Metrics for providing model confidence should utilize model predictions and observed data to compare residence times of tracer signals, develop correlation between signals to evaluate path mixing, and compare tracer signal distributions to evaluate dilution effects. While individually these metrics do not provide an adequate picture of model confidence, together they indicate the ability of the network model to represent the gross transport and detailed mixing that occur in a largely interconnected hydraulic network.

In all likelihood, the physical scale of the actual distribution system should prohibit the evaluation of the entire system simultaneously. Instead, individual sub-regions should be determined that, as a whole, represent the entire distribution system yet provide a more manageable field-study. Sensors should be placed throughout the distribution system to provide adequate coverage of the distribution system. This 'coverage' includes providing adequate spatial distribution as well as ensuring the data collected represent the underlying distribution of, for example, hydraulic residence time and water quality variability. By providing such coverage, the likelihood of determining the areas of the distribution system that are well or poorly represented by the network model is increased.

3.4.2 CWS Sensor Placement Tool

The development of an adequate network model provides the first step in improving the utility of the sensor placement tool discussed in Section 3.2. While there is much that goes into the vulnerability and risk assessment portion of the sensor placement tool, there is little that can be done to evaluate true optimality under real-life conditions. Instead, the field evaluations should be focused on establishing metrics associated with different sensor network designs and evaluating potential trade-offs between various sensor network designs. The general type of tracer tests (employed above) provide opportunities to estimate the coverage of different sensor configurations as well as the spread of the tracer signal after passing a sensor, which is important when evaluating the impacts of response time to a trigger event. Additionally, smaller-scale tracer tests that simulate a potential intrusion event can be used to specifically evaluate sensor network configurations for observing specific attack events.

The majority of this work should rely on conductivity sensors for observing the signals, which allow coverage of the network to be better evaluated. The ability of a suite of water quality sensors to trigger a response to an event (or non-event) is discussed in the following section.

3.4.3 Water Quality Event Detection Systems

The most important function of an event detection system is to filter out changes in water quality that normally occur or which have known causes (e.g., changes in chlorine residual resulting from tank cycling) and signal only those anomalies that are likely to be indicative of possible contamination incidents. In short, the purpose of the event detection system (EDS) is to reduce the false positive rate without missing possible contamination incidents.

In order to characterize available event detection systems, a three step evaluation is proposed. First, laboratory-scale pipe-loop studies should be performed by T&E and Technology Testing and Evaluation Program (TTEP) to test available event detection systems for correctly triggering an alarm when a contaminant is introduced into a water stream representative of the utility's treated water. The second step of the evaluation should use the water quality data collected from the deployed WS-CWS sensors for the specific purpose of characterizing the false-positive rates associated with various event detection systems. This phase of the evaluation should use data from multiple sites and different water quality baselines to assess the effect of variability on the performance of the event detection system. The third step in the evaluation should use a few of the deployed WS-CWS sensor stations, with modifications to allow for the safe introduction of test contaminants. This should provide the opportunity to test the ability of the event detection system to correctly trigger an alarm under field conditions and thus characterize the false negative rate of the event detection system. Unlike laboratory-scale experiments, these field experiments should provide an opportunity to evaluate the ability of the event detection systems, which should ideally 'learn' on-line, to correctly identify contamination events in the presence of actual background water quality variability. The modified sensor stations would need to have proper safeties in place such as backflow prevention and a high level of physical security.

3.4.4 Sensor Stations

The initial selection of the WS-CWS online sensors should be based on evaluations of equipment from multiple vendors by T&E and TTEP under controlled conditions in pipe loop studies. The field-scale studies should provide the opportunity to evaluate the equipment under actual field operating conditions. The evaluation of the equipment itself should focus on the robustness and reliability of the sensors over time. Some of the metrics that should be considered when evaluating the sensor stations should be calibration frequency, operation and maintenance, percentage of downtime, ease-of-use (as per utility personnel), etc. The information from the pipe loop and field studies should be compiled and evaluated to determine which combination of sensors and ancillary equipment provides the best overall performance, and to select the components of the semi-permanent CW sensor stations. As new technologies become available, this equipment should continue to be tested through T&E and TTEP prior to being evaluated in the field.

Upon deployment, the performance of the semi-permanent CWS sensor stations should be subject to continual evaluation using the same metrics listed previously as well as the overall costs and benefits of operating the system. The dual-use application of these sensor stations should also be assessed. For example monitoring and transmission of water quality data in real-time to the utility SCADA system can serve the dual purpose of contamination warning and providing information necessary for optimizing distribution system operations, while saving utility staff hours of sampling and testing time that would otherwise be required to collect even a fraction of this data. The cost of maintaining online water quality monitors in the distribution system for water security may thus be offset by the time and cost savings from manual collection and analysis of water quality samples.

Section 4.0: Sampling and Analysis

Water utilities have active sampling and analysis programs to support regulatory compliance monitoring. However, the objectives of compliance or process monitoring are significantly different from those of the WS-CWS, which relate to the protection of public health from acute hazards. Thus, compliance and process monitoring generally do not serve a useful function in the context of CWS implementation, with the possible exception of daily distribution system monitoring for chlorine residual. The utilities' experience, however, with compliance monitoring may benefit sampling and analysis for WS-CWS activities. One principle difference between compliance monitoring and WS-CWS requirements is related to the frequency at which samples are collected and analyzed. The precise frequency is, in turn, based on the design of the WS-CWS. Table 2-8 summarizes the manner in which sampling and analysis satisfies the requirements of the design basis in the WS-CWS.

The ability to rapidly detect and identify specific contaminants, or contaminant classes, in drinking water samples is a critical component of the WS-CWS program. Sampling and analysis of water samples collected from the distribution system are used in the WS-CWS to detect the presence of specific contaminants (and related constituents). However, the specific application of these analytical tools should be considered in the design of the WS-CWS. The following three applications were considered in the design of the WS-CWS:

- Routine, periodic sampling and analysis to provide an indication of contamination
- Baseline sampling to establish the background levels of contaminants of concern
- Sampling and analysis in response to a trigger generated from other WS-CWS components as part of the consequence management process

The use of routine sampling and analysis as a means of initial detection of contamination was eliminated from the design based on several considerations. The results of the contamination incident timeline analysis demonstrate that routine sampling and analysis does not provide timely detection of the majority of WS baseline contaminants, and provides information substantially later than the other WS-CWS components, with the exception of some forms of public health surveillance (USEPA, 2005b). Furthermore, the results of this analysis indicate that the sampling interval for routine sampling would need to be in the range of 4 to 48 hours, depending on the contaminant class, to serve as a timely indicator of contamination. This presents substantial challenges to the sustainability of the program in terms of staffing, cost, and laboratory capacity. However, sampling and analysis does serve an important role in the design of the WS-CWS for baseline monitoring and triggered sampling and analysis, as described below.

The objectives of baseline and triggered sampling and analysis are closely coupled. Due to the low specificity of other WS-CWS components in terms of their ability to identify specific contaminants or contaminant classes, there is a critical role triggered sampling and analysis to assist in the credibility determination process and planning specific response actions based on the threat posed by the specific contaminant. However, the analytical results from triggered sampling should be evaluated in the context of background or baseline levels of contaminants to accurately interpret the results and assess credibility. In order to establish baseline levels for contaminants, it is necessary to conduct baseline monitoring at a predetermined frequency that takes into account seasonal and system variability. The baseline monitoring program can also be designed around specific, predefined sampling circuit.

Selection of sites for triggered sampling is situation-specific, and often times more complicated and uncertain than setting up a baseline sampling circuit. It is likely that there would be multiple sites that need to be sampled, (e.g., at multiple places downstream or upstream) for a control sample. Furthermore, the timing of triggered sampling presents a challenge not faced during baseline sampling. As demonstrated in the timeline analysis, it is important to minimize the time necessary to collect and analyze triggered samples. This need for rapid-turn around should be balanced against the need to identify sample collection sites that would likely represent the water suspected of being contaminated and to produce reliable analytical results. By contrast, the issue of timeliness for baseline monitoring is much less significant because these samples are not expected to contain any hazards. One of the more important objectives of baseline sampling and analysis is accurate measurement of contaminant concentrations.

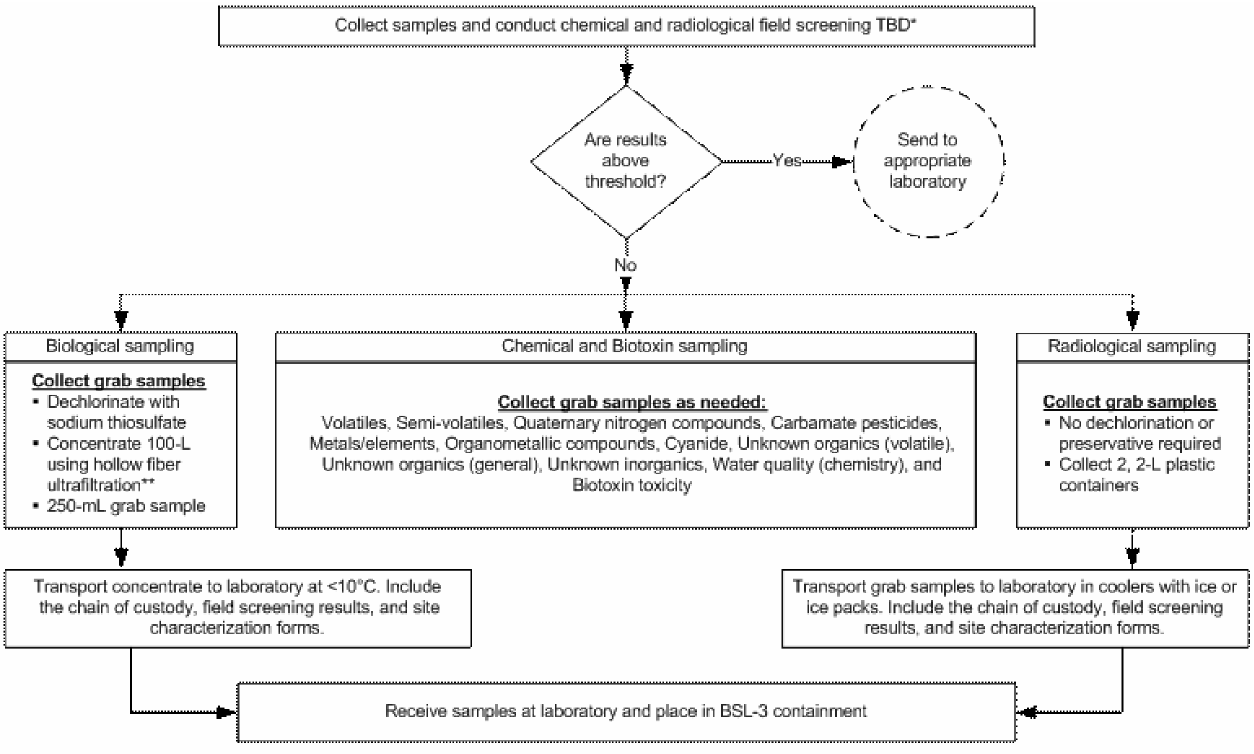
The two types of sampling and analysis activities serve distinct roles in WS-CWS and have differing spatial variability in sampling locations, so separate sampling plans need to be designed for baseline and triggered sampling, as discussed in Sections 4.2.1 and 4.2.2, respectively. Namely, baseline analysis should quantitatively determine existing levels of analytes in the distribution system whereas analysis for triggered sampling should be performed to determine whether the concentrations of contaminants in the area(s) targeted for monitoring differ significantly from the baseline values. The actual sampling (Section 4.1.1) and analysis (Section 4.1.2) of samples is similar, regardless of the sampling plan, because the analytes should be the ones measurable by an ‘unknowns’ protocol as described in Section 4.1.2. Section 4.1 describes the sampling and analysis component of the WS-CWS, while Section 4.2 describes the sampling circuit design. Data management and analysis is discussed in Section 4.3, while Section 4.4 provides a framework that should be used as a basis for evaluation of the overall WS-CWS sampling and analysis program.

4.1 Sampling and Analysis

The ability to rapidly detect and identify targeted—and other—water contaminants is a critical component of the WS-CWS program. Comprehensive sampling procedures and analytical methods are being developed to support baseline monitoring efforts and to provide rapid detection capabilities for unidentified radiological, chemical, and biological contaminants in response to a credible contamination event. This includes an ‘unknowns’ protocol that provides coverage of the 33 WS baseline contaminants as well as other contaminants and water quality conditions. The protocol is, in many cases, designed to detect specific WS baseline contaminants as well as contaminant classes or surrogates. The latter approach may be used because the direct methods may not be validated for use during the initial stages of the WS program or because reliable screening methods can provide more timely measurement of a broader array of contaminants. Sections 4.1.1 to 4.1.3 describe the sampling and analytical elements of the WS-CWS.

4.1.1 Sampling

In support of WS-CWS objectives, EPA is developing the *Sampling Guidance for Unknown Contaminants in Drinking Water* (‘unknowns sampling protocol guidance’) (USEPA, 2005e). This document builds on the approach described in Module 3: Site Characterization and Sampling Guide of EPA’s *Response Protocol Toolbox* and includes a comprehensive suite of procedures for collecting samples that may be analyzed for radiological, chemical, and biological contaminants in drinking water. Sampling procedures are described for all WS baseline contaminants and contaminant classes, as well as other potential contaminants (**Figure 4-1**).



* Field screening tests and procedures are to be determined pending Technology Testing and Evaluation Program (TTEP) results and analysis from system architecture design basis

**Other concentration options may be evaluated

Figure 4-1. Overview of WS Sampling Process

The unknowns sampling guidance applies equally to both non-emergency sampling (e.g., baseline monitoring) and sampling conducted in response to a trigger generated by other WS-CWS components. The specific sampling procedures used for either scenario are identical, but implementation of the procedures may differ based on the analytical objectives or scope (i.e., number and type of analyses). For example, a subset of the sampling protocols could be used to support targeted analysis for contaminants clearly implicated by other sources of information. The entire suite of unknowns sampling procedures would be used in situations when no information about the nature of the suspected contaminant(s) is available. The use of these standardized sample collection procedures for baseline monitoring should also enable sampling teams and the analytical laboratories to practice and prepare for a triggered sampling event using the same procedures.

Safety Screening. As depicted in Figure 4-1, prior to collection of samples for laboratory analysis, an initial field safety screen for radiological analysis may be performed using hand-held radiation meters for alpha, beta, and/or gamma emissions. If abnormally high levels of radioactivity are detected, the site should be characterized as a radiological hazard, and grab samples would likely be sent to a qualified laboratory for analysis. If the radiological screen indicates that this class of contaminant is an unlikely source of concern, the remainder of the sampling procedure should be performed. Note that other safety screening and site evaluation would likely be conducted as part of site characterization (USEPA, 2004a).

Sample Collection. Samples for chemical and biotoxin analyses should be collected according to specific analyte and method requirements. It is critical that samples are collected in the appropriate containers, at the appropriate volumes, and are preserved and/or dechlorinated as specified by the method in order to obtain reliable analytical results. In some instances, it is desirable to not preserve, dechlorinate, or otherwise alter a portion of the sample, in order to perform certain types of analysis, especially if the sample is later sent to a specialized laboratory for analysis. The container types, required sample volumes, and required sample preservatives for each contaminant or contaminant class are detailed in the sampling protocol and summarized in **Table 4-1**, as presented in the *Response Protocol Toolbox* (USEPA, 2004a).

Table 4-1. Preservation and Holding Time Table for Radiological, Chemical, and Pathogens

Contaminant Class/Type	Container Volume and Type	No. of Containers	Dechlorinating Agent	Preservative	Holding Time	Analytical Technique
Radiological	1 L, Plastic	2	None	None - mark samples not preserved	6 months	Gross alpha, gross beta, gamma isotopes, specific radionuclides
Volatiles	40 mL, Glass w/ Teflon faced septa	5	Ascorbic acid	1:1 HCL to pH <2, see method	14 days	P&T - GC/MS
						P&T - GC/PID/ELCD
Carbamate Pesticides	40 mL, Glass w/ Teflon faced septa	4	Thiosulfate	Potassium dihydrogen citrate sample pH to ~3.8	28 days	HPLC-fluorescence
Unknown organics (volatile)	40 mL, Glass w/ Teflon faced septa	5	None	None - mark samples not preserved	7 days	P&T - GC/MS
Metals/ Elements	125 mL, Plastic (i.e., HPDE)	2	None	Trace metal grade nitric acid, see method	6 months	ICP-MS
						ICP-AES
						AA
Organometallic compounds	125 mL, Plastic (i.e., HPDE)	2	None	Nitric acid to pH <2, see method	30 days	AA - cold vapor manual
						AA - cold vapor automater
Toxicity	125 mL, Glass	2	Consult manufacturer's instructions	Consult manufacturer's instructions	Consult manufacturer's instructions	Rapid toxicity assay (several vendors)
Cyanide	1 L, Plastic	2	Ascorbic acid	Sodium hydroxide to pH 12, see method	14 days	Titrimetric Spectrophotometric
Quarternary nitrogen compounds	1 L, Amber PVC or silanized glass	4	Thiosulfate	Sulfuric acid to pH 2	14 Days	SPE HPLC - UV
Semi-volatiles	1 L, Amber w/ Teflon-lined screw caps	4	Sodium sulfite	6M HCl, see method	7 days to extraction, 28 days to analysis	SPE GC/MS
Unknown organics (general)	1 L, Amber Glass	4	None	None - mark samples not preserved	7 days to extraction, 28 days to analysis	**Prep:** SPE, SPME, micro LLE, direct aqueous injection, headspace
						Analysis: GC/MS, GC, HPLC, LC-MS
Unknown inorganics	1 L, Plastic	2	None	None - mark samples not preserved	28 days	ICP-MS
Water quality: Chemistry	1 L, Plastic	1	None	None - mark samples not preserved	Immediate to 14 days	Conductivity, pH, alkalinity, hardness, turbidity
Biotoxins	1 L, Amber Glass	2	Consult manufacturer's instructions	Consult manufacturer's instructions	Consult manufacturer's instructions	Immunoassays

Contaminant Class/Type	Container Volume and Type	No. of Containers	Dechlorinating Agent	Preservative	Holding Time	Analytical Technique
Water quality: Bacteria	250 mL, Plastic	1	Sodium Thiosulfate	None	24-30 hrs	Fecal coliforms, *E. coli*
Biologicals	100 L concentrated, Plastic	5 (20 L Carboys)	Thiosulfate	None	TBD	PCR

Biological analyses should require direct grab sampling or large volume ultrafiltration sample concentration, depending on the analytical objectives. Grab sampling (250 mL to 1 L each) should be used when water samples are suspected to contain high levels of one or several biological contaminants and/or when high levels of particulates are present that would preclude field concentration. Most drinking water samples are amenable to concentration in the field or laboratory using simple membrane filtration procedures prior to analysis (PCR- and culture-based methods) for bacterial or protozoan contaminants, but this concentration option may not be applicable to viral contaminants. The broad 'screening' procedure for unidentified pathogens requires that large volume samples (100 to 500 L) be concentrated in order to obtain the level of sensitivity necessary to determine if pathogens are present in the water at levels above the baseline (which may be zero). The ultrafiltration approach for concentrating drinking water samples in the field ensures that most or all potential biological contaminants, including viruses, are collected for analysis. This sampling approach involves the use of a hollow-fiber ultrafiltration device to filter large volumes of water (e.g., 100 L) and produce a small volume retentate (e.g., 250 mL). This retentate is then collected and separated into aliquots for field testing, and laboratory analysis using PCR-based and/or culture-based analytical methods (see Section 4.4).

The unknowns sampling procedures guidance document should assist utilities in developing proper sampling procedures for use in routine, baseline, or triggered sampling and should also supplement the utility's emergency response plan to provide more detailed sampling procedures for drinking water utility personnel during a possible contamination incident. In addition, the unknowns sampling guidance document should provide guidance and recommendations for the assembly and training of sampling teams, preparedness planning, establishing a support network and chain of communication, potential field or on-site testing and screening procedures, site characterization responsibilities, and development of information management systems.

4.1.2 Analysis

The ability to screen drinking water samples for the presence of potential contaminants when the nature or identity of a suspected contaminant(s) is not known is a critical element of the WS-CWS. No single analytical method is capable of detecting or identifying all potential contaminants, which may include radiochemical, chemical, or biological agents. The unknowns sampling guidance document discussed above is complemented by *The Protocol for the Analysis of Unknown Contaminants in Drinking Water* (USEPA, 2005f). The unknowns analysis protocol builds on the concepts and analytical approaches described in Module 4: Analytical Guide of EPA's *Response Protocol Toolbox* and provides a detailed analytical approach, including methods for the detection and identification of the WS baseline contaminants in drinking water. The analytical methods in the unknowns protocol were developed for use by laboratories to support baseline monitoring activities in preparation for triggered sampling and analysis performed in response to a 'possible' contamination incident when the identity of the contaminant is unknown. However, these analytical methods may also be suitable for targeted analysis when specific contaminants are suspected or known to be present (e.g., such as remediation and recovery efforts). An overview of the 'unknowns' analysis protocol is presented in **Figure 4-2**.

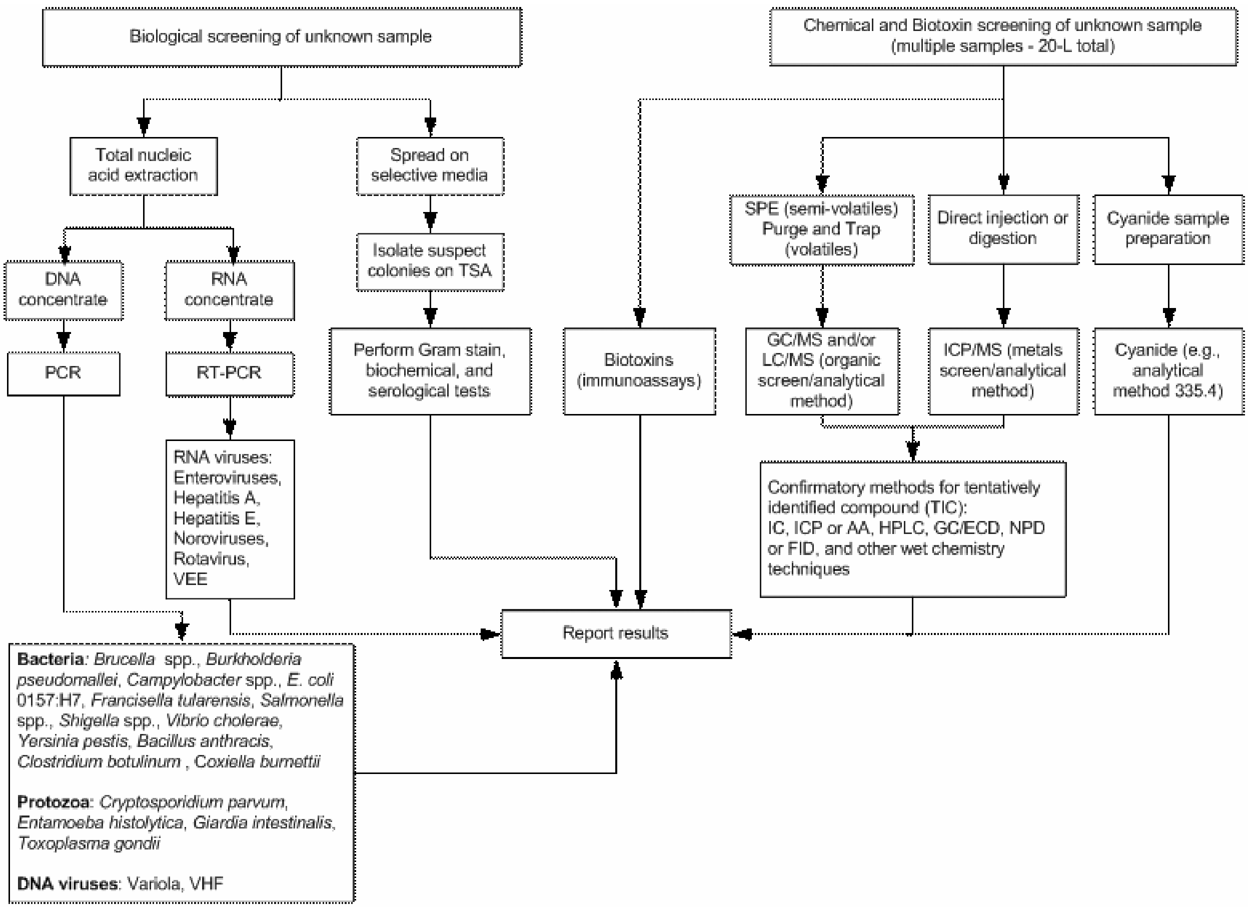


Figure 4-2. Overview of WS Unknowns Protocol

Although this analytical approach is designed to detect WS baseline contaminants or contaminant classes, as well as other contaminants, not all laboratories should have all of the instrumentation listed in the protocol available. EPA plans to work with the WS pilot utility to prioritize in-house analytical capabilities and identify areas for expanding this capability. This in-house capability should be supplemented and expanded by qualified laboratories to provide comprehensive coverage for unknowns as well as confirmatory analysis where necessary.

In addition to laboratory capability, laboratory and method performance should be evaluated on an ongoing basis as discussed in Section 4.4 to ensure that analytical results of known and reliable quality are generated and transmitted for use with other WS-CWS data streams. The use of these standardized analytical procedures and guidelines during baseline monitoring activities should exercise the integrated response capabilities of the analytical laboratory network, sampling teams, and the information communication network of the WS-CWS and should be instrumental in preparing for a triggered sampling event. Contaminant-specific (or surrogate agents) proficiency testing (PT) testing may also be implemented to periodically evaluate laboratory and method performance, along with analytical accuracy.

The ‘unknowns’ analysis protocol also should provide guidance to the laboratories supporting WS on preparedness planning (defining capabilities, establishing a chain of communication, information management, and laboratory network integration), laboratory safety and containment, sample receipt and safety-screening procedures, and sample referral procedures for when additional laboratory analysis is necessary. The ‘unknowns’ analysis protocol should also assist these laboratories in the development of practices and standard operating procedures during contamination events. The analyses outlined in the unknowns analysis protocol, which should be used to support the WS-CWS pilot, are described below.

Radiological analyses. Radiological analyses should be performed only by licensed, specialty laboratories, and the need for such analyses should be indicated by the field screening for alpha, beta, and gamma emitters, along with any relevant information gathered during the credibility determination process. The field screening results should determine the appropriate laboratory to receive radioactive samples (e.g., high levels of radiation would indicate a radiation hazard, and a qualified radiation laboratory supporting the WS pilot would receive samples).

Radionuclides should be measured for gross alpha, beta, or gamma radiation using EPA Method 900.0 or handheld equipment. If the sample is positive for high levels of gross alpha, beta, or gamma radiation and the laboratory is not equipped to handle radioactive samples, the samples should be sent to an appropriate laboratory qualified to handle radioactive samples. This laboratory should perform targeted analyses to identify the specific radionuclide(s) present. If the sample does contain radioactive material, specific radioisotopes should be determined by the laboratory using EPA 900-series methods or similar acceptable procedures developed in-house.

Chemical analyses. The analytical approach described in the ‘unknowns’ analysis protocol integrates several analytical techniques to screen for a broad range of chemical classes. Depending on the screening results, these analyses may serve as a ‘springboard’ for more complete characterization and can be used to determine which compounds from the method target list are detected. The chemical screen consists of two elements: (1) application of multiple analytical techniques to screen for a wide range of analytes, and (2) analytical confirmation of tentative results. The analytical approach and analytical methods described in the unknowns analysis protocol are designed to accomplish both objectives.

The established analytical techniques, in conjunction with standardized methods for the analysis of contaminants in water, do not provide complete coverage for all of the WS baseline contaminants. To address these gaps, exploratory techniques are used, which do not have standardized methods associated with them. It is important to note that all screens are not prescriptive, and laboratories should have some flexibility to develop an analytical approach that is consistent with their existing capabilities and experience. Of the many analytical exploratory techniques available, those used for screening are the techniques that show the most promise for water analysis, including those with established applications in other media, but not yet validated for water. The exploratory analytical techniques include not only wet chemistry and instrumental analysis, but also various types of hand-held equipment and commercially available test kits. In the unknowns analysis protocol, analysis of contaminants is divided into chemical classes, such as organic/inorganic, volatile/semivolatile, etc.

Confirmatory analyses should substantiate contaminant identity or quantify unidentified chemicals, and can provide legally defensible data. Confirmatory analysis may be required in the case of a tentatively identified chemical. In general, a positive result from a rapid field test or safety screening, performed in the field or laboratory, should be considered tentative identification and require independent confirmation. By contrast, chemicals identified through the application of standardized methods typically do not require independent analytical confirmation because recommended confirmatory steps are often incorporated into the methods themselves. In some cases, another laboratory with specialized capability may need to perform the confirmatory analysis. When possible, confirmatory analyses should be performed using existing standardized methods accepted for analysis of the target analyte in a water matrix.

Biotoxins analysis. There are hundreds of biotoxins produced by a wide variety of plants and microorganisms. The two biotoxins included in the WS baseline contaminant list, ricin and botulinum toxin, are protein toxins and can be detected using immunological (antibody-based) procedures. Detection of ricin and botulinum toxins using PCR-based methods that target the genes encoding these proteins are available; however, this is an indirect approach and these assays do not measure the actual toxins. Several commercial immunoassay formats have been identified for inclusion in the 'unknowns' analysis protocol. The detection of ricin and botulinum toxin using current immunoassay procedures may require sample concentration to enable detection of these contaminants at concentrations that would pose a threat to humans. Sample concentration using ultrafiltration, as summarized above, and described in the unknowns sampling protocol guidance, is likely to achieve this sensitivity due to the relatively large sizes of both ricin (65 kilodalton) and botulinum toxin (150 kilodalton) compared to the molecular weight cut-off (60 kilodalton) of the hollow fiber filtration device. This concentration procedure should be evaluated as part of WS method development activities. The ability of direct analysis of grab samples to provide acceptable detection limits should also be evaluated.

The non-protein biotoxins may be considered as organic chemicals, albeit complex in structure, and the same types of sample preparation and instrumental analysis techniques may be applicable, depending on the chemical properties of the specific biotoxin. Low molecular weight biotoxins may be treated much like other organic chemicals and may be analyzed by the same type of analytical techniques (e.g., GC/MS). Because most biotoxins tend to be water soluble, LC techniques have been used for the detection of biotoxins in water. When LC/MS is used, the same precautions may be necessary as those for other toxic organic chemicals. The analysis of biotoxins is one area where LC/MS has proved particularly valuable, especially if the molecular weight of the biotoxin precludes its analysis by GC/MS. Analytical methods for additional biotoxins should be included in the 'unknowns' analysis protocol as detection capabilities are expanded under the WS-CWS program.

Pathogens. Analytical methods for pathogen detection and identification rely on unique properties of a specific biological agent or family of agents. Both culture-based and molecular-based (nucleic acid or protein) detection methods are included in the unknowns analysis protocol to take advantage of the strengths of each of these analytical techniques. Currently, EPA is working with the US Army's Edgewood Chemical and Biological Center (ECBC) to evaluate both culture-based and PCR-based methods for five of the six biological WS baseline contaminants. The methods are currently being optimized and standardized, and a single laboratory validation study is expected to be conducted in 2006. EPA is also evaluating availability of commercial PCR-based methods for these same five bacterial contaminants and may include these methods in the single laboratory validation study being planned for 2006. Molecular (e.g., PCR or reverse transcriptase PCR) based methods provide no information on the public health significance of the detection of genetic material of a particular pathogen in an environmental sample.

Because current molecular assays do not determine viability, it is necessary to attempt to determine if viable organisms are present in a recovered water sample through the use of culture techniques. This process should be initiated as soon as possible, as many of these organisms may be fragile, and may have been damaged during the sample collection process. Furthermore, the preparation of samples for molecular analysis is a destructive process, and culture-based assays should need to be undertaken to enable the collection and preservation of potentially significant trace numbers of microbial contaminants. The information from this activity is significant to public health response, for example, testing for antibiotic and vaccine susceptibility, toxin production, and forensic analysis. Culture-based analytical methods provide a sensitive means for detecting and enumerating viable bacterial pathogens in water and are considered the 'gold standard' for water quality monitoring. However, these methods may require several days (or longer) for growth and subsequent characterization of the target analyte. For some pathogens, particularly viruses and protozoa, may be difficult or impossible to 'grow' or replicate in culture and identification of these agents requires the use of genetic and/or immunological techniques.

Molecular-based analytical methods for pathogen detection and identification, particularly PCR-based assays, are faster and yield results in hours rather than days, but they do not directly address pathogen viability or infectivity. However, the speed, sensitivity, and specificity of these assays provide the potential for rapid detection of biological agents during the evaluation of a 'possible' or 'credible' contamination threat. However, PCR analyses provide assay results that are often difficult or impossible to interpret when used in environmental samples. Often closely related organisms or species that have not been previously identified may be identified by the application of molecular testing techniques to novel environmental matrices. Every large scale application of these techniques to date has essentially generated information of this type, and interpretation in the absence of cultured bacteria is problematic at best, and impossible in many situations. Recent publicly reported examples of the detection of *Francisella tularensis* in several cities in the BioWatch program point out problems with sole reliance on molecular techniques for identification of threat agents in environmental samples (ProMed, 2005). Within the WS program there is the opportunity to correct these problems by initiating practices that are designed to maximize the opportunities of using 'gold standard' recovery techniques along with more rapid molecular assays. This creates the unique opportunity to maximize the potential benefits of this program in a reasonable and economic manner, while minimizing the potential for high consequence mistakes that might arise from reliance on a single analytical technique.

4.1.3 Laboratory Support Network

As part of the WS pilot, laboratories should be identified to support the pilot utility for baseline monitoring as well as triggered sampling and analysis. These laboratories should have the necessary capability and capacity to support analysis of samples generated through WS-CWS sampling and analysis activities and may include a combination of state, Regional, federal, and/or commercial laboratories. Considerations for participation in this laboratory support network include, but are not limited to the following:

- Demonstrated laboratory capability for the analysis of WS baseline contaminants in drinking water
- Demonstrated laboratory capacity to support baseline and/or triggered sampling and analysis
- Proximity to the utility laboratory
- Certifications and/or accreditations for the analysis of drinking water samples
- Membership in existing laboratory networks (e.g., LRN)

EPA recognizes that there should be a sustained investment in the laboratory resources required to support the WS-CWS. This investment also develops a foundation for a laboratory network to conduct additional studies to promote the dual-use benefits of the WS-CWS (e.g., microbial analyses for agents that may cause taste and odor, or corrosion problems). The resources should also be available for additional environmental studies of other related matrices such as surface and recreational waters as it is likely that these resources should need a sustained investment to maintain their technical capability for the WS-CWS, particularly with evolving technological solutions to detection of pathogens.

In response to HSPD 9, and by its authority under section 300i-3 of the Safe Drinking Water Act (42 USC section 1434), EPA intends to build upon and expand current 'integrated laboratory networks' to provide analytical support to enhanced monitoring and surveillance activities. The WS-CWS pilot provides EPA with an opportunity to begin to build a laboratory network for the analysis of drinking water samples that can be expanded to support other environmental matrices to address the larger capability and capacity issues resulting from increased homeland security sampling and analysis activities. The laboratory support network for the WS-CWS pilot should provide an opportunity to test the concept of the Water Laboratory Alliance (WLA) in a real-world application. The WLA should be a network of laboratories with extensive capability for the analysis of water samples for a wide range of potential contaminants. The WLA should integrate water quality laboratories with the existing LRN, established by Centers for Disease Control and Prevention (CDC) and with EPA's new environmental LRN (eLRN). To parallel the organizational structure of the LRN as established by CDC, the WLA should consist of three tiers of laboratories including the following:

- **Sentinel laboratories.** Sentinel laboratories should be responsible for baseline monitoring through application of the unknowns analysis protocol at a determined frequency for baseline monitoring and analysis of samples in response to a trigger, depending on laboratory-specific capabilities. For triggered samples, Sentinel laboratories should provide preliminary analyses and should 'rule out' contaminants or refer the sample to a Confirmatory or Reference laboratory for further analysis, as appropriate. For pathogen monitoring, the Sentinel laboratory should have, at a minimum, Biosafety Level 2 (BSL-2) capabilities for work involving agents of moderate potential hazard to personnel and the environment. Although some of the WS baseline pathogen contaminants can be responsibly analyzed in a BSL-2 laboratory; others, if present in the water samples, require a more stringent biosafety level and upon detection or other evidence, the Sentinel laboratory would transfer such samples to the next level laboratory. For certain pathogens, a Sentinel laboratory may be capable of initiating specific culture protocols, which, if preliminary molecular indications dictate may be transferred to laboratories with appropriate biosafety level facilities.

- **Confirmatory laboratories.** Confirmatory laboratories should be responsible for detection and confirmatory identification of pathogens, toxins, chemical contaminants, and/or radiological contaminants in referred samples using rapid, advanced technology and specialized methods, assays, reagents, and support services. Confirmatory labs also are responsible for communication and coordination with Sentinel labs, including providing training on sample collection, presumptive analyses, and sample transfer chain of custody procedures. Additionally, Confirmatory labs may provide guidance and technical assistance to other Confirmatory labs that encounter difficulties with certain analytical methods. Confirmatory laboratories for pathogen analysis, which would include the State public health laboratory, would be BioSafety Level 3 (BSL-3). In BSL-3 facilities, all procedures involving the manipulation of infectious materials are conducted within biological safety cabinets or other physical containment devices, or by personnel wearing appropriate personal protective clothing and equipment. Moreover, BSL-3 laboratories have special engineering and design features, such as double-door access zone and sealed penetrations. Additional requirements for confirmatory laboratories, depending on their specialties should include limited surety capability (i.e., able to handle dilute solutions of Schedule 1 Chemical Warfare Agents) and/or the ability to analyze radioactive samples. Also, pathogen confirmatory laboratories should comply with the Select Agent act, and chemical Confirmatory laboratories for chemical warfare agents should comply with Army Regulation 50-6.

- **Reference laboratories.** Reference laboratories should have highly specialized containment facilities, specialized analytical capabilities, and specially trained staff. They should be responsible for definitive identification and/or characterization of chemical structures, pathogens, along with chimeras and engineered organisms. Reference laboratories should have primary responsibility for forensics analysis, including attribution, and thus should meet standards of legal defensibility. However, Sentinel and Confirmatory laboratories should be aware that their results may be subjected to legal scrutiny as well.

4.2 Sampling Circuit Design

The WS-CWS sampling circuit design should address the sample collection location, the sample collection schedule, and the number of samples to collect. Approaches for consideration in the sampling circuit design for both baseline and triggered sampling are discussed below. In addition, the TEVA tool and approach for sensor network design discussed in Section 3.0 can also be used to identify sampling locations as part of the baseline monitoring program. For triggered sampling, the utility's hydraulic model, if appropriately calibrated, can be used as a tool to identify triggered sample locations under certain scenarios.

4.2.1 Baseline Sampling

In deploying the sampling and analysis component of the WS-CWS, the initial phase should focus on establishing the baseline levels of the constituents measured by the 'unknowns' protocol. Establishing the baseline for each contaminant is critical to distinguish naturally (i.e., those not resulting from intentional contamination) occurring levels of the contaminant from higher levels observed during triggered sampling that might be indicative of contamination. For many of the contaminants, the baseline is expected to be below the minimum detection level, typically because the contaminant should not be present in the distribution system at any level. Because triggered samples might need to be collected and analyzed at any location in a distribution system and at any time, the baseline should capture the spatial and temporal (including seasonal) variability of unknown protocol results. Given this objective, the primary focus of the baseline sampling plan design is on the selection of sampling locations, sampling schedule, and the number of samples that capture this variability. Further, it should address the variability in the measurements made with the unknowns protocol to ensure that the threshold levels established during baseline sampling are reliable for evaluating levels measured following trigger monitoring.

Sample collection location. In selecting locations at which to collect baseline samples, it should be important to consider the locations of the on-line monitoring stations, because anomalies detected at these stations may trigger sampling events in response to 'possible' contamination threats and incidents. Therefore, it may be important to know the background in their vicinity, i.e., hydraulically related areas. In addition, selection of candidate sample collection locations for baseline monitoring may be aided by consideration of distribution system locations identified through existing sampling plans that are used at the utility. These established sampling location plans include those which are (or would have been) used for compliance related sampling such as the Total Coliform Rule and the Unregulated Contaminant Monitoring Rule. Other potential locations include those used for monitoring water treatment plant operational performance, including disinfection byproduct and lead and copper sampling. These existing sampling plans should be evaluated to identify locations that represent the full spectrum of water quality conditions and variability. The following areas reflect the scope of distribution system extremes and should be considered in designing the sampling circuit:

- **Areas pre-positioned to be sampling locations in response to triggered events.** If a CWS online monitoring station detects an anomaly that triggers site characterization and sampling, time should pass before the sample can be collected. Samples should be collected in locations that bear a spatio-temporal relationship to the sensor station. This may be addressed to some extent through the use of auto-samplers as a component of the monitoring station, as discussed in Section 3.1.3. Thus, baseline samples should also be collected from these locations.
- **Historically high consumer complaint areas.** These are localized areas within the distribution system from which the utility receives consumer complaints associated with poor water quality. These areas may contain differing levels of some measured contaminants and should be accounted for when establishing a baseline.

- **Locations immediately downstream of pumping stations.** Changing of flow and pressure may cause disturbance within the distribution system mains and alter the water quality downstream of the pumping station.
- **Areas of differing water ages.** Represents water quality at locations throughout the distribution system at different distances from the water treatment plant.
- **Disinfectant booster stations.** Addition of a disinfectant (e.g., chlorine) to a distribution system due to low disinfectant concentration residual values. Areas located upstream and downstream of the booster station should potentially have differing water qualities.
- **Water storage tanks.** Tanks have differing rates of water turnover, based on supply from the water treatment plant and consumer demand within the distribution system. These differences may result in different levels of measured contaminants and other constituents, compared to the rest of the distribution system.
- **Cross-connection hazards.** A cross-connection is an unprotected actual or potential connection between a potable water system and a source of contamination (such as wastewater, industrial fluids, pesticides, etc), where backflow can occur from the source of contamination into the potable water distribution system. These areas may contain higher levels of some measured contaminants and other constituents.
- **Locations of high/low pressure.** In particular, areas that are prone to low pressure, or wide pressure fluctuations, can present an opportunity for infiltration, and thus are candidates for baseline monitoring sites.
- **Areas of deteriorating water mains.** The age of the pipes, coupled with corrosion and sediment accumulation over the years, should affect the flow rate and quality of water in distribution systems.
- **Areas of stagnation due to low water use.** In addition to causing odor problems and pressure degradation, these areas should likely contain different levels of some measured contaminants and other constituents in comparison to other areas in the distribution system.

These factors should be used to identify a cost–effective, yet comprehensive, sampling plan that should capture the distribution system variability as a whole, allowing for an accurate characterization of baseline levels, that should be necessary to properly interpret the results of triggered sampling and analysis.

Sampling schedule. Baseline monitoring should establish the levels against which future routine or triggered monitoring should be compared, so it is important that not only the sampling locations, but the sampling scheduling reflect the extremes within the distribution system. Temporal variation factors that should be considered during design of the sampling circuit for baseline sampling include the following:

- **Seasonal biological changes.** Variation in the seasons can produce fluctuations in the concentrations of waterborne organisms in the source water, which typically increase during spring runoff and during the warmer months of the year.
- **Input changes**. Storm water or snowmelt can cause runoff from agricultural centers that can introduce pesticides, organisms, and other substances into the water supply. Heavy rain directly into surface water reservoirs also can dilute contaminant concentrations to unnaturally low levels.
- **Source water changes**. During high-demand periods, it may be necessary to draw from groundwater to supplement the surface water supplies. This would lower the concentrations of biological organisms that are normally introduced to the open surface water supplies, but could also increase the mineral and chemical concentrations in the system.
- **Treatment changes**. A change in treatment techniques or chemicals used by the public water system should also affect the levels of parameters measured by the ‘unknowns’ analysis protocol. Periodic changes to chemical treatment or the introduction of new chemicals and processes should change the makeup of the water and should be reflected in the baseline sampling plan.

- **Distribution system hydraulics**. Many factors can influence the system hydraulics and in turn impact water quality in the system. Certain times of the day can produce a greater demand over different legs of the system, flushing them and, thus, providing a different quality of water than when the water has been stagnant for some time.

To encompass the variations associated with these factors, initial baseline sampling should be performed over a period of time that should capture this variability, most likely over the course of a year. It is important to note that the baseline thresholds produced from the initial sampling should not remain static. Ongoing sampling should be incorporated into the threshold calculations to provide a continually changing threshold for comparison to levels measured during triggered sampling.

Number of samples. The number of samples that should be collected to establish the baseline level for each contaminant for the WS pilot is driven by the number of sampling locations, the sampling schedule, and the measurement variability of the unknowns protocol. The smaller the systemic variability in the measurement technique, the fewer number of data points should be required to address the last factor. After the number of samples has been established, the sample load should be compared to laboratory capacity and field sample collection logistics and limitations, and a workable sample number should be determined.

4.2.2 Triggered Sampling

Analysis of triggered sample is an important part of the process of credibility determination and consequence management in WS-CWS (USEPA, 2005i). In general, it should be necessary to develop a unique sampling plan for triggered monitoring in response to a ‘possible’ contamination incident. The purpose of sampling in this case should be to determine whether the results from triggered monitoring differ significantly from the baseline in the areas of the distribution system suspected of being contaminated.

The sampling plan for triggered monitoring should not only reflect the need to reliably detect a contaminant in the distribution system, but for contaminants for which the baseline is greater than zero, determine whether the level detected is significantly greater than expected. As with baseline monitoring, the sampling plan for triggered monitoring should address the location of collection, the schedule for collection, and the number of samples to collect. It is important to remember that each triggered sampling event should be fundamentally different and should be based on the specifics of the trigger. Therefore, triggered sampling plans should be rapidly developed for each situation. A generic triggered sampling plan should be developed to assist in this process. Some considerations regarding the design of this sampling plan is discussed below:

Sample collection location. If information from other CWS components involved in the trigger is specific enough to narrow the focus of the monitoring to a specific area, samples may be collected from sites downstream and upstream of the location of the trigger (e.g., the location of a sensor station that detected a water quality anomaly). The analytical results of these samples should drive subsequent sampling efforts. If no additional information is available, samples may be collected from select locations from the baseline monitoring plan.

Sampling schedule. Unlike baseline monitoring, there is no design for timing of sample collection for triggered monitoring. Samples should be collected as rapidly as possible after the decision is made to do so.
Number of samples. Each triggered monitoring sample should to be compared to the individually that most closely reflects the temporal and spatial conditions of the possible contamination incident, rather than based on some summary statistic, e.g., the mean of all monitoring samples. Accordingly, the choice

of the number of samples is not based on achieving an appropriate level of statistical power. Instead, the number of samples should be sufficient to adequately represent the size and level of variability of the distribution system area being investigated, which is suspected of being contaminated. This should vary based on the specifics of the situation, such as how far the contaminant might have spread and pressure zones or tanks that may define the bounds of the potential spread. Hydraulic models can be valuable tools in deciding on both the number and the location for collection of triggered samples.

4.3 Data Management, Analysis, and Interpretation

Sections 4.3.1 and 4.3.2 provide considerations for management, analysis, and interpretation of data from the sampling and analysis component of the WS-CWS.

4.3.1 Data Management

A data management system should be capable of delivering data from the field to the laboratory and the analytical results from the laboratory along with the field data to a data collection system for analysis, storage and notification of designated responders and managers. The overall data management system should include the following elements:

1. Source: Pre-determined sampling locations on a routine basis and analytical results for pre-determined sampling locations on a routine basis; or sampling locations and analytical results in response to a trigger.
2. Collection: Sample number, field sample data (i.e., pH, temperature, etc.), any associated field duplicates, field blanks, or equipment blanks, and analytical results for WS baseline contaminants.
3. Storage: For sampling, either with a personal digital assistant (PDA) or laptop with sample collection information from each predetermined location or manually entering sample collection information from the Chain of Custody and field notes into software data entry system. For laboratory analysis, analytical results stored in either a Laboratory Information Management System (LIMS) or an analytical laboratory database. The analytical results would either be taken directly from the instrument for chemicals or manually entered into the data storage system for pathogens and radiologicals.
4. Transmission: The field sampling data and the analytical results need to be transmitted to a central communication interface at a data warehousing and analysis location. Common communication methods used include manual and automated software data entry systems.

In order to select the specific data management elements to be used in a CWS, the following should be considered:

1. Evaluate whether the existing means of collecting field sampling data has the capacity to transmit the data to either the laboratory or the central data management facility.
    a. Evaluation of using PDAs in the field
    b. Evaluation of using laptops in the field
    c. Evaluation of manually entering field data into a data storage system
    d. Communication method effectiveness, reliability, and maintainability
2. Evaluate whether the existing means of storing the analytical results data has the capacity to transmit the analytical data to the central data management facility.
    a. Evaluation of the existing laboratory database or existing LIMS
    b. Evaluation of manually entering pathogen and radiological data into the existing laboratory database or existing LIMS
    c. Communication method effectiveness, reliability, and maintainability

3. Determine whether the CWS data management system can interface directly with the data warehouse at the central facility or if it should be routed to a data management system, and then made available to the CWS data system.
4. Requirements for providing maintainability by the utility and laboratory staff and minimizing cost of ownership.
5. Vulnerabilities introduced and methods required for minimizing and mitigating those vulnerabilities. See Section 8.0 for additional requirements in determining and addressing data management vulnerabilities.
6. Use of historical data collection storage and retrieval hardware and software for CWS data management for a limited capability system.

4.3.2 Data Analysis and Interpretation

The question that the data analysis should need to answer in response to the WS-CWS is whether or not a contamination incident (either accidental or intentional) has occurred. This question should be addressed through evaluation of the data from all the components of the CWS, including the results of baseline and triggered sampling and analysis..

The field and analytical baseline data should need to be integrated with online water quality monitoring data, consumer complaints data, and public health surveillance data. The field and analytical data can be made available to a special purpose CWS data management system, which might provide services such as:

- broad trend analysis of data from routine baseline monitoring results
- analysis of data from triggered sampling results
- comparison of field sampling data from multiple sampling locations
- comparison of baseline monitoring results from multiple sampling locations
- comparison of triggered sampling results to routine monitoring results that correspond to the temporal and spatial conditions under which the triggered sample was collected
- establishing control limits for each field and analytical baseline sampling location
- establishing control limits around the variable baseline by taking into account temporal and/or spatial trends in the data.

Also, by comparing the triggered sampling results from multiple sampling locations with the baseline monitoring results that have been collected over time, it may be possible to determine what foreign contaminant(s) have been introduced into the drinking water and the appropriate response actions to take.

When interpreting the data, the data user needs to consider the following information regarding the data from either baseline monitoring or triggered sampling:

- The quality control (QC) results associated with each analytical method and any potential bias the analytical results
- Common interferences for each analytical method and how this could affect the results
- False positive and false negative rates of each analytical method

In addition to the circumstances identified above, the following should also be considered when interpreting the data:

Radiologicals: If either gross alpha/beta or gross gamma levels are detected above background levels and there is other corroborating evidence to suggest contamination, the sample should be referred to a Confirmatory laboratory that can handle radioactive samples. The Confirmatory laboratory would perform targeted analyses to identify the specific radionuclides present in the sample.

Biologicals: Samples would be sent to a Confirmatory Laboratory for further analysis under one of the following conditions:

- The initial PCR assay gives a reactive result, and the more specific PCR assay gives a reactive result.
- The culture-based result is positive.
- The initial PCR assay (single loci) gives a reactive result, there is no presumptive result for one of the five biologicals, but there is other corroborating evidence.

Chemicals: Samples would be sent to a Confirmatory Laboratory for further analysis under one of the following conditions:

- It is suspected that the sample contains any chemical warfare agent. This sample would be sent to a Confirmatory laboratory that has surety capability for analysis.
- An analyte is tentatively identified but the Sentinel laboratory does not have the analytical capability to perform a positive identification and quantification.

4.4 Framework for Evaluation

Section 2.4.1 discusses that reliability encompasses two aspects—system operation and system performance. System operation requires little discussion in the context of sampling and analysis because it relates to issues utilities and others are familiar with: equipment maintenance, downtime, availability of supplies and reagents, etc.

System performance related to sampling and analysis is a more complicated subject. As discussed in Section 2.5.2, it is related to the ability to characterize and correctly interpret the all data streams, not just sampling and analysis. A significant part of interpretation is the false positive rate, which is highly dependent on the precise sampling and analysis method employed. For established methods (such as EPA drinking water methods), this false positive rate can be low for the concentration ranges potentially associated with intentional contamination incidents.

The results of baseline sampling should be used to support the proper interpretation of the results from triggered sampling and analysis. In turn, the overall reliability of the WS-CWS results should depend on the method that this data stream is integrated with the others (see Section 2.4.1). In this data fusion process, consideration should be given to the probability of detecting the contaminant through sampling and analysis. A broad context of the reliability of sampling and analysis in WS-CWS is related to consequence management activities that should accompany data collection and interpretation.

Baseline sampling and analysis lends itself to dual benefits because the frequency of sampling and the data obtained may also help improve utility operations and routine water quality. Regardless of the cost, baseline sampling is vital to the application of the results from triggered sampling and analysis the credibility determination process. Baseline monitoring provides additional value to utilities and laboratories involved in implementation of contamination warning systems by providing an opportunity to practice and improve proficiency in sampling and analysis activities that should be necessary for response and triggered sampling and analysis.

In assessing the costs of triggered sampling, it is important to remember that the WS-CWS as a whole would probably not be vital, let alone sustainable, without a well developed and exercised consequence management plan. Triggered sampling as part of site characterization activities would likely be an important part of such a plan. Accordingly, the driving issue of sustainability of WS-CWS depends, in part, on sampling and analysis program that is sustainable.

The overall goal of the WS sampling and analysis program is to accurately measure what is present in the drinking water. To evaluate that the sampling and analysis program is accurately measuring what is present in the drinking water, the evaluation program should consist of the following items:

- Field and lab assessments to verify that organizations are implementing key practices required for the program
- Evaluation of QC samples to identify errors in specific components of the sampling and analysis program
- Proficiency testing to evaluate each laboratory's ability to correctly characterize contaminants in a sample
- Tabletop exercises and real-time water contamination drills.

4.4.1 Sampling Locations

The development of an adequate network model is an important tool in the selection of suitable sampling location, for both baseline and triggered sampling. While there is much that goes into the vulnerability and risk assessment portion of the various sampling locations, there is little that can be done to evaluate true optimality. Instead, sampling locations should be evaluated based on the potential trade-offs between various sampling locations. Through application of the TEVA methodology, the distribution system model should provide opportunities to estimate the coverage of different sampling locations as well as the potential spread of a contaminant, which is important when evaluating the impacts of response time to a triggered event.

Sampling locations should be placed throughout the distribution system to provide adequate coverage of the distribution system. This 'coverage' includes providing adequate spatial distribution as well as ensuring the data collected from the various sampling locations represents the entire distribution system. By providing such coverage, the likelihood of determining the areas of the distribution that are well or poorly represented by the network model is increased.

4.4.2 Assessments

***Sampling Assessments*:** EPA plans to assess the WS sampling program before the pilot program begins to determine if the practices in place are sufficient and meet the needs of the WS-CWS and to verify that the sampling practices are being properly implemented for WS. The assessment should include: (1) a review of the utility's documentation (e.g., standard operating plans (SOPs), training records), (2) observations of sampling personnel collecting samples for 'unknowns' analysis to verify that proper procedures are being followed, and (3) interviews with utility staff, and other potential responders, to ensure they understand their roles and responsibilities both for baseline monitoring and triggered sampling and analysis. If the field sampling assessment identifies a number of errors (such as the utility not having sufficient documentation of their sampling procedures), EPA anticipates conducting additional training as necessary.

EPA plans to occasionally conduct follow-up assessments of the pilot utility's sampling program for WS. The frequency of these assessments should be based on need, as indicated by results of the pre-pilot assessment and results of field QC samples collected during the pilot program. Prior to conducting the first assessment, EPA aims to develop a field checklist to facilitate the assessments. This checklist should be revised as needed during the course of the pilot study to streamline or improve the effectiveness of the assessments.

To ensure the effectiveness of all field assessments, EPA plans to provide the pilot utility with a debrief immediately following the assessment and with a written report following completion of the assessment.

The field assessment results should be used to identify and assess areas in which additional attention or training is needed to sample correctly for either baseline monitoring or triggered sampling for a water contamination threat or incident.

Lab Assessments: EPA plans to assess the utility laboratory, or other laboratories that are identified as the Sentinel and Confirmatory laboratories for the WS-CWS, before the sampling and analysis pilot program begins to determine that the laboratory is following the appropriate techniques for either the 'unknowns' protocol and/or the analytical methods that should be used to analyze samples for the WS-CWS. EPA anticipates using the existing Drinking Water Laboratory Certification Program to verify that basic drinking water laboratory qualifications are met for chemical, biological, and radiological analyses at Sentinel and Confirmatory laboratories and the LRN program to verify that Confirmatory methods meet the current requirements established for the biological analyses for this program. The Drinking Water Laboratory Certification program includes routine on-site assessments of participating laboratories and EPA plans to supplement these existing programs with on-site assessments to evaluate laboratory facilities, QA practices, personnel qualifications, and performance for specific contaminants and methods that are required for the WS but not routinely used in either the LRN or traditional Drinking Water program. For example, Sentinel laboratories may use PCR methods for WS, which may not be covered under the other programs, and would thus need to be evaluated under WS to ensure proper sample flow and containment. Also, the ability of Confirmatory laboratories to acceptably process drinking water samples should be evaluated to ensure reliable data quality for environmental matrices and sample handling practice for dangerous agents.

EPA plans to develop a suite of laboratory assessment checklists designed to address unique aspects of the WS program that are not addressed in assessments conducted as part of the LRN or Drinking Water Certification program. The checklists also should address the laboratory's ability to support both the baseline and triggered monitoring program. Separate checklists could be developed to address each major lab activity or analytical method that should be used in the WS program, including application of the 'unknowns' analysis protocol. These checklists should be revised as needed during the course of the pilot to streamline or improve the effectiveness of the assessments.

EPA may occasionally conduct follow-up assessments of the WS Sentinel laboratories. The frequency of these assessments should be based on need, as indicated by results of the pre-pilot assessment, results of proficiency testing (PT) samples, and evaluation of laboratory QC samples collected during the pilot program. To ensure the effectiveness of all laboratory assessments, EPA plans to provide the audited laboratories with a debrief immediately following the assessment and with a written report following completion of the assessment. The laboratory assessment results should be used to identify and assess areas in which additional attention or training is needed.

4.4.3 Evaluation of Field and Laboratory QC Data

For baseline monitoring, during the WS pilot program, a suite of field and laboratory QC samples should be employed, such as field and laboratory blanks, field and laboratory duplicates, equipment blanks, ongoing precision and recovery samples, and matrix spikes. These QC samples provide information about the precision and bias associated with various components of the sampling and analytical process. EPA and the utility would review the results of these QC samples to determine if results are acceptable. Results that are outside of established limits should be examined in the context of other factors to identify the potential cause and appropriate corrective actions. For example, if results of field duplicates do not agree within established limits, but results of lab duplicates do agree, EPA may reassess the sampling team to determine that the samplers are following the utility standard operating plans (SOPs) and identify any additional training needs. If laboratory QC data suggest a consistent, unexpected bias in a particular type of analyses, EPA plans to work with the laboratory to identify and correct the source of that bias.

4.4.4 Proficiency Testing (PT) Program

Any laboratory that is supporting the WS pilot program should be expected to participate in Proficiency Testing (PT). PT samples provide a means of evaluating a laboratory's performance under controlled conditions through analysis of unknown samples provided by an external source. Performance is evaluated against static criteria or against criteria determined using data from all laboratories analyzing samples during a round of testing. For biological analyses, EPA anticipates working with CDC to identify the most efficient approach for the distribution of reagents Sentinel and Confirmatory laboratories for the analysis of pathogens in drinking water samples, including standards and controls necessary for participation in the PT program. For chemical and radiological analyses, EPA plans to explore the use of vendors with which EPA has existing contracts/agreements for PT samples.

It is proposed that the PT samples should be distributed on a quarterly basis to the laboratories supporting the WS-CWS. EPA plans to monitor the results of the PT samples submitted for each laboratory. If there are serious deviations with the PT results, the laboratories should be notified so that corrective actions can be initiated and problems can be resolved.

4.4.5 Tabletop Exercises and Water Contamination Drills

Tabletop exercises and drinking water contamination incident simulations should be used to evaluate how well utility and laboratory staff respond when a trigger from the WS-CWS indicates the need for triggered sampling and analysis.

The utility and laboratories that are part of the WS pilot should take part in tabletop exercises. The tabletop exercises should take place before WS-CWS monitoring and surveillance activities are initiated to verify that the roles and responsibilities of the utility and supporting labs in WS are clearly understood. It should also establish whether or not the utility and the laboratory are able to respond effectively and appropriately during a water contamination threat or incident. A 'lessons learned' report should be developed from the tabletop exercise and put into practice during implementation of the WS-CWS.

The utility and laboratory should also participate in real-time, drinking water contamination incident simulations to determine how well the utility and laboratories follow the consequence management plan and credibility determination process during a water contamination threat or incident. Such contamination incident simulations should take place periodically after the WS-CWS has been implemented at the utility, and should mimic real-life situations as much as possible. This means a component of the CWS should indicate that there is a 'possible' contamination incident, the utility should collect samples, and the laboratory should analyze the samples by their routine analytical methods and the unknown protocol. EPA expects that most, if not all, of these drills would be planned events, in which specific circumstances are communicated to the utility and laboratories. If feasible, however, a 'blind' drill may be conducted to determine if the baseline and/or triggered sampling program is capable of detecting a change. Such a blind drill could be achieved through the use of off-line CWS components that still feed information into the WS-CWS data management system (the event would be known to EPA and the utility manager but not to any other participants). EPA plans to document results from the drinking water contamination incident simulations in a study report that should be used to identify and assess areas in which additional attention or training is needed to respond effectively to a water contamination threat or incident.

Section 5.0: Enhanced Security Monitoring

Enhanced security monitoring includes the systems, equipment, and procedures required to detect and respond to security breaches. This includes detection by physical security systems such as alarms and cameras, witness accounts, and notifications by perpetrators, media and law enforcement as well as response methods linked to these. A security breach is an unauthorized intrusion into a secured facility that may be discovered through direct observation, an alarm trigger, or signs of intrusion (e.g., cut locks, open doors, cut fences). Security breaches are probably the most common threat warnings for a utility, but in many cases an apparent security breach is actually a false alarm related to routine operation and maintenance activities. In most cases, actual security breaches are due to criminal activity such as trespassing, vandalism, and theft rather than attempts to contaminate the water. However, any security breach should be assessed with respect to the possibility of contamination. Ideally, an enhanced security monitoring system should be designed so that security breach alarms and notifications related to a contamination event can be differentiated from other events.

To provide sufficient time for law enforcement to respond and prevent a contamination event, physical security design features such as fences, locks, and reinforced doors and hatches should be incorporated into certain facility designs. It may be difficult to physically protect most water facilities from security breaches that may occur as part of a contamination event, but some facilities can be sufficiently hardened to prevent intrusion and contamination. However, it may be cost prohibitive to install physical security features which provide sufficient delay against a sophisticated adversary who possesses the proper tools and know-how. Therefore, it is often desirable to focus on physical security designs that utilize effective detection systems that, in turn, should provide reliable warnings and assessments of a security breach. The security breach may indicate the potential introduction of a contaminant and the appropriate response actions could begin as soon as possible.

Enhanced security monitoring is one component of the WS-CWS with the potential to detect a contamination incident before any exposures occur because the alert is linked to an intrusion that occurs prior to the introduction of a contaminant. Furthermore, this type of monitoring has the means to detect an intrusion in progress, and thus may provide an opportunity for law enforcement or security personnel to prevent the introduction of a contaminant and apprehend the perpetrators. Enhanced security monitoring can also potentially detect an activity that would result in the introduction of any class of contaminant into a water system.

The consequences of a potential contamination event that is detected by an enhanced security system can, in some cases, be eliminated or significantly reduced through operational responses that are triggered by an enhanced security system. These responses may include linking detection alarms to automatically open and close valves or disable pumps.

5.1 Integration of Enhanced Security Monitoring into the WS-CWS

An effective physical security system should detect a security breach early enough and provide adequate delay to allow sufficient time for law enforcement to respond and prevent the adversary from completing their intended act. The consequences of a potential contamination event can in some cases be quickly eliminated or significantly reduced through an operational response that is triggered by a security alarm or notification. These operational responses include linking detection alarms to automatically open and close valves or disable pumps. The time to enact these measures would typically range from a fraction of a minute to more than an hour if non-automated processes are used and/or large manual valves are required to be closed.

This section discusses these concepts in more detail and describes how they should be used to properly design a physical security system. The elements of a physical security system are depicted in **Figure 5-1**.

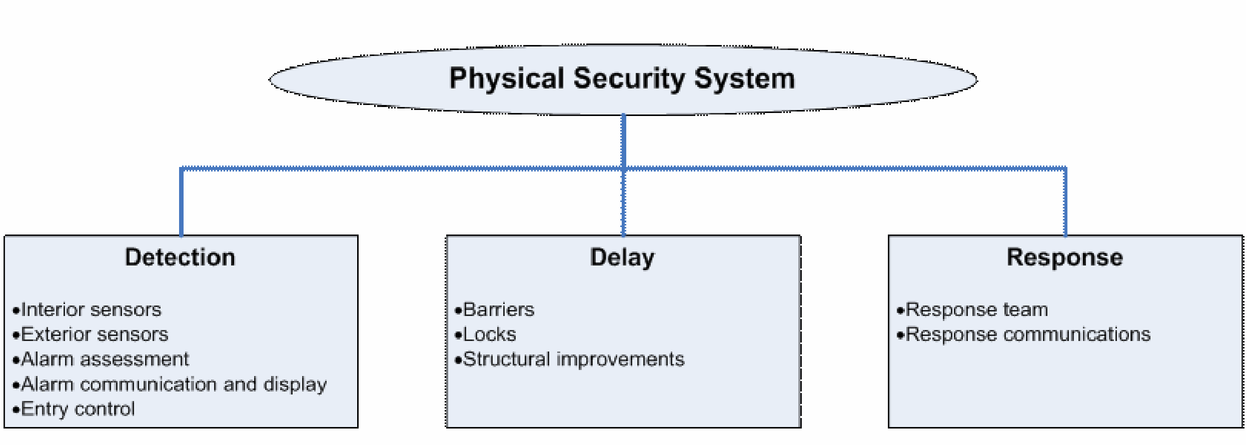


Figure 5-1. Elements of a Physical Security System

Due to financial constraints and practical considerations, enhanced security monitoring should generally be limited to selected locations in the utility's system that could serve as a likely location for potential contamination of the drinking water. Such locations may include water storage facilities, wells, pump stations, and treatment plants. However, protecting these facilities could be critical depending upon system configuration and hydraulics because if contamination were to occur at some of these points like large storage tanks, the consequences could be high. In addition, facilities like storage tanks are usually highly visible and may be an obvious target for contamination making it important to monitor and protect.

Detection

The first parameter that affects the probability that the adversary should be successful in a security breach is the likelihood that the intrusion should be discovered. A properly designed detection system includes the following:

- A sensor (equipment or personnel) reacts to its designed initiating event (door opening, movement, etc) and initiates an alarm.
- The information from the sensor should be reported and displayed.
- The information is assessed and a determination is made if the alarm is valid.
- The system to assess alarms should provide two types of information associated with detection: whether the alarm is valid or a nuisance alarm, and details about the cause of the alarm (what, who, where, and how many).

Physical detection systems that should be considered include but are not limited to interior and exterior intrusion detection systems such as door contact switches, glass break sensors, motion detectors, and fence mounted sensors. For monitoring and assessing alarms, an evaluation comparing methods, including monitoring/assessment by utility staff versus using an outside contractor, should be done. If monitoring is to be done by utility staff, the needs of the monitoring facility including communications, security, and staffing should be addressed.

The most common method of alarm assessment is through the use of cameras and image display monitors. Cameras can capture images of the adversary entering the facility and contaminating the system and may be capable of identifying the quantity and possibly even the type of contaminant, thereby quickly moving the event from a ‘possible’ to a ‘credible’ contamination scenario. The most effective type of camera system would be one in which images are transmitted in a manner such that utility or security staff are quickly alerted to the security breach and the images from the camera are immediately available for review to help determine if the threat warning is credible. This may be accomplished by complementing the cameras with interior or exterior sensors like door alarms or motion sensors and by ‘freezing’ the image on the monitor, which shows the intrusion event.

The camera system design should define the required level of resolution categorized in one of three ways:

- Detection: Assists remote assessment that simply determines the presence of an intruder.
- Classification: Allows operator to determine if the alarm is due to a human intruder rather than an animal or an object.
- Identification: Allows operator to identify a specific human intruder.

Other camera options like pan-tilt-zoom capabilities, focal length, color vs. black and white, covert vs. visible location, height above ground, tamper-proof encasement, and others options should also be considered during design to ensure the successful implementation of a camera based security system.

Delay

Delay is the function of slowing the adversary on their way to the ‘target’. The types of delay that should be evaluated as part of a physical security system that addresses the contamination threat include: locks, hardening of doors, windows and walls, barriers for storage tank access ladders, fences, covers for water storage reservoir vents, and barriers to prevent vehicle access. The physical security system should incorporate as many ‘layers’ of protection as possible in order to maximize delay, increase the probability of detection, and decrease the probability of a successful intrusion. Layers of protection may include a fence around the site, hardened doors and access hatches on the structures, and access control to the door where the intended target is located, for example a chemical feed pump or reservoir access hatch.

Delay devices placed ‘ahead’ of detection are of little or no value. An intruder not faced with detection has sufficient time to climb a fence or cut a lock without detection. After the penetration has been detected and response is initiated, any delay provides more time for response, thereby decreasing the likelihood of intruder success.

Response

Response is the time required by the response team or law enforcement to interrupt an adversarial event. Response includes both interrupting and stopping the adversaries. The measure of response effectiveness is the time between receiving a communication of adversarial action and interrupting and stopping it. An effective security system should be able to detect the adversary early enough so that they do not have time to carry out their task, are delayed long enough for the response to arrive, and are stopped before the action is accomplished. However, detecting a contamination incident without being able to stop it does have value because after an adversary is detected, actions can begin to be taken to mitigate the incident.

For a physical security system to be effective, it should perform the functions of detection, delay, and response in less time than that required for the adversary to complete the insertion of a contaminant. The adversary faces certain tasks (which equate to time) to accomplish his objective. In this example, the adversary should climb a fence, run to the building containing the target equipment, break through the building door, introduce the contaminant, and leave. This total time is known as the ‘adversary task time.’ The physical protection system (PPS) time required starts at first detection and includes the time associated with the alarm detection and assessment and the time required for the response force to intercept the intruder.

Figure 5-2 illustrates an ineffective security system and represents what may occur if the first detection opportunity were at the target facility itself. In this case, the intruder has completed his tasks before the response force gets to the scene. The adversary has more time to complete the contamination since he has already climbed the perimeter area fence before initial detection. Since the first alarm is at the target facility and the time required for detection and response is greater than the system delay, the security system is ineffective against the adversary.

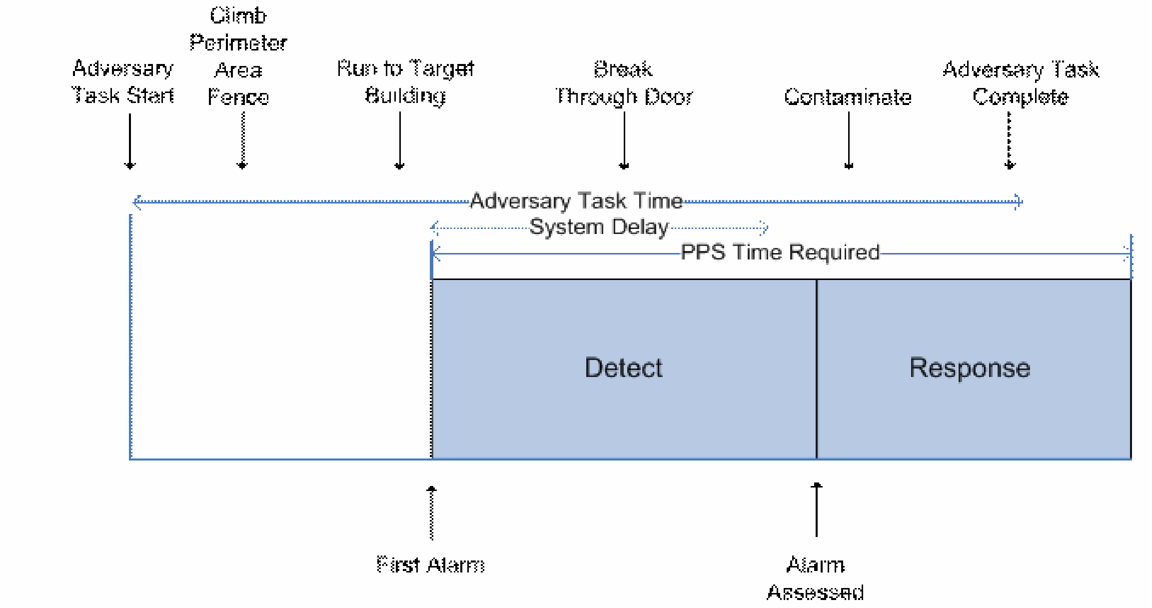


Figure 5-2. Adversary Task Time versus Security System Time Requirements for an Ineffective System

Given that the detection and response times should be the same regardless of the location of initial detection, the addition of an intrusion sensor to the perimeter fence allows detection and response to start earlier. **Figure 5-3** represents this system configuration. The two boxes representing ‘detect’ and ‘response’ are now shifted to the left because the first detection system is moved ‘farther out’ from the target building to the perimeter fence, illustrating that the security system should be effective in interrupting the same adversary and preventing the contamination act.

However, as discussed previously there is value in detecting a contamination act even if the adversary is not stopped from completing the act because getting this warning would provide the ability to begin consequence management efforts.

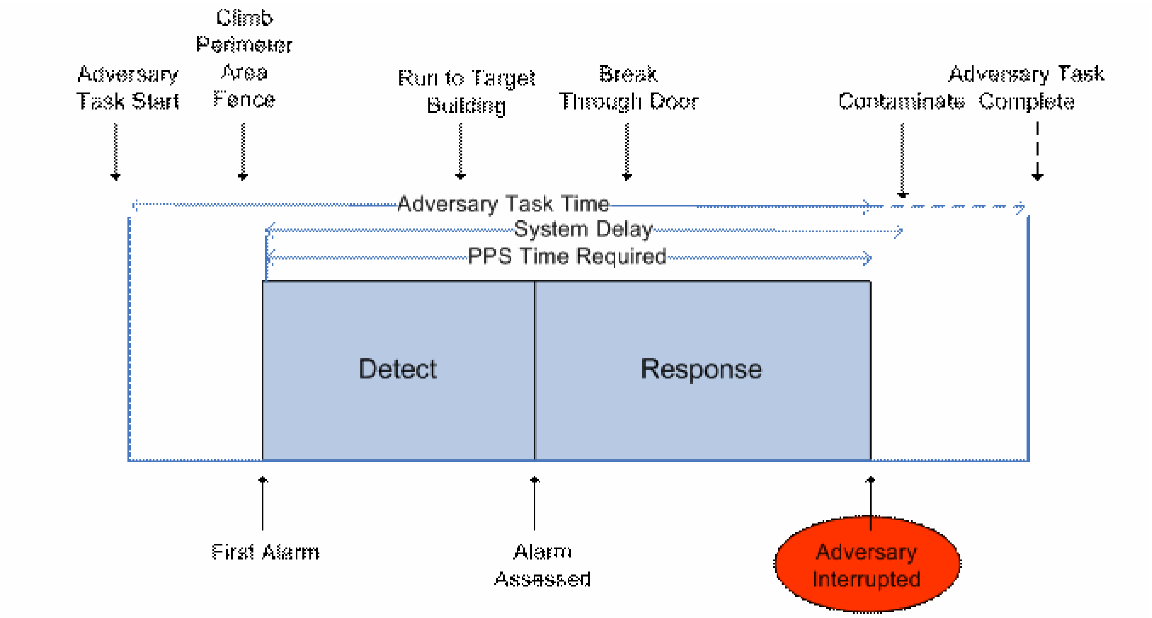


Figure 5-3. Adversary Task Time versus Security System Time Requirements for an Effective System

5.1.1 Other Security System Design Considerations

Other issues that should be addressed as part of a physical security system design include the following:

- Install access control devices and intrusion detection sensors on doors or hatches to areas that provide the opportunity for water contamination.
- Hardening of doors, hatches, windows, vents, and locks to areas that provide the opportunity for water contamination.
- Communication of intrusion alarms using the utility SCADA system, independent electronic security system monitored by the utility, or directly to law enforcement agency, depending on the response procedures which have been developed for potential contamination incidents.
- Camera systems should be scalable to allow future system expansion.
- Compatibility of potential upgraded monitoring and recording equipment with any existing cameras.
- Definition of the camera system transmission media (fiber cable, coaxial, or twisted pair cabling).
- Determine the number, type and location of viewing monitors and the need for a matrix switcher or multiplexer that allows effective monitoring and recording of images.
- Ensure there is sufficient light for cameras – the most common reason for poor image quality is that light levels are too low or poorly designed. Provide sufficient light to discern individuals at a distance of 75 feet and to identify a human face at about 33 feet. Avoid backlighting and high contrast viewing areas.
- Use an image compression standard that results in acceptable transmission speed.
- Design electrical power supply to be reliable by considering backup power, lightning protection and redundant systems.
- Interconnecting wiring between security system components should be monitored for integrity so that an abnormal condition such as a wire break or ground fault is indicated.
- Establish the number and type of video image recording devices required to store sufficient data.

- If cameras are not feasible for a particular location, install a secondary detection sensor to provide verification of the primary sensor. For example, a motion detector could be installed to verify the contact alarm on a door or hatch.
- Design physical security systems based on the threat level including the type of contaminants that may be used as the level of physical protection required and the type of contamination agents may vary.
- Implement policies and procedures to ensure the physical security systems operate as intended.

For additional detailed information regarding the design consideration for physical security systems see references such as the EPA's *Water and Wastewater Security Product Guide* (USEPA, 2005l) and AWWA's *Interim Voluntary Security Guidance for Water Utilities* (AWWA, 2005).

5.1.2 Other Detection Methods

In addition to physical security detection methods, other methods of detection are possible as described at the beginning of this section. To make these methods more effective and timely the following should be considered:

Witness accounts: The utility should establish a close working relationship with local law enforcement since witnesses should likely contact them rather than the utility. It should also be advantageous for a utility to establish a system to collect as much information as possible from the witness to support the initial threat evaluation which could be done by using the checklist form available in Module 2 – Contamination Threat Management Guide of EPA's *Response Protocol Toolbox*. Both utility staff and law enforcement should be made aware that timeliness of notifications is critical.

Notifications by perpetrators: Procedures should be established for handling threatening phone calls as well as the handling and recognition of suspicious letters and packages. A checklist such as the one available in Module 2 – Contamination Threat Management Guide of EPA's *Response Protocol Toolbox* should be used during phone calls to assist staff who might receive a threat in gathering and providing information to law enforcement. All staff who could potentially receive notifications should be trained in the use of the checklist and the checklist should be made readily available at all times to staff.

Notifications by media: It would likely be important that utilities establish close relationships with the members of all forms of the media to emphasize the importance of notifying the utility immediately if a threat against the water supply is received. An established utility contact should be available to receive calls from the media at any time. Regular periodic contacts should be made with the media to ensure that media staff are aware of notification procedures.

Notifications by law enforcement: The utility should establish a procedure for reviewing the available notification information with law enforcement to assess whether the threat is possible and decide on appropriate response actions. While law enforcement agents should have the lead in the criminal investigations, the utility has primary responsibility for evaluating the technical feasibility of the threat and planning and implementing utility response actions.

For each of the above, proper training of utility staff should be essential for the detection methods to be effective. Also, contact lists for media and law enforcement should be updated regularly. In addition, tabletop and full scale exercises as described in Section 5.3 would help improve the methods.

5.1.3 Operational Response Actions

The utility consequence management plan should describe actions that can be taken to mitigate the impacts of a contamination event (USEPA, 2005i). Unlike most of the actions described in this document, the consequences of a potential contamination event that is detected by an enhanced security system can in some cases be eliminated or significantly reduced through operational response actions that are triggered by an enhanced security system. Physical security detection systems with door contact switches or motion detectors can be designed so that the detection system automatically or manually (with operator action) triggers operational responses. Examples of operational responses that can be designed into the system are discussed below.

An alarm triggered by the opening of a hatch, detection of motion, or detection of an intruder by a strain gage on a ladder at a water storage tank could be tied into the control system to automatically or manually prevent potentially contaminated water from entering the distribution system. This could be done several ways depending upon the distribution and storage system configuration, operation, and hydraulics. Depending upon the design of the storage system, doing this in many cases would not result in an immediate significant loss of water pressure or flow in the distribution system. Therefore, notification of the public of a potential contamination event would not be necessary unless the event is later determined to be credible. Some methods of preventing potentially contaminated stored water are:

- Isolating a water storage tank from the distribution system, either manually or automatically, upon detection of an intrusion alarm. After further investigation, the water storage tank could be brought back online if no threat of contamination existed. If water contamination was suspected, then the tank could be drained through the sanitary sewer system after testing to verify that the water would not adversely impact the sanitary sewer system.

- For elevated storage tanks that use a single acting altitude valve to control maximum and minimum level in the tank, the control system could be configured so that an intrusion alarm opens the altitude valve to fill the tank to its maximum level. Doing this should usually result in the distribution system being fed by a pumping station rather than the storage tank because the hydraulic grade line should have changed. While the tank is being filled, the tank could be isolated from the system by manually closing the influent and effluent isolation valves. If possible, the influent and effluent isolation valves for the tank could close automatically upon an intrusion alarm. This would isolate the tank from the rest of the system and prevent a contaminant from spreading as described above.

- Ground water wells often use pumps to pump water into an adjacent storage tank where booster pumps are then used to distribute water to consumers. If an intrusion is detected by a storage tank hatch contact alarm, for example, then the booster pumps and/or well pumps can be automatically disabled to prevent contaminated water from being distributed. As part of this system, locks should be installed on pump controls to prevent them from being operated in manual mode by an intruder.

- If a contamination event in the distribution system is suspected, but the entry location of the contaminant is unknown, the distribution system chlorine residual could be increased in an attempt to counteract those contaminants that may be inactivated or oxidized by chlorine. In selecting the chlorine dose, consideration would have to be given to impacts on water taste and odor and potential toxicity levels. Increasing chlorine levels would likely only be done where the flow of water to the distribution system could not be stopped using methods described above. If the contaminant was not known or non-reactive to chlorine, then a ‘Do Not Drink’ or ‘Boil

Water' warning could be issued by the utility until additional information about the contaminant and the extent of contamination becomes available.

In addition to linking intrusion detection alarms at distribution system facilities to automatic operational responses as described above, other types of contamination threat warnings could also trigger similar operational responses throughout the distribution system and possibly at treatment facilities. For example, if a witness sees suspicious activities around a specific fire hydrant, the pipes in the vicinity of that hydrant could be isolated by closing valves. Using a hydraulic model, the extent of contamination could be estimated and additional isolation could be implemented. Depending upon the contaminant of concern, the isolated portion of the system may be disinfected with a high dose of chlorine and/or flushed. Additional adjustments to other components of the distribution system, like booster pumps, water storage tanks, or the water treatment facility, would likely be required to compensate for the of the area taken out of service. Details of these response activities should be addressed in the WS consequence management plan as developed by the pilot utility (USEPA, 2005i).

5.2 Data Management, Analysis, and Interpretation

In order to avoid taking unnecessary response actions and prevent potential threat warnings from going undetected, it should be essential that effective procedures be established for responding to threat warnings from enhanced security systems. Utility staff that are responsible for responding to alarms should be trained in how to identify false alarms, interpret alarm signals, and communicate potential threat warnings. Section 8.0 provides additional discussion regarding the integration of information streams and data as part of the WS-CWS.

5.2.1 Data Management

Analog or digital signals from intrusion detection sensors may provide continuous system status (i.e., door open/closed) or provide indication that an alarm condition is present (i.e., door contact broken thus door has been opened). As is the case with process monitoring signals, alarm signals are typically input into a data concentrator device such as a programmable logic controller (PLC), a remote terminal unit (RTU), or remote input-output (RIO) device. This device could be the local PLC used for process control or an independent, security-only PLC. Intrusion alarm signals should be transmitted from the remote sensing location to a central communications interface at a data warehousing and analysis location. This location may house the central process control PLC or a central security-only PLC. Data are transmitted to this location via the most convenient data transmission pathway available (i.e., telephone line, radio frequency, ethernet, etc.). If desired, data logging of alarms or local indication of alarm condition (i.e., audio or visual indication at the facility) may be desired. In addition, intrusion alarms may be transmitted to the appropriate staff or law enforcement officials through the use of an automatic phone number dialing system or through the display of camera images on a remote monitor.

If cameras are used, a separate data collection and transmission system is usually required due to the size of data being handled. One of the significant challenges of designing a cost effective assessment system that uses cameras is transmission of large amounts of video image data. A number of video compression methods are available to reduce file sizes but transmitting large video data streams to remote monitoring locations can be costly even with compression. To reduce costs, some utilities use video recording systems that are installed at the same remote sites as the cameras are located. This video recording may be useful in determining the credibility and nature of the contamination event but response would not be as fast as with a system that can immediately transmit images. There currently are emerging technologies that have the potential to more cost effectively transmit images to remote monitoring locations or handheld devices such as cell phones. These technologies include systems that transmit images through the SCADA systems that are already installed at many utilities and wireless transmission systems. In addition, camera systems have another advantage in that there is a potential dual use in that they can in some cases be used to monitor the system operation.

5.2.2 Data Analysis and Interpretation

The analysis and interpretation of intrusion alarms and images from cameras is often the responsibility of utility staff. Upon receipt of an intrusion alarm, utility staff can either immediately contact law enforcement officials about the intrusion, if the system does not do so automatically, or conduct further analyses to determine if an actual intrusion and/or contamination event has occurred. For safety reasons, it is preferable for utility staff to not visit the site where the alarm was tripped. Rather staff should, where possible, remotely view a monitor at a control room or other location that provides access to video images. Password protected, web-based displays of alarms, camera images, and even process control information can be made available if set up in advance.

5.3 Framework for Evaluation

The ability to quickly assess a security breach alarm is essential to determining if the breach is indicative of a credible contamination event. In many cases, an incident as indicated by a security breach alarm should not immediately signify if there is a contamination event in progress. For many utilities, law enforcement, supported by water utility staff, should first respond to the facility to determine if the alarm is a credible indication of a contamination event. In many cases, they may not observe evidence that contamination has or has not occurred. Further, it may be difficult to determine if the event is a false alarm triggered inadvertently by utility staff or by another cause such as animals or wind. Therefore, proper assessment of alarms through enhanced security monitoring using means such as cameras is essential to quickly and reliably determine if an alarm is a credible and possibly an indication of contamination.

Many drinking water utilities already utilize some or all aspects of enhanced security monitoring. Basic access type alarms such as door contact switches and motion detection devices are relatively commonplace at water utilities. In addition to reducing the risk of potential contamination, security monitoring systems should deter and prevent other malevolent acts such as vandalism and theft. Access control systems can be used to limit access to selected facilities to only authorized employees and can record employee entry/egress to ensure duties such as equipment monitoring are being done. Also, camera systems can be used to remotely monitor process operations such as equipment performance and hydraulic levels, providing the utility with multiple benefits.

Several aspects of enhanced security systems can be evaluated to help determine its effectiveness. Since actual intrusions may be relatively rare, tabletop and full scale simulation exercises dealing with several threat warning scenarios that test the efficacy of security systems could be developed. The exercises should involve all those who may be involved in a genuine event including operations and maintenance staff, treatment and distribution system staff as well as, law enforcement, and contracted security firms. Full scale exercises could be run in an effort to confirm how distribution system operational responses such as turning pumps on and off, isolating water storage tanks, or flushing fire hydrants would impact the system hydraulic grade line and direction of the flow of contaminants. These aspects and potential methods for evaluation include the following:

- **Detection, delay, and response effectiveness:** Through exercises and simulations, track the number of security breaches that were or were not detected by the physical security systems within the time period specified in the system design. The reasons why the breaches were not detected in a timely manner should be documented. In the event of an intrusion, document if the physical barriers provided sufficient delay to allow time for law enforcement to respond. Also, document law enforcement response times.

- **Assessment:** In the event of an intrusion, document if the assessment system was capable of assisting the operator in identifying the nature of the threat.
- **False/nuisance alarms:** Through analysis of actual operational history, simulations, and exercises, determine what percentage of physical security system alarms are false or nuisance, as well as the reason for the false alarm. Based on this determination, establish a procedure to reduce false/nuisance alarms and/or identify needed system changes, such as relocating or replacing a sensor.
- **Operational response actions:** In the event of an intrusion, document if the proper operational response actions were followed and if they were effective.
- **Other detection methods:** In the event of an intrusion detected through means other than the physical security system, document the effectiveness of the procedures for detecting a potential contamination event through witness accounts, and notifications by perpetrators, media and law enforcement.

A non-intrusive method for evaluating the effectiveness of the enhanced security system is to run a quantitative analytical computer model simulation on the facility of interest and its physical security system. Several such models have been developed by Sandia National Laboratories, including EASI (Estimate of Adversary Sequence Interruption) and SAVI (System Analysis and Vulnerability to Intrusion), and other commercial products are available. These models are useful tools in providing an initial determination of the effectiveness of the enhanced security system and identifying the areas where additional protection is needed. The model analyzes all aspects of physical security design including detection, delay, and response and improvements may be identified in one or several of these aspects.

Section 6.0: Consumer Complaint Surveillance

Consumer complaints, if systematically tracked and responded to in a timely and appropriate manner, can be a valuable component of a CWS. Located throughout a utility's service area from the beginning of the distribution network to its far reaches, consumers can provide near real-time input regarding changes in water characteristics, as well as report on suspected tampering to pipelines, hydrants, valves and other appurtenances. Consumers may detect contaminants with organoleptic characteristics that impart an odor, taste or visual change to the drinking water. Commercial and industrial consumers may be able to detect contamination that alters the chemical and physical properties of the water not obvious to the residential consumer due to anomalies in the products produced from the water, or from impacts on advanced treatment processes used by a consumer to provide ultra-pure water. Reports of illness, although not often reported initially through the water utility, can provide important information in confirming water contamination events detected through public health surveillance as discussed in Section 7.0. Moreover, historically consumer complaints have played a role in the detection of several drinking water contamination incidents. For example, a 12 hour diversion of excess hydrofluorosilicic acid from a water treatment plant to a residential community water supply in Connecticut resulted in the population's ingestion of fluoride and copper at levels several times greater than normal (Petersen LR et al., 1988). Consumer complaints reported at the water utility during this event ranged from taste and color to nausea, vomiting, diarrhea, cramps and skin irritation.

Coverage provided by consumer complaint surveillance includes residential and commercial consumers throughout the entire distribution system, and thus can provide system-wide coverage for the WS-CWS. Both the number and geographic distribution of consumer complaints can assist the utility in not only detecting potential contamination, but the area of contamination as well. However, consumer densities vary from utility to utility, and also vary within different portions of a utility's service area, possibly leaving some locations in the service area without this typically spatially continuous component.

The most critical factor when considering consumer complaint surveillance is receiving enough qualified complaints within a designated period of time for the utility to further investigate. Odor, irritant, and taste complaints are often received by the utility fairly quickly; within the first few hours after a consumer notices a problem. However, consumption of water in every portion of the distribution system is not consistent, and certain portions of the service area may have very few consumers during the late night hours (e.g., residential areas), or on the weekends (e.g., industrial areas). Consequently, while the time from a consumer recognizing a problem with their water may be relatively rapid, the time between a contamination incident and the consumers' use of the water may be lengthy. Timeliness should be a function of the time between initial exposure, consumer reporting to the water utility and subsequent categorization, assessment and investigation of the complaint. For contaminant detection classes 1 through 4, consumer reporting and categorizing of the complaint should be fairly quick as they have particular organoleptic characteristics. Although most microbiological contamination does not affect the aesthetic characteristics of water they do cause clinical symptoms that might be detected initially by either consumer complaints or public health surveillance. Usually in cases of microbial contamination or chemicals that do not affect the aesthetic quality of water, consumer complaint surveillance should provide secondary detection and corroboration of the contamination event during credibility determination. Consumer complaints have been effective in prompting investigation or corroboration of contamination events on numerous occasions. For example, during the cryptosporidiosis outbreak in Milwaukee, WI and in the fluoride diversion incident in Connecticut there were widespread clinical symptoms and consumer complaints (Foldy, 2004; Petersen LR et al., 1988).

6.1 Attributes of an Effective Consumer Complaint Surveillance Program (CCSP)

Consumer complaints, when integrated with other primary utility information streams (online water quality monitoring, sampling and analysis, public health surveillance, and enhanced security monitoring) can contribute to the accurate detection of a contamination event. Developing and maintaining a timely and accurate consumer complaint surveillance program requires a systematic review and enhancements to the program over time. Educating consumers, as well as communicating with them about the information they provide, is critical to creating an effective program that minimizes false alarms.

In addition to residential consumers, commercial and industrial consumers may be able to detect more subtle changes in drinking water quality from observations of abnormal reactions in manufacturing processes or from upsets in water purification systems used for specialized applications such as the production of computer chips or pharmaceuticals. Incorporating vital information from the monitoring and surveillance activities of certain key customers, industries, and institutions (such as hospitals) into the consumer surveillance program can provide an additional source of valuable data.

Program goals, available resources, and sophistication of data management systems should all be considered when developing an effective consumer complaint surveillance program. These factors are different for different utilities and should have an effect on the specific design of a utility's program. However, all programs need to incorporate the components of an effective consumer complaint surveillance system, assess their current system, enhance their existing system where appropriate, and evaluate their system's performance. **Figure 6-1** identifies the main components of a consumer complaint surveillance program and illustrates an adaptive process for continuing to improve the program over time.

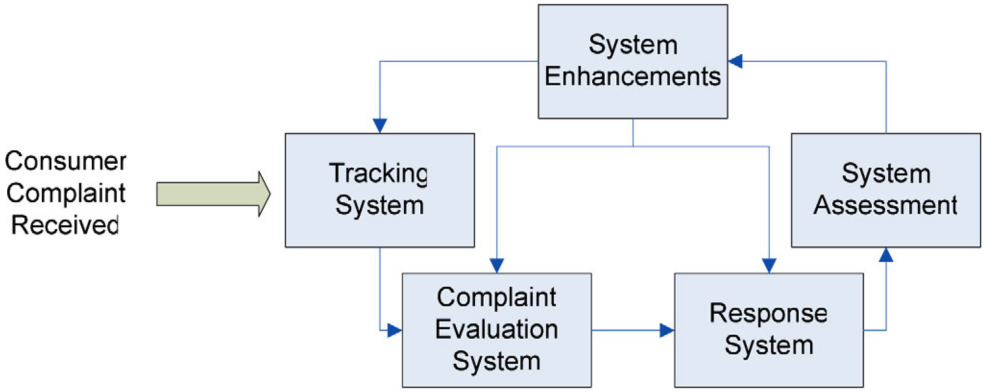


Figure 6-1. Components of a Consumer Complaint Surveillance Program

Several key elements are important to ensure that consumer complaint management is translated into an effective surveillance program. These elements are incorporated into the utility's business processes and operating procedures, and supported by written policies and procedures by which consumer complaints are managed. They describe in detail which staff should be involved in consumer complaint management, including how they should handle the complaint from receipt through resolution and evaluation. Each of the following elements is important to consider during the integration of a consumer complaint management system into a WS-CWS.

- Complaint receipt and documentation
- Categorization and routing
- Assessment and investigation
- Complaint tracking

- Senior staff oversight
- Staff training
- Consumer education

Complaint receipt and documentation. Ideally, consumer complaints should be received by the utility's call center. Specific staff are assigned to document complaints received by telephone, fax, e-mail, U.S. mail or private carrier, or in person. Calls coming in on the phone system can be identified by Customer ID based on incoming phone number (or other similar tools). Complaints submitted with payments that go to a lockbox rather than to the utility should be routed to the person in charge of documenting them at the call center. A single electronic database should be used to log all complaints and assign a unique identification number to each complaint. The database should include a standard data entry-screen. The database may be part of, or integrated with, the utility's customer information system. Off-site daily back-up of the database is recommended, as is a daily paper printout that could be used should computers not be available. In addition, a single number for consumers to call with complaints should be identified. This line should be answered 24/7 but approaches may vary by utility. Consideration should be given to the call center's capacity and an overflow strategy developed. 'Many cities have emergency phone lines and call centers available, and these can be requested for use by a water utility during high call volume periods. These numbers and operators are typically available through a city's emergency manager or emergency operations center. Staff training should be provided and a shift system designed for dealing with volumes. Linking to the Utility's Work Order and GIS systems could assist in identifying known problems or discovering potential problems in need of evaluation. Historic events are also considerations.

Categorization and routing. Develop a decision tree for call center staff to categorize the type of complaint and where to route the complaint for assessment and action. The decision tree should permit staff to easily rule out common causes of complaints, such as entrained air, rusty water, etc. to quickly identify any complaint that may be indicative of drinking water contamination. Those complaints not easily ruled out should be sent to a water quality expert who should serve as a single point of contact. This may be one individual staff member in a small utility or a team of individuals in a larger utility. Assure that complaints that cover several issues (e.g., overcharge, potholes, and cloudy water) are dissected for routing to multiple points as appropriate. All complaints (and portions of complex complaints) that may be associated with contamination (including tampering) should be immediately routed to the water quality expert who is available 24/7. The single-point of contact promotes clarity in handling potential contamination problems, facilitates mapping of complaints, allows for more efficient communication with other CWS components and, with properly assigned authority, instills urgency throughout the organization.

Assessment and investigation. Complaints should be assessed to determine the possible causes of the complaint, such as hydrant flushing, change in treatment process, or construction activity. Such assessment along with inquiries to other components of the CWS can assist in determining the risk associated with the complaint and the response time necessary. Complaints that cannot be resolved over the phone, or those which have unknown causes, will likely require an on-site investigation and sampling for field and laboratory analysis. A site characterization and sampling protocol should be developed to support investigation of any trigger from the CWS, and this same protocol, possibly with some modifications, could be used to investigate consumer complaints. The protocol should also include criteria for determining whether additional field analysis with more advanced equipment such as portable toxicity analyzers is required and for determining the parameters that should be assessed in the laboratory. A well thought-out decision tree should also aid utility managers in making decisions about the actions to take based on the results of field and laboratory analyses. Decision trees can also be developed to help identify the nature of the problem. For example, the nature of the complaint (characteristic smell or taste) might provide insight into the nature of a potential contaminant. Use of EPA's Water Quality/Consumer Complaint Report Form, included in the *Response Protocol Toolbox* could further aid the utility in assessing a potential contamination event.

Complaint tracking. All consumer complaints that may be related to contamination should be tracked using a database to record geographic and complaint-type data, as well as results of investigation and related illnesses. Thus, this database should be a subset of a larger database that should track all complaints. While a GIS linked to the complaint database is preferable, manual tracking on a paper map is sufficient for smaller systems. Some systems allow complaint data to be managed through their utility work order system. Whether electronic or manual means are utilized, results should be displayed on printed maps in a format where the staff can quickly and easily recognize patterns and increasing spatial extent. Each complaint should be tracked through every step of its assessment, investigation, and findings/resolution. Links to information generated from other CWS components should be noted in the database. Periodic reports summarizing complaints by type, location and findings should be submitted to utility management and kept available for future analysis. For widespread problems, the ability to use hydraulic/water quality distribution system models can be a useful tool to understand the pattern of complaints.

Senior staff oversight. The responsibility of the consumer surveillance program should rest with one individual at the senior staff level of the utility, perhaps the Water Utility Emergency Response Manager. While not necessarily a line-manager position, the individual should have the authority to direct the consumer complaint process through all stages for matters that may relate to contamination. This authority should include related activities in customer service, operations, and the laboratory. Consideration should be given to having this individual report directly to the chief executive officer (CEO) or chief operating officer (COO) of the utility. Communications with the call center manager, water quality manager, and distribution manager, and other agencies that may also receive water quality complaints, such as the local public health department, should occur.

Staff training. Because consumer complaints may be presented to any member of the utility's staff in an office or in the field, formally or informally, all staff members should be trained to effectively handle consumer complaints, find the written procedures, and determine whom to contact with questions. Training should include the questions to ask consumers to discern water quality problems that may be associated with contamination. The staff should clearly understand the serious consequences that may be associated with some consumer complaints and the necessity for quick action. Staff specifically assigned to key departments related to water contamination and consumer complaints should receive more rigorous training that includes functional exercises and coordination with public health officials and representatives of other CWS components. Call center staff would require some specific training. Some cross training with other functional areas is encouraged.

Consumer education. A truly effective consumer complaint surveillance program should include educated consumers. Utilities with existing public outreach programs should inform consumers about the characteristics of their drinking water, connections to hydrants, including meters and backflow prevention devices, and suspicious persons working on the water distribution system. Telephone numbers to consumer complaint lines should be published in telephone books, printed on bills, and prominently appear on websites. Overall, consumers should feel empowered to call when they are concerned about the quality of their water or tampering of the water system.

Figure 6-2 depicts the consumer complaint surveillance process, beginning with the information noted and reported by the consumer to the utility and how the utility manages the complaint, monitors the information it receives, and proceeds once an anomaly is detected.

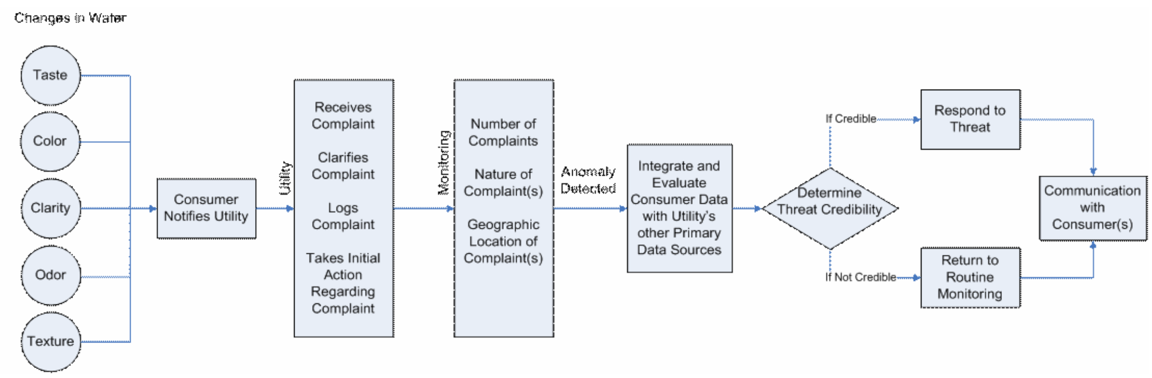


Figure 6-2. Consumer Complaint Surveillance Process

The integration and evaluation of consumer data with the utility's other primary data sources results in a determination of a threat's credibility, which leads to either responding to the contamination event or returning to routine monitoring. The last step in the process is to ensure the consumer presenting the complaint is communicated with after their complaint has been assessed. This communication may happen as part of a call being received and addressed by the call center, or by way of a thank you note from the utility following the utility's response to a contamination event. It is another way in which the utility can help to educate its consumers.

6.2 Data Management, Analysis, and Interpretation

The data management system for consumer complaint surveillance can be managed through the utility's customer information system, work order system or other enterprise information system. Another option, often used by smaller utilities is to manage complaints with a stand-alone database or even manually, with logbooks. A utility managing a consumer complaints surveillance program as a component of a CWS should maintain rigorous recordkeeping, provide seamless tracking, and make information and data quickly available to staff for evaluation and decision making within the utility.

To gain the most benefit from the consumer complaint surveillance program of a CWS, the information and data should be integrated with output from other information streams of the CWS, both within the utility and from outside the utility, such as public health surveillance. In addition to making the data available to the utility's public health partners, the data should also be made available to other relevant agencies. An example of the components of a data collection, transmission and integration system for consumer complaint surveillance are presented in **Figure 6-3**. Roles (field sample collector, law enforcement, call center operative, data analyst, etc.) need to be identified and explained in detail. Primary and backup representatives should also be identified. Data types and formats should be listed, with references to supplementary documents for further detail as warranted (i.e., explanations of lab analysis results). Primary and, ideally, backup mechanisms for each data collection, communication, and transmission point should also need to be identified. Data sharing agreements need to be listed and should also need to be implemented and executed. In addition, vulnerabilities for each data collection, transmission, and storage point should need to be identified and addressed. Other data management design issues that need to be considered include data privacy, sensitivity and security, authorization, encryption, timeliness, cost, redundancy, and availability. Communication procedures among those parties involved in specific roles should need to be developed.

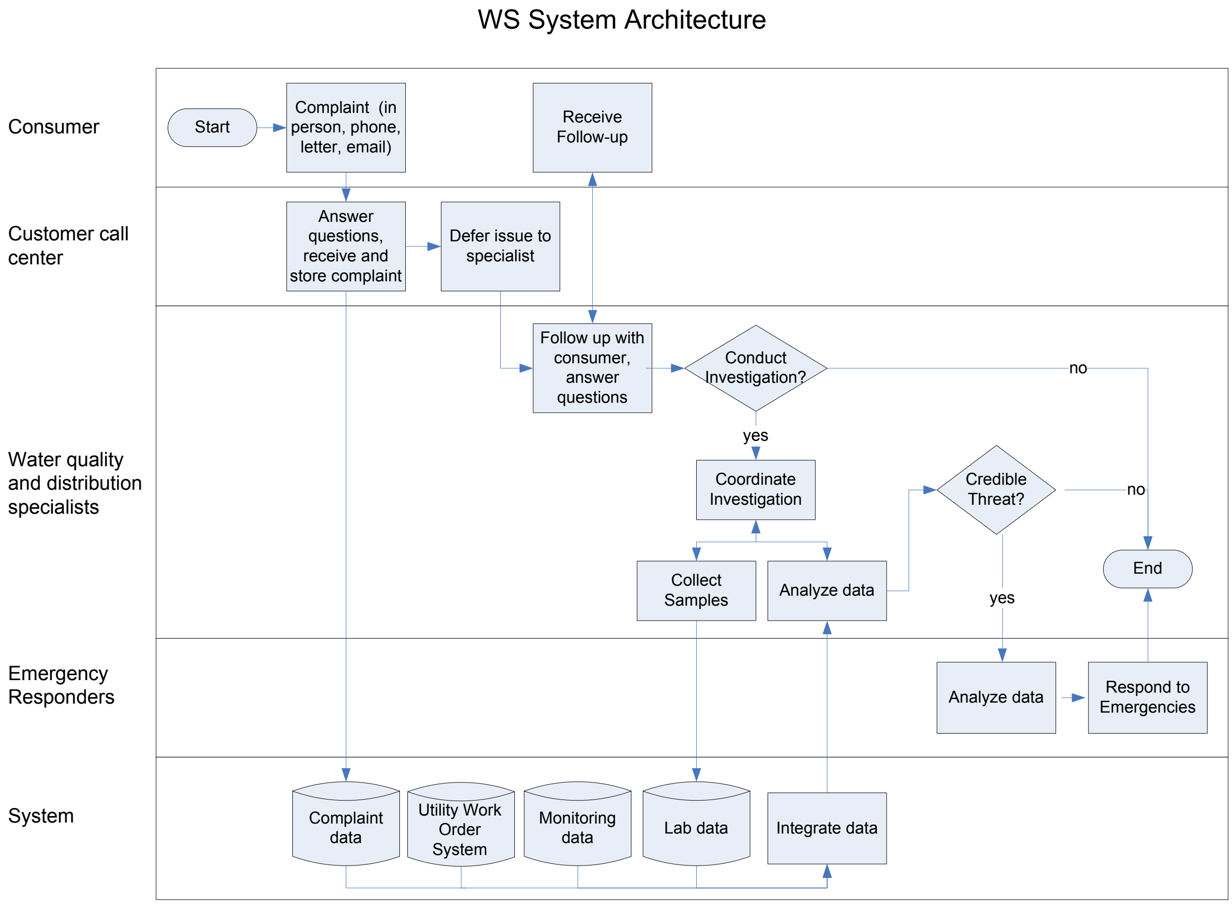


Figure 6-3. Utility Consumer Complaint Data Flow

Overarching information about information integration, management, and communication can be found in Section 8.0.

In order to determine the specific elements of the utility's data management system for consumer complaints, the following questions should be explored:

- How does the current consumer complaint data management system function?
- Is it efficient?
- Is it capable of recording and tracking all consumer complaints?
- How does it capture multiple information streams?
- Can it integrate data?
- How does it interface with the utility's other data management systems?
- What support does it provide for decision-making?
- Is information readily available?
- Does it have a geographic component?
- Is it able to correlate customers and complaints?
- Is storage fireproof?
- Where are back-ups of consumer complaint information kept?
- Who is responsible for managing the data?
- Can the data be accessed 24/7?
- Can complaint data be received from and shared with other government agencies?

6.3 Framework for Evaluation

Most complaints from consumers are subjective and are handled and assessed by individuals not trained in water quality analysis. Consumers may be reluctant to report a change in the characteristics of their tap water, or they may not see any significance in the change. Consumers may not know whom to contact to report a complaint, or they may believe that they cannot sufficiently describe the issue and, therefore, decide not to complain. Also, the link between consumer symptoms and contaminated water is difficult to make and may not ever be considered by the consumers or their health care providers. Further, the efficacy of consumer complaint surveillance in a CWS may be constrained by the lack of processes and procedures, as well as staff training, at the utility to adequately assess, route, interpret and react to a complaint. Nonetheless, it is a potentially reliable indicator for contaminants with detectable characteristics if a robust complaint reporting and tracking system is in place. Additionally, it could be used by the other components of the CWS as an indicator or to corroborate potential contamination events.

Over the past several years, the water industry has focused on improving the management of consumer complaints through the funding of research projects and development of guidance materials. While most of the investment has been on the management of traditional complaints (e.g., aesthetics, insufficient pressure, rates/fees and billing), more recent work has concentrated on water quality complaints that could be related to intentional or unintentional contamination. Properly trained staff, effective complaint handling procedures, and carefully developed decision tools can not only improve the consumer surveillance component of the WS-CWS, but also enhance a utility's image among its customers and other stakeholders. Several cities and special purpose districts have made efforts to consolidate all citizen concerns to ensure that all complaints are going to the appropriate city agency or department in a timely manner. One example is New York City's 311 phone number for government information and non-emergency services. The 311 call center answers calls 24/7, has immediate access to translation services, uses a state-of-the-art database of city information and services that can be updated in real time and can quickly adapt in an emergency situation (www.nyc.gov/html/doitt).

The utility's consumer complaint surveillance program can be evaluated through a series of processes and tools, many of which may already be in use within a utility. This information can begin to assess the adequacy and efficiency of the program and whether the consumer complaint surveillance system is operating optimally. If the program is falling short of its goals, or if a component is inadequate and failing to optimize the information being fed into the system, the utility should have the opportunity to identify these shortcomings and make the necessary enhancements.

6.3.1 Evaluation Tools

Most customer information systems can produce detailed reports on the average time a caller waits to speak with a customer service representative, the number of complaints and the type of complaints recorded. Linked to a GIS, complaints by type can be exported from a customer information system to generate maps showing areas with chronic, seasonal, or repetitive complaints occur, which may warrant further investigation in the field.

Periodic review of audio tapes from customer service representatives may also be useful in refining employee training. In addition, process mapping can assist in evaluating the efficacy of the processes being employed in the consumer complaint surveillance program.

Assessments of specific or randomly selected complaints can highlight procedures in need of improvement and program assessments can help to reveal bottlenecks in procedures, reduce response times and encourage ongoing communication between staff, management, and utility customers.

6.3.2 Data Sets

Essential to the evaluation of a consumer complaint surveillance program are any correlations between the number, type, and location of complaints to actual findings by utility personnel or through laboratory analyses of any anomalies due to operational, maintenance, or construction activities; fire suppression; or contamination.

While integrated information systems are valuable for all aspects of a consumer complaint surveillance program and its evaluation, smaller utilities can adequately track and evaluate this aspect of their programs with basic database or spreadsheet software and manual record keeping.

6.3.3 Consumer Confidence Surveys

Consumer confidence is a good indicator that consumers feel their concerns have been heard and that their complaints have been addressed appropriately and in a timely fashion. Following up with consumers who have submitted a complaint is not only good customer service, but an important part of a thorough consumer complaint surveillance system. Annual or bi-annual surveys should assist the utility in knowing whether or not its customers feel the consumer complaint surveillance system is working.

Field investigations and consumer follow-up should also be considered in the evaluation. Optimization of consumer complaint surveillance systems provides other benefits to drinking water utilities beyond the security objectives of the WS-CWS. Collection and management of information from drinking water customers can assist in identifying treatment issues and water quality issues throughout the distribution system.

Section 7.0: Public Health Surveillance

Close coordination between drinking water utilities and public health departments is a critical component of the WS-CWS for both detection of contamination events and initiation of response actions. In addition, the public health sector offers tools, procedures, and lessons learned that can be leveraged to enhance detection capabilities for a range of contaminants. Furthermore, lessons learned from recent outbreaks of waterborne disease, including the 1993 outbreak of cryptosporidiosis in Milwaukee, and an outbreak in Walkerton, Ontario, in May of 2000 caused by *E. coli* illustrate how the integration of environmental, health-care, and other types of data can provide earlier warning or more robust validation of problems than clinical signs and symptoms alone (Foldy, 2004; Hrudey, 2002). As another example, a retrospective study from two waterborne outbreaks in Saskatchewan and Ontario, Canada comparing over-the-counter sales with the frequency of emergency room cases of gastrointestinal illness caused by *Cryptosporidium*, *E. coli O157:H7* and *Campylobacter* indicated that information from this type of syndromic surveillance could provide a more timely indication of illness in the population than other, more traditional, types of surveillance (Edge, 2004).

As defined by CDC, public health surveillance is the ongoing, systematic collection, analysis, interpretation, and dissemination of data about a health-related event for use in public health action to reduce morbidity and mortality and to improve health (German, 2001). Although public health surveillance can be used as a tool in outbreak detection, it also has other applications such as supporting public health interventions, determining distribution and spread of illness, evaluating prevention and control measures, and facilitating planning (Buehler, et. al., 2004). Syndromic surveillance is a specific type of public health surveillance that relies on electronic data such as 911 calls, ER visits, EMS logs, OTC medication sales, laboratory test orders, workplace or school absenteeism, and other types of data that may be available in the early stages of an outbreak.

Syndromic surveillance systems seek to use existing health data in real-time to identify changes in community health status, facilitating notification to those charged with investigation and follow-up of potential public health crises (Henning, 2004). With the increase in utilization of syndromic surveillance since September 11, 2001, as a tool for early indication of a bioterrorist attack, many local health departments are now confronted with the challenge of how to evaluate the effectiveness of these systems in the absence of a bioterrorism event. Many of these considerations also apply to the evaluation of the WS-CWS and are discussed in greater detail in Section 6.0.

As a result of the privacy concerns and data sharing restrictions codified by the Health Insurance Portability and Accountability Act (HIPAA), only summary data may be presented to the water utility officials by public health. Under the conditions of an aggregate data set agreement, actual date and time and a full zip code associated with distinguishing health event details can be shared when personal identifying details such as medical record numbers, names, street addresses, ages and genders are omitted from the data to be shared. Numerous techniques may be employed by the data providers and public health systems to summarize and strip protected data elements prior to aggregated transmission to WS-CWS.

The types of data streams most commonly monitored by public health officials include the following:

- **Aggregate diagnosis counts by date and geographic area:** for a given date and zip code, the number of patient diagnoses for each relevant condition (i.e., water-borne infection or irritant) across the public health jurisdiction. This detail would be provided typically by disease-specific

surveillance activities at the public health department as reported by physician and health care facilities.
- **Aggregate lab tests (order counts and/or results) by date and geographic area:** for a given date and zip code, the number of ordered laboratory tests for each relevant condition and, when possible, the lab results across the public health jurisdiction. This detail would be provided typically by disease-specific or syndromic surveillance activities at the public health department as reported by physician and health care facilities or laboratories.
- **Categorized chief complaint, 911 call, EMS runs, or Poison Control counts by date and geographic area:** for a given date and zip code, the number of categorized complaint descriptions (i.e., symptoms and possible background for the symptom onset) for each relevant condition across the public health jurisdiction. This detail would be provided typically by disease-specific or syndromic surveillance activities at the public health department as reported by physician and health care facilities, 911 operators, EMS, and/or the Poison Control Center.
- **Categorized over-the-counter (OTC) medication sale counts by date and geographic area:** for a given date and zip code, the number of product units sold for each relevant condition across the public health jurisdiction. Information regarding sales/specials of OTC sales is also reported in order to normalize the data.

Public health surveillance should be able to provide coverage for drinking water utilities within the health department's jurisdiction. In some cases a single utility may provide drinking water to customers across multiple health jurisdictions. Adequate communication, coordination, and exchange of data between the health department, drinking water utilities, laboratories, and healthcare providers is critical in terms of spatial coverage of this component of the WS-CWS. However, any breakdown in this communication might sever a portion of a department's area from occurring events. For example, if a health care provider was unaware they needed to report certain symptoms or conditions; the health department may be oblivious to these events. Effective networking and strong, clear communication and exchange of information between all stakeholders should alleviate any spatial coverage issues related to public health surveillance as a WS-CWS component.

7.1 Overview of Existing Syndromic Surveillance Systems

The type of public health surveillance employed at the local level varies from traditional surveillance activities to sophisticated syndromic surveillance systems that are customized based on available software and/or rely on national syndromic surveillance systems to manage local data. New York City, for example, relies on a customized syndromic surveillance system that collects data from a variety of different sources. In fact, New York City's first syndromic surveillance systems were established in 1995 to detect outbreaks of waterborne illness by the New York City (NYC) Department of Health and Mental Hygiene (DOHMH). The program included diarrheal illness at nursing homes, stool submissions at clinical laboratories, and OTC pharmacy sales. In 1998, daily monitoring of ambulance dispatch calls for influenza-like illness began; after the 2001 World Trade Center attacks, concern about biologic terrorism led to the development of surveillance systems to track chief complaints of patients reporting to emergency departments, OTC and prescription pharmacy sales, and worker absenteeism. These systems have proved useful for detecting substantial citywide increases in common viral illnesses (e.g., influenza, norovirus, and rotavirus) and diarrheal illness following the August 2003 blackout. However, though this system is useful for early detection at the city-wide level, this system has yet to detect localized, such as specific hospital or institution outbreaks earlier than traditional surveillance. Future plans include monitoring school health and outpatient clinic visits, augmenting laboratory testing to confirm syndromic signals, and conducting evaluation studies to identify which of these systems should be continued for the long term (Heffernan, 2004).

Although New York City has the capacity to execute a fairly sophisticated public health surveillance system, other local health departments may be utilizing more basic surveillance measures. As of 2002, only 25% of local health departments were able to deliver the majority of essential public health services (Baker, 2002.) The reasons behind these disparities are varied and should provide further challenges for assessment and implementation of WS-CWS. While impractical to raise the level of all local health departments' capacities to that of a major city, surveillance standards should be improved to a level where their integration enriches the capacity of WS-CWS.

There are three primary national syndromic surveillance systems, and a nationally available tool that could be utilized as part of the WS-CWS for integrated analysis of water quality and public health data. These systems include the following:

- BioSense
- Electronic Surveillance System for the Early Notification of Community-Based Epidemics (ESSENCE)
- Real-Time Outbreak and Disease Surveillance (RODS)
- National Retail Data Monitor (NRDM)

The national syndromic surveillance systems are summarized in **Table 7-1**.

Table 7-1. Summary of National Syndromic Surveillance Systems and Tools

Attributes	BioSense	ESSENCE	RODS	NRDM
Developer	CDC	DOD, Johns Hopkins University Applied Physics Laboratory (JHU-APL)	University of Pittsburgh in collaboration with Carnegie Mellon	University of Pittsburgh in collaboration with Carnegie Mellon
Objective	Enhance nation's capability to rapidly detect, quantify, and localize public health emergencies, by accessing and analyzing diagnostic and pre-diagnostic health data.	Collect and analyze a variety of data sources for the early recognition of abnormal community disease patterns that could result from natural causes or terrorist activities.	Computer-based public health surveillance system for early detection of disease outbreaks; the initial objective of RODS was to detect large scale outdoor aerosol releases of anthrax.	Public Health surveillance tool that utilizes info from OTC sales for early disease outbreak identification by health departments.
Brief Description	Internet-accessible secure system that permits users to visualize information about public health trends from early detection data sources. BioSense is in the process of implementing the beginning of Phase 2 with what is called Real-Time Clinical Connections (RTCC) – direct data feeds from select hospitals. The goal is to implement feeds from 10 hospitals by end of year, but achieving that goal is becoming increasingly less likely due to issues around data use agreements and specification of the data stream; no data streams are active at this point.	Data providers de-identify, encrypt, and post data to a secure file transfer protocol (FTP) site at a regular interval (e.g., daily at midnight or once every 8 hours). ESSENCE polls the FTP sites to look for new entries, which are then ingested, cleaned, formatted, and archived in the primary system archive and applies A secure website allows for information transfer to users. Through this website, users also can view a map of the geographic distribution of raw data and data clusters, view alerts, conduct queries, and generate summary reports.	ER and OTC data are incorporated in the RODS user interface, the registration chief complaint is automatically classified into one of seven syndrome categories using Bayesian classifiers. Data are stored in a relational database, aggregated for analysis using data warehousing techniques, univariate and multivariate statistical detection algorithms are applied to the data, and users are alerted when the algorithms identify anomalous patterns in the syndrome counts.	Collects data for RODS on selected OTC health care products from over 20,000 stores for use by public health departments free of charge. Data is transmitted by a secure FTP link with a delay of 24 hours or less into a data warehouse. These data are merged by geographic area and distributed in raw or analyzed form to users in 46 states, the District of Columbia, and the CDC.

WS System Architecture

Attributes	BioSense	ESSENCE	RODS	NRDM
Data Sources	U.S. Department of Defense (DOD) and Veterans Administration (VA) medical treatment facilities, LabCorp, BioWatch air monitoring system.	Military ambulatory visits, prescription medications, chief-complaint data from emergency rooms, patient visits for private practice groups, OTC sales of pharmaceuticals, nurse hotline calls, school absenteeism records, data about local endemic disease, sales promotions, weather events, occurrence of high profile events in the community, 911 calls, poison center calls, requests for laboratory work	Absenteeism data, sales of OTC health care products, and chief complaints from ERs.	Uses Universal Purchase Code (UPC) data to collect info from large national and regional retail chains.
Event Detection Algorithms	Advanced algorithms for visualizing and analyzing data to provide a nationwide, real-time picture.	Spatial and spatial-temporal outbreak-detection algorithms, forms clusters in time and space across the region by using zip codes as the smallest spatial resolution.	RODS has two detection algorithms: the Recursive-Least-Square adaptive filter and What's Strange About Recent Events 1.0.	MapPlot can be used to detect standard deviations from normal sales for any area; Epiplot can be used for trend analysis.
Timeliness	Hospital systems data available in near real-time via PHIN connection.	Most of the data are received within 1 to 3 days of patient visit	Hospital data received in near real-time from clinical encounters over virtual private networks and leased lines using the Health Level 7 (HL7) message protocol.	Retail data is transmitted and received less than 24 hours after point-of-sale
Additional Information	http://www.cdc.gov/phin/component-initiatives/biosense/	http://www.geis.fhp.osd.mil/GEIS/SurveillanceActivities/ESSENCE/ESSENCE.asp	http://rods.health.pitt.edu	http://rods.health.pitt.edu/NRDM.htm

7.2. Public Health Surveillance and WaterSentinel

In the context of the WS-CWS, certain types of agents should be more readily recognized by a public health surveillance network due to the severity and time of onset of symptoms. Contaminant Detection Classes 2 to 10 produce symptoms that would elicit ER visits, poison control calls, or 911 calls, generally within a short time of symptom onset. Ricin contamination, for example, would be first detected by public health surveillance due to its sudden and severe symptoms onset. These symptoms would prompt most people to call the poison control center or visit the ER. Consequently, for these contaminants, public health surveillance would likely identify a contamination incident before the online monitoring, sampling, or consumer complaints components of CWS.

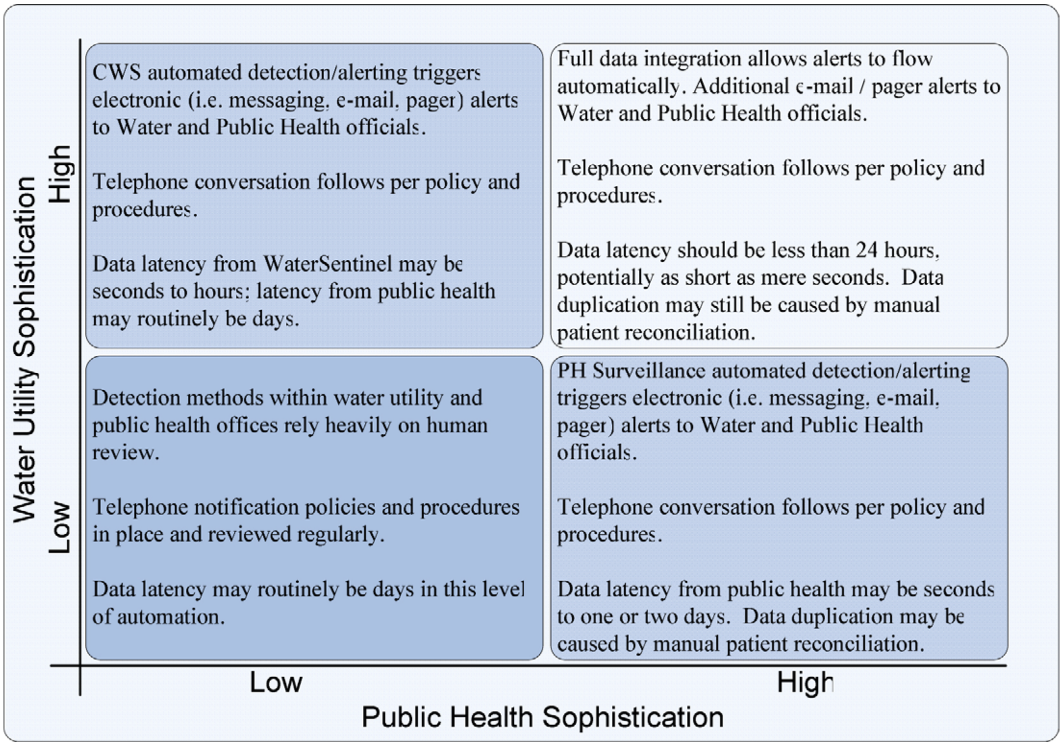
The timeliness of information from public health surveillance varies in relation to other components of the WS-CWS, depending on the type of contaminant present, the level of cooperation between health departments and health care providers, and the technical and staffing support available to a health department. Timeliness provided by public health surveillance is also contingent on the capacity of health departments to receive and integrate data from clinical laboratories, health care providers, and syndromic surveillance sources (OTC sales, EMS logs, etc.). This capability is directly dependent on the health department's staffing and technical support, as well as the cooperation between the different components. While a patient may present with symptoms within four hours of exposure, the time by which a health department is made aware of an event may vary from hours, days, or longer. If a clinical laboratory does not have electronic reporting capabilities, reporting time should be adversely affected; the data may not be reported until days or weeks after an event. Additionally, an outbreak may go undetected or unconfirmed if there is no ability for a health department to analyze the data. It may be the case the health department has sufficient resources to gather and organize the data on a relatively frequent basis, but may not have the technical means or time to evaluate the information.

Utility and public health officials in a jurisdiction deploying WS-CWS should have coordinated, cooperative two-way communication any time that a waterborne event resulting in health effects is suspected or detected. This communication should usually include human conversation and may be augmented by electronic notification as technical sophistication increases within the water utility and/or public health offices of the area.

Assessment of existing collaboration methods should be initiated in advance of WS-CWS implementation. Various techniques exist for performing and improving inter-agency collaboration; minimally, the following questions should be asked as part of the assessment effort:

1. What is the current relationship between the utility and local public health department(s) within the utility's service area? Is there a high degree of cooperation and collaboration? Are there established communication protocols, and do they include electronic and 24/7 notification?
2. What types of health data are monitored and what are the sources of these data? What is the timing associated with collection, transmission, receipt, and analysis of this information? What are the data-use agreements associated with this information and are these agreements able to be leveraged to support WS-CWS?
3. What are the current electronic surveillance systems used by the public health departments? Are there capabilities for electronic notification by the public health surveillance systems of other entities, such as the water utility and health care providers?
4. What are the current methods for submitting water quality data to the local public health department(s) within the utility's service area, whether baseline or alert data? What options exist for WS-CWS to integrate with existing public health systems?

Figure 7-1 provides a high-level characterization of notification and integration schemes based on the information technology sophistication of water and public health organizations for a given area.



Water Utility Sophistication	Public Health Sophistication: Low	Public Health Sophistication: High
High	CWS automated detection/alerting triggers electronic (i.e. messaging, e-mail, pager) alerts to Water and Public Health officials. Telephone conversation follows per policy and procedures. Data latency from WaterSentinel may be seconds to hours; latency from public health may routinely be days.	Full data integration allows alerts to flow automatically. Additional e-mail / pager alerts to Water and Public Health officials. Telephone conversation follows per policy and procedures. Data latency should be less than 24 hours, potentially as short as mere seconds. Data duplication may still be caused by manual patient reconciliation.
Low	Detection methods within water utility and public health offices rely heavily on human review. Telephone notification policies and procedures in place and reviewed regularly. Data latency may routinely be days in this level of automation.	PH Surveillance automated detection/alerting triggers electronic (i.e. messaging, e-mail, pager) alerts to Water and Public Health officials. Telephone conversation follows per policy and procedures. Data latency from public health may be seconds to one or two days. Data duplication may be caused by manual patient reconciliation.

Figure 7-1. Water Utility – Public Health IT Sophistication Matrix

Upon consideration of all factors, likely options for implementation include the following:

- If less than significant automation exists at both water utility and the associated public health department(s), policies and procedures for notification and coordination resulting from manual detection methods should be implemented until a WS-CWS is available.
- If significant automation does not exist within the public health department, WS-CWS should implement an electronic data notification system according to coordinated policies and procedures with the associated public health department(s) to provide alert notification. This 24/7 automated alerting system would provide for faster information exchange amongst the proper water utility and public health officials.
- Once WS and public health departments are sufficiently automated, the data submission and alert notification should utilize a shared system with specially designed user screens for the public health officials and the water utility.

Simultaneously analyzing integrated water quality data and public health surveillance data streams is the ultimate goal for public health integration with WS-CWS.

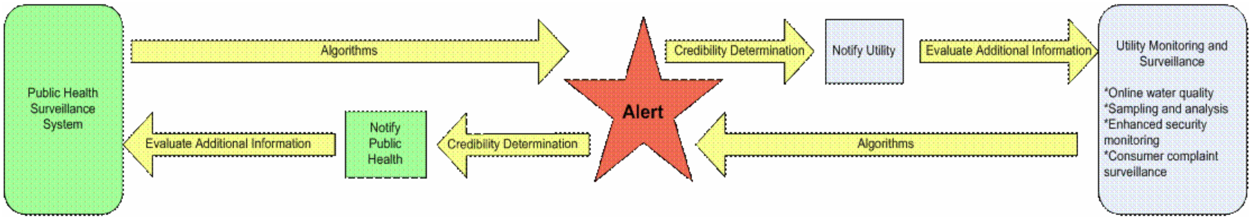


Figure 7-2. WS integration with Public Health

7.3 Data Management, Analysis, and Interpretation

Accepting and integrating indicative, aggregate data from public health surveillance activities provides opportunities for fine-tuning the WS-CWS detection and notification models as a post-event feedback mechanism. The aggregate public health data should allow predictive models to be verified or adjusted in order to allow better predictions to be provided by WS in the future; this data also provides additional feedback on the accuracy of sensors in the affected area. Aggregated diagnoses can provide confirmatory feedback but are typically available one or more days after the onset of an event. Aggregate lab test orders and counts of categorized chief complaints can provide more timely indicators of possible health events if provided on a real-time basis. Aggregate OTC sales data, while readily available from NRDM, needs significant baselining and analysis to eliminate false signals.

Analysis of the integration between data from the WS-CWS implementation and from public health should occur as a result of post-event activities. The profile of public health notifications should optimally include the following, at minimum:

- Aggregate indicator counts by severity, date, and sensor
- Aggregate alert message type counts transmitted by date and triggering sensor(s)

This profile should be coupled with the WS-CWS data set that includes categorized consumer complaint counts, sampling and analysis results, and physical security alert or intrusion counts in order to provide a fully detailed information base from the water utility perspective; the WS data set and the WS algorithms provide the basis for the notification profile. Analysis at this level of detail coupled with data received from public health and correlated by date, message type, and geographic area as indicated by sensor locations should provide the WS staff, the pilot utility, and WS-CWS, the ability to validate or improve the configuration and control settings as well as processes and procedures within a given area. Without a basis for careful and detailed feedback analysis, WS may be unable to improve its usability as a warning system. More details on data analysis approaches are provided in Section 8.

7.4 Framework for Evaluation

As discussed in Section 2.4.1, system reliability, in the context of system operation and system performance, and system sustainability provide a means to evaluate the effectiveness of the WS-CWS.

7.4.1 System Reliability

In terms of public health surveillance, system operation is generally reliable. BioWatch operation reliability, for example, has depended mostly on the stability of the public health information network (PHIN). Once data definitions, reporting protocols and monitoring systems are in place, they should need minimal maintenance; computing issues such as server failures would account for the majority of operation errors. While there may be a human component to system operation error (e.g., worker absenteeism at a health department,) these events should be minor, especially as more data are transmitted electronically. Electronic reporting software may require occasional updating and/or staff training.

System performance has the greater affect on public health surveillance, as it is conditional on a system's ability to discern actual events of concern from those of other consequence. This ability is dependent on the components of the public health surveillance algorithm; if these components are well refined, then public health surveillance can aid in the detection and confirmation of outbreaks and become an important event detection and quality assurance tool. However, if the algorithm is not satisfactory, the information gathered from public health surveillance can become a liability towards the sensitivity and specificity of contaminant detection. Three suggested components of a successful surveillance program algorithm are (Buehler, 2004):

- Timely and complete case reports and investigation (data quality)
- The ability to recognize differences in data
- Continual receipt of new types of data

Data quality, comprised of complete and timely reporting, is one portion of the event detection algorithm. Expectations of what needs to be reported, as well as accurate definitions of these expectations, are necessary. The participants in public health surveillance (e.g., health care providers, health departments, hospital coding) should be speaking in congruent terms for any real understanding of events. For example, if only vague symptoms are reported, then a relationship between cases might never be established because a definitive connection is lacking. New York City utilized a standard data format for ER visits to incorporate computer algorithms in its syndromic surveillance system to ensure data quality for the purpose of detecting temporal and spatial clusters (Heffernan, 2004.)

The timeliness and accuracy of disease reporting also affects data quality. A lack of accurate disease reporting can lead to over or underreporting of disease. If numerous data gathering sources are being utilized (e.g., electronic reporting, paper reporting,) it is possible for one instance of disease or symptom to be reported two or more times. There is also the potential for duplicate reporting in the event a person is treated by multiple providers. Over reporting in public health surveillance could artificially inflate events above that of the alarm threshold, resulting in unnecessary emergency responses Careful monitoring of cases, a workable electronic reporting system and effective communication between data reporting entities can minimize this effect on WS-CWS implementation.

Conversely, certain pathogens may have vulnerability towards underreporting. Pathogens that cause gastrointestinal illness or vague ‘flu-like’ symptoms can be underreported or misdiagnosed due to lack of severity. For example, the CDC estimates that for every reported case of salmonellosis, 38 actually occur (CDC, 2005.) It has also been suggested that only 8% of those with gastrointestinal illness seek medical care (Khan, 2001). However, most of the contaminant classes identified for WS-CWS create severe or unusual symptoms that would increase the incidence of people seeking medical attention and decrease the incidence of misdiagnosis. Further, deficiency of data can cause QA problems when trying to confirm contamination events. Being conscious of this issue can ensure safeguards are built into the surveillance system to account for lack of data.

The ability of public health professionals to recognize differences in data events is also an important part of the surveillance algorithm. Data gathering is only as useful as the ability to analyze the data; having the expertise to recognize when an increase of events is, in fact, an outbreak is imperative to the sensitivity and specificity of a surveillance system. Analysis that does not take into account seasonal inflections, day of the week changes, and other variables may mistake increases in events as an outbreak, when in fact it is a normal occurrence. This may elicit false-alarms.

The inability to recognize an increase in events as a contamination event may have more dire consequences, as preventative and containment measures should not be initiated. Having trained professionals in positions of recognition is one of the major challenges of public health syndromic surveillance today. Prior to September 11, 2001, it was estimated that 75% of local public health administrators never received formal public health training (Gerzoff et al, 1999) While these numbers may have improved, the CDC still recommends that a 45.3% increase in Epidemiologists is needed to fully staff terrorism preparedness programs (MMWR, 2004). Recruiting trained persons into these positions should increase the reliability of public health surveillance by increasing event recognition abilities.

Receiving new types of data is critical to the new and developing systems of syndromic surveillance. Integrating OTC sales data, worker absenteeism, or other types of non-traditional data sources can pose a challenge for health departments. A report on the NMRD found that checking weekend data was still low among health departments, suggesting surveillance of these data was a challenge (Wagner, 2004.) It is also necessary to obtain a suitable number of participants in OTC and worker absenteeism surveillance to ensure a proper sample size. New York City performs worker absenteeism on a company employing 15,000 in multiple locations; not all cities would contain a similar company, and may have difficulty incorporating worker absenteeism data into their algorithm (Heffernan, 2004). Successful use of these new data with more traditional surveillance methods should depend on the appropriate utilization of statistical models and careful consideration of all components.

7.4.2 System Sustainability

Sustainability of a public health surveillance system within WS-CWS should be dependent on the cost of public health surveillance as well as the maintenance of communications between health departments and utilities. Cost of surveillance should vary greatly, dependent on the size of the health department, the resources already available to them, and the depth of surveillance they wish to maintain. New York City’s syndromic surveillance system costs approximately $150,000 annually in maintenance (Heffernan, 2004.) However, this amount would not be typical of the majority of health departments. Small and even moderately sized health jurisdictions should be able to sustain a system on far less.

Sources of funding, particularly for smaller departments, may become an issue in sustainability, as they are more dependent on local tax levies and grants for support. One study estimates that local taxes provide 43% of health agencies' revenues (Gostin, 2004.) A levy failure could be detrimental to the sustainability of public health programs, including surveillance activities. Similarly, securing grants and other funding has been especially difficult in poor, rural minority areas due to a lack of philanthropy and grant writing effectiveness (Siegel, 2001). Gaining adequate funding may be a challenge for sustainability in some areas. However, if the problems surrounding funds sustainability can be circumvented in parallel with maintained cooperation between utilities and public health, then public health surveillance support to WS-CWS can be sustained.

7.4.3 System Evaluation

The integration of public health surveillance as a component of the WS-CWS should be evaluated jointly between the public health office and the water utility. Through collaboration and cooperation, the effectiveness of the communication policies and procedures should be evaluated with a holistic approach along the lines of the CDC's Framework for Program Evaluation in Public Health (Koplan, 2005):

- **Engage stakeholders:** Consideration of those involved in program operations, of those affected by program operation, and those who should take decisive action as a result of the evaluation.
- **Describe the program:** Consideration and documentation of the program's need, the program's expected effects and activities, the program's resources and current stage of development, and the program's operational context and high-level logic model.
- **Focus the evaluation design:** Concentration on the program's purpose and uses, its user base, the questions about the program to be addressed in the evaluation, the methods of evaluation to be utilized, and the agreements in place (or to be established) regarding how the evaluation should be executed are key.
- **Gather credible evidence:** Identification and assessment of indicators (aspects of the policy / procedure worth monitoring), sources (from where the evaluation evidence is provided), quality (appropriateness and integrity of the evaluation evidence and its collection methods), quantity (amount of evidence collected), and logistics (details around evaluation evidence collection) should provide significant benefits in the evaluation process. Each organization can utilize system testing and preparedness drill scenarios to generate data sets for use in pre-implementation evaluation as well as in post-implementation calibration exercises. Additional evaluation data may be collected and recorded post-implementation when an event is identified by whatever means in order to support the calibration exercises and evaluation of system improvements.
- **Justify conclusions:** The methods of analysis, interpretation of the results provided by the evidence, the judgments based on the analysis and results interpretation, and the recommendations from those judgments.
- **Ensure use and share lessons learned:** Documenting the evaluation's design and preparation, recording feedback and follow-up from the evaluation, and dissemination of the knowledge gained from the evaluation effort.

At a high level, evaluation of what works, what does not work, and what improvements are necessary and feasible should be performed on regular intervals as part of the policy and procedure review by the joint working group between the water utility and the public health office(s); the joint working group should routinely ask, 'How effectively does the defined notification process indicate or validate a health event occurrence?' This sort of question directly relates to the design basis defined in Section 4.1. Public health officials can use this process to determine how often a water-sourced event was detected by WS, and water utility officials can similarly determine how often a detected (or undetected) event is validated (or indicated) by analyzing aggregate data from the public health department.

The current capabilities of each office should be well understood by its officials and the joint working group in order to provide a roadmap and project plan for reaching the next level of desired integration; policies and procedures should be prepared for update in accordance with proposed improvements in system integration, whether manual or automated. Leverage of existing or new evaluation tools or processes and the existing expertise of both organizations are critical to the success of long term cooperative efforts.

Section 8.0: Information Integration, Management, and Communication

A key to the success of the WS-CWS is the effective and timely management of information. Information management in WS begins with source data collection, but this information passes through a variety of phases in order to ultimately support decision-making. This section focuses on the collection and transmission of data, the integration and evaluation of this information, and finally the communication of this information to the appropriate personnel so that action can be taken.

8.1 Data Collection and Transmission

The data available to WS come in a variety of forms and formats. Each data source should be collected and transmitted appropriately, generally using means specific to that data source. The guiding design principle involves using existing data collection and transmission methods as much as possible, and augmenting these methods when necessary to produce additional or enhanced data flows. These methods are summarized in the context of WS information management in **Table 8-1**. Each of these methods has inherent limitations that should need to be addressed in order to increase the robustness of the system.

Table 8-1. Summary of WS Information Streams for Managing Data

WS-CWS Component	Source	Collection	Local Storage	Transmission	Central Storage
Online Water Quality Monitoring	Utility Water Sensor	Sensor, SCADA	Intermediate communications interfaces	Licensed and unlicensed radio, frame relay, digital subscriber line (DSL), cable television digital data service, cellular telephone digital data service	Data Warehouse, SCADA
Sampling and Analysis	Utility Field Sample Collector, Analyzer	Collector Notes, Chemical Analysis of Sample by Machine	PDA, laptop (chain of custody data), Sentinel, Confirmatory Laboratory LIMS	Cell phone, Pager, PDA, Email Automated	Laboratory / Utility DB (LIMS)
Consumer Complaint Surveillance	Utility Consumer	Phone, written, email, in person	Email database, message pads, hard copy files	Manual and Automated Software Data Entry Systems, Call / Defect Reporting & Tracking Software	Central Database, Audio Tapes
Public Health Surveillance	Local Health Department	Lab, Observation, Phone, written, OTC sales	Spreadsheets, notes, database silos	Telephone, cell phone, pager, e-mail, electronic transfers	Public health, OTC databases
Enhanced Security Monitoring	Utility Systems, Individuals, Law Enforcement, Media, Perpetrators	Security systems, cameras, Manual observation, Phone, written, email	Email database, Local digital video storage	Digital video transmission, SCADA, Manual and Automated Software Data Entry Systems, Call Reporting & Tracking Software	Central Database, Video Tapes / Digital Storage

Online water quality monitoring data originate as a signal from a sensor, which is transmitted to a remote communications interface for processing, including digital signal processing and aggregate and summary calculations. These data are then transmitted to a central communications interface which further processes the data for optimized transmission, and finally to a data management module for storage and analysis. These data provide input to the event detection software for determining whether an anomaly trigger has occurred. Transmission can occur via a variety of formats, such as radio, cellular, or cable or DSL internet service. A SCADA system, if available, can be used for this last step.

Sampling and analysis data originates from a field technician collecting a lab sample. Field record forms and chain-of-custody forms are filled out manually on site and subsequently entered electronically (PDA, laptop, desktop). A sentinel and possibly confirmatory laboratory should conduct an analysis of the sample, resulting in analytical data stored electronically alongside the field data. For chemical analyses, the data are produced by automated tools that analyze the sample, and the data are saved into a local data store (spreadsheet style or database, such as a LIMS). For most biological analyses, the data are recorded manually and entered into a local data store. Ultimately the data are transferred to the central utility database in electronic fashion for storage.

Consumer complaint data typically originates from phone calls, emails or written mails. Initial call information is collected by operators using call tracking software. Written mails or emails are often entered into the same system. This type of system then typically provides reporting, routing, and email capability so that the call information can be transmitted to the appropriate personnel for further analysis.

Enhanced security monitoring data vary widely in nature and formats are collected through a variety of manual and automated methods. The data itself may be notifications of incidents such as break-ins, or may be video feeds from a camera. The providers of this data may be individuals or automated systems. Examples of individual data providers include witnesses, perpetrators, the media and law enforcement agencies. These individuals may provide information via a phone call, mail, email or other means. Examples of automated data providers include alarms, security systems and video surveillance. These data providers should typically communicate via automated means using distributed control panel warnings, pagers, remote monitors and other methods. Some data, such as video data, may not be readily available but should need to be downloaded from the video data storage site on demand.

Public health surveillance data are collected via a variety of sources, such as laboratory data, chief complaints from hospital visits, 911 calls, poison control calls, and OTC sales. Systems that conduct public health surveillance are already in place to varying degrees. In addition, much of the data that is available from public health surveillance systems is available only in aggregated fashion due to HIPAA regulations developed to protect the privacy of individual patients. Thus, while the true data source for these data streams is widely varied (phone calls, lab tests, physician notes, OTC sales), the collection and transmission of these data streams for and to WS should likely be less dynamic. These data streams should likely be aggregated before transmission. Transmission methods will likely be electronic and asynchronous, due to the nature of the data processing that is likely to occur. The transmission may be automated to some degree, dependent on the technological advances of both the source data providers and the utility. Manual communications (telephone, cell phone, pager, e-mail) should also typically be present to transmit more urgent communications.

A data management plan should be established in order to address how data should be managed throughout the CWS. The specifics of each data type, including source, destination, and collection, transmission and storage methods (as summarized above), should be presented in detail to illustrate generally and specifically how data flows through the system. An example general consumer complaint data flow is presented in Figure 6-3. Roles (field sample collector, law enforcement, call center operative, data analyst, etc.) should be identified and explained in detail. Primary and backup representatives should need to be identified. Data types and formats should be listed, with references to supplementary documents for further detail as warranted (i.e., explanations of lab analysis results). Primary and (ideally) backup mechanisms for each data collection, communication, and transmission point should need to be identified. Data sharing agreements should be listed and should need to be implemented and executed.

Vulnerabilities for each data collection, transmission, and storage point should need to be identified and addressed. Other data management design issues that need to be considered include data privacy, sensitivity and security, authorization, encryption, timeliness, cost, redundancy and availability.

A data management plan should be established in order to address how data should be managed throughout the CWS. The specifics of each data type, including source, destination, and collection, transmission, and storage methods (as summarized above), should be presented in detail to illustrate generally and specifically how data flow through the system.

8.2 Integration and Analysis of Information

Evaluating information in a timely and successful manner is critical to the success of the WS-CWS, and the ability to make appropriate response decisions in time to reduce consequences. With many different data sources, data can be evaluated at a number of different levels. This evaluation can occur for each single data source, and for a combination of data sources. The data sources may be integrated within each data provider (i.e., utility or local health department) or across data providers (utility and local health department). This section discusses the possible levels of integration and evaluation, the forms of integration and evaluation, and the feasibility of automating the processes of integration and evaluation.

As mentioned in previous sections, a variety of data sources exist for each data provider. A local utility should typically have data collection systems such as SCADA, LIMS, hydraulic distribution system models, consumer complaint databases, water quality databases, and work order systems.

A local health department should typically have data collection systems such as chief complaints from hospital visits, EMS records, and calls to 911 or poison control. Over-the-counter sales of pharmaceutical and other items are also often available, as well as access to more broad surveillance systems such as RODS, ESSENCE, BioSense and/or the state's National Electronic Disease Surveillance System (NEDSS). Each of these data streams has different attributes regarding data format, data size, collection frequency, collection mechanism, storage mechanism, and others.

The first step in enabling the integration and evaluation of this information is identifying the attributes of each data stream. In the context of the WS-CWS, it may be necessary to evaluate each data source independently for the purpose of initial event detection. For example, data from the online water quality sensor network should need to be evaluated independent of other primary data streams in order to identify water quality anomalies that might indicate a possible contamination incident. This may allow detection of abnormal levels of contaminations or other triggers in that data source alone. Similarly, call center data can be evaluated independently for abnormal volumes of calls, common call complaints, and other events. However, even at this level, some integration and analysis of information are necessary to produce more reliable triggers and reduce the number of false alarms. For example, the analysis of unusual water quality data from a single sensor may benefit from data from other nearby sensors, information from a work order system regarding recent maintenance activity in the vicinity, and operational data from utility SCADA (e.g., tank and pump operations that could change water quality). This first level of evaluation is critical because initial detection of an anomaly should likely occur at the individual WS-CWS component level. Also, the reliability of signals from the individual components should have a significant impact on the rate of false positives and false negatives for the entire system.

Generally, there are three levels of data integration involved in the design, presented in **Figure 8-1**:

- **First Level:** Integration of a primary data stream (e.g., water quality data) with supplemental information from ancillary data sources and systems (e.g., work order systems), all within the domain of the data provider. This first level of integration is important for improving the reliability of event detection and minimizing the number of false alarms. Ideally, this level of data integration and analysis would be automated as part of an event detection system, and thus would be part of the actual 'triggering mechanism' for a possible contamination incident.

- **Second Level:** Integration at the data provider level of multiple primary data streams (e.g., water quality data and consumer complaint information). This level of integration is important for the initial stages of credibility determination and threat corroboration. From a data management perspective, the difference between the first and second levels exists on an operational basis - the first level of integration occurs automatically within the context of an event detection system, while the second level of integration is a manual process that requires a person to connect the dots.

- **Third Level:** Integration of information across multiple data providers. This should primarily occur between the utility and public health, but might also involve law enforcement and other agencies. This level of integration is critical to establishing the credibility of a potential contamination incident (or ruling it out).

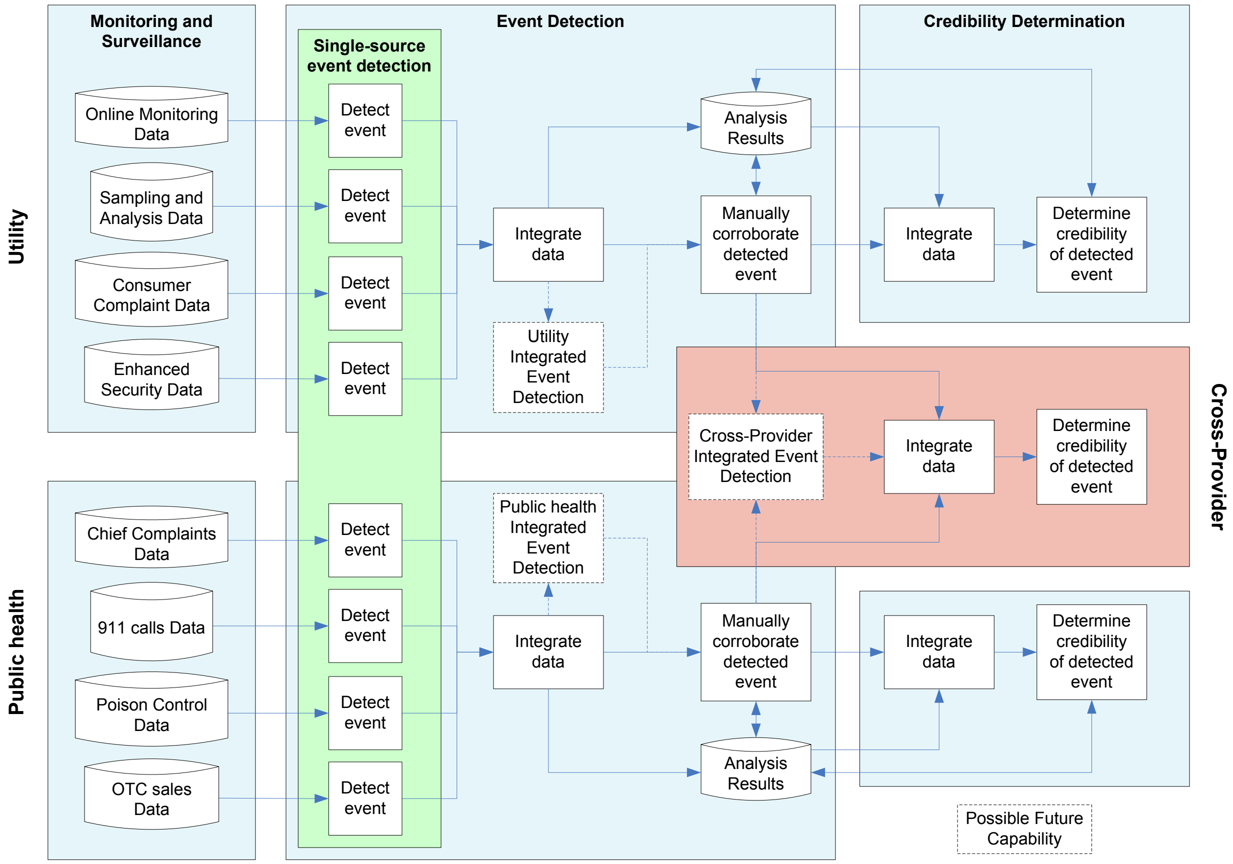


Figure 8-1. Data Integration for Event Detection and Credibility Determination

The first two general levels of data integration are at the data provider level. This could be at the utility, the local health department, a Sentinel laboratory or other participant in the WS-CWS. Each of these data providers may contain multiple primary data sources, each of which can be relatively quickly reviewed at the data provider level, ideally in an automated or semi-automated fashion. For example, a utility contains in-house data regarding online monitoring, operational data, consumer complaints, sampling and analysis, and enhanced security monitoring. As part of the event detection process, online water quality monitoring data should be analyzed in and of themselves, but should also be supplemented by and integrated with other data streams for corroboration of possible events.

This allows data integration to occur relatively quickly at the utility level, as most of the data are in-house and available to the appropriate utility personnel. Initial efforts should focus on integrating these data sources manually – obtaining the data from each utility data source manually, and integrating them manually so that they may be evaluated in the context of other information from the WS-CWS. It is also possible to conduct the integration in a semi-automated fashion, so that certain steps of the overall integration are automated (for example, data retrieval, pre-processing or presentation), but manual intervention is needed for full integration. Ideally, information integration should be completely automated at the utility level, so that information from all utility data sources should be collected, pre-processed and presented to the data evaluator(s) at once. This provides a quicker response capability at the expense of upfront development cost.

It is useful to evaluate the data-provider integrated set of information separately from each independent data source. This potentially allows the detection of events that cannot be identified from analyzing a single data source. Integrated data evaluation can be conducted manually, automatically, or in some combination thereof. While there are tools and algorithms that can be used to evaluate integrated data, it should take some time to properly design, train and/or implement these tools as part of the WS-CWS. It is reasonable to conduct this evaluation manually as a first step, while working towards automated analysis and evaluation of integrated information. A utility domain expert can manually evaluate multiple data sources, integrated at the utility level, for anomalous events. It is possible to ease the manual analysis burden through presentation technologies that present the information in a manner that may more easily be analyzed. For example, graphical tools can present and overlay time-series data from multiple sources, and GIS tools can be used to present the information geographically. These tools can enable a manual data visualization step to assist event detection. Initially, pilot utilities should rely on manual integration of most data streams, leveraging existing tools, such as GIS platforms, where possible. Fully automated integration of the various data streams should be a focus of supporting research throughout the WS pilots.

The third general level of data integration involves integration of data across data providers such as the utility, local health department, and sentinel laboratories. Generally, this data and information integration should be used as part of the credibility determination process, to corroborate events that have been previously detected. However, it is also possible to conduct an integrated analysis of all possible data sources at once, perhaps enabling the detection of events that would not otherwise be identified. For example, 911 calls, ER physician data, online water quality monitoring, and OTC sales may be analyzed in unison. Enabling this integration is difficult because of data privacy concerns and regulations such as HIPAA. Public health data are typically available only at roll-up levels, such as yearly and by the first three digits of the zip code. It may be possible to obtain more detailed data (daily, by zip code) through the use of data-sharing agreements. Integration of this data can occur by data sharing between entities (a utility sharing data with the local health department, and vice versa), or by data sharing with an independent entity. Most likely, the initial cross-entity integration efforts should involve automated (e.g., daily) delivery of data dumps from local servers to remote servers. Special consideration should be paid to ensure that data transferred between providers can be interpreted by the destination system. This should generally involve the use of agreed-upon data standards to represent the data (typically, using extensible markup language (XML)), as well as software systems to transform the source data into this format, and to transform the received data from this format to a format that can be understood by the destination system.

Evaluation of data streams across data providers follows the integration of these data streams. While it may be possible to use similar data analysis techniques across data providers as within a single data provider, the nature of the information should likely require more coordination across the data providers to provide reasonable results. Recent advances in privacy-preserving data mining may allow the sharing of more detailed information while still addressing privacy concerns, but it is likely that in many cases, only aggregated (by location, by time, etc.) data should be available. It should be useful or even necessary to have domain experts (utility, health department) on hand to properly present and/or analyze the source data streams. Ultimately, this level of analysis should likely be manual for some time, until data sharing agreements can be put in place and automated analysis tools can be properly designed, tested and deployed. Pilot efforts are underway to perform this sort of integrated analysis; these projects are described in further detail in *Overview of Event Detection Systems for WaterSentinel* (EPA, 2005k).

8.3 Communication of Information

A CWS should contain many types of information that should need to be communicated. These types of data include source data, aggregated data, integrated data, results of analysis (manual or automated), internal recommendations, and public notifications. Each of these types of information has a different target audience and a variety of possible communication mechanisms. Previous sections have focused on the transmission of source data from primary data collectors. This section describes the communication of information – typically, this should be information that has become available after some data analysis has occurred, during event detection and consequence management phases.

There are many recipients of information in a CWS. These recipients include operators, technicians, data analysts, decision-makers, action-takers and the general public, including the media. Each recipient has different information needs with respect to content, format, frequency and timeliness. During the event detection phase, data analysts would need to communicate with each other and other technicians and operatives as part of the initial corroboration. This communication should occur both within and across organizations including the utility, public health agencies, and response agencies. The credibility determination phase should see similar communication as more data and information is shared at higher levels of the organizations. This may involve several data analysts across multiple jurisdictions, in order to provide multiple opinions, ideally reach some sort of consensus, and communicate this information to decision-makers. The consequence management phase should involve communication of information between many of the roles listed above; this phase and credibility determination are described in more detail in *WaterSentinel Consequence Management Strategy* (USEPA, 2005i).

There are many possible communication mechanisms which may be employed, such as land-line, pager, cell phone, satellite communications, radio, television, internet, and reverse 911. The type of communication mechanism is dependent on the information provider, source, recipient, content, format, timeliness, and other requirements. Many of the communication pathways fall into common use cases, such as within a data provider (e.g., utility), across data providers or jurisdictions (utility to public health department, and vice versa), and the public at large. For example, communication between data analysts and decision-makers during event detection and credibility determination would likely take place via voice calls, with supplementary data transmitted electronically. Communication during consequence management should take on many forms, depending on the message and target audience. Emergency broadcast warnings to the public can use well-established communication mechanisms, such as radio and television. This information may also be published on relevant internet web sites. Targeted communities of households, businesses or other facilities can be reached via systems such as reverse 911, which can relatively quickly place land-line calls to specific geographical areas.

Redundant communication mechanisms are necessary to reduce the likelihood of communication failures due to breakdowns. For example, a warning from a public health operative to utility operatives should take place over multiple communication channels – land line, cell phone, pager and email. Multiple designated contacts should be identified for key transmissions, as well as someone who is always available (on call) to receive the transmissions.

A communications plan is needed to encapsulate the use cases, sources, recipients, contents, formats and mechanisms of communication that are envisioned. This plan should outline the procedures by which communication can and should take place, both within and across organizations, to ensure that responders can respond in a timely fashion. The hardware (i.e., cell phones, supporting hardware and software) necessary for each communication should need to be identified. Special consideration should need to given to systems that communicate automatically, to ensure that the systems are interoperable across different jurisdictions, hardware and software systems.

Section 9.0: Approach to Evaluation

Evaluation is a key step in both the design and implementation of the WS-CWS. As part of the WS-CWS pilot demonstration project, EPA plans to develop an evaluation plan. Through the development of the WS system architecture, considerations for the technical and programmatic evaluation of the WS-CWS pilot were documented and are discussed below. Section 9.1 describes considerations for the approach for a technical evaluation of the WS-CWS and Section 9.2 describes considerations for the approach for a programmatic evaluation conducted from the perspectives of EPA, the pilot utility, and key stakeholders. Independent evaluations may also be valuable. Information documented within this section is not meant to be exhaustive; rather it should be viewed as an initial framework for development of the WS evaluation plan. In general, the objectives of this evaluation should be to:

- Provide ongoing assessment and feedback into the design of the WS-CWS
- Ensure that the WS-CWS is implemented as planned and achieves all of the program’s goals
- Document enhancements/changes that were made as a result of the pilot demonstration project
- Document benefits and costs of the WS program, based on the initial pilot demonstration project

9.1 Technical Evaluation

As illustrated in Figure 1-2, continual evaluation during the WS pilot is a key part of the success of the project. In this respect, evaluation is not an end unto itself. Rather, the evaluation is intended to strengthen and support the WS pilot as well as inform future guidance for the implementation of a CWS. The process for conducting a constructive technical evaluation as part of the WS-CWS pilot includes the following steps:

1. Determine where WS should achieve results based on the hypotheses identified in Section 1.1.2,
2. Define evaluation criteria for these areas. The nature of these criteria varies with the area evaluated. For some areas, the criteria are related to the desired goals in the area. For others, the criteria are related to performance metrics within that area,
3. Identify an evaluation methodology that can be used for each evaluation criteria. Depending on the nature of the area, this can range from a qualitative analysis of performance toward goals to using quantitative metric data directly,
4. Develop systems and procedures to collect and evaluate the necessary data, and
5. Utilize these results to help refine and develop the WS model.

As the initial step in this evaluation process, the areas in which WS should achieve results are the elements of the WS ConOps, illustrated in Figure 1-1. Important considerations for the development of evaluation criteria for monitoring and surveillance, event detection, credibility determination, response, and remediation and recovery, as well as proposed methodologies for data collection and evaluation are discussed in Section 9.1.1 – Section 9.1.5.

Each element of the system should be evaluated using specific criteria; for monitoring and surveillance, each of the WS-CWS components should also be evaluated (i.e., online monitoring, sampling and analysis, enhanced security monitoring, consumer complaint surveillance, and public health surveillance). This is a necessary step in the overall evaluation process because each element has unique attributes that are important to its functionality. This evaluation may also help to identify and mitigate potential challenges with the overall system. In addition, evaluation of each of the elements of the WS ConOps embodies the evaluation of the linkage between the design of the system (‘system architecture’) and the functioning of the system (‘consequence management’). The discussion below attempts to separate the elements to the greatest extent possible, however, overlap in the evaluations should exist, resulting in the need to employ a holistic, yet focused, technique in evaluating the WS ConOps.

9.1.1 Monitoring and Surveillance

As described in Section 1.0 of this document, the fundamental concept underlying WS is the collection, management, analysis, and interpretation of different information streams in a timely manner such that possible contamination incidents can be detected early enough to respond effectively and reduce consequences.

Specific considerations for the evaluation of each monitoring and surveillance component: online water quality monitoring, sampling and analysis, enhanced security monitoring, consumer complaint surveillance, and public health surveillance, are discussed in Sections 3.0- 7.0. Thus, the evaluation of monitoring and surveillance activities from a systems perspective should focus primarily on the overall data management, integration, and analysis across all monitoring and surveillance components.

Evaluation Criteria. For information collected from monitoring and surveillance activities conducted by both the utility and public health, the evaluation should mainly be one of data availability and management. In this regard, the evaluation should be set in the larger context of data flow throughout all elements of WS because this aspect of the evaluation goes beyond just the database operability illustrated in the WS ConOps. Rather, it speaks to all the steps from data collection and transmission, integration and analysis of information, and finally accurate communication of the information to decision-makers and other individuals, organizations, and entities involved in monitoring, surveillance, or response related to a contamination threat or incident.

Evaluation Methodology. This portion of the evaluation may consider the information technology involved as well as the information sharing culture of the utility and public health community. Evaluation and iterative improvement regarding the interaction of the databases should likely be a far more challenging process, because these databases are, in most localities, maintained by different entities. Thus, the evaluation should focus on the ability of the databases to communicate, both from an information technology and a policy perspective. The evaluation should improve understanding of:

- Methods to improve compatibility of the various monitored by the utility.
- Methods to promote the coordinated sharing of information between the utility and public health officials regarding potential incident triggers.

In any case, the process should be straightforward because the goal is simple—to ensure that the data flows to its intended user in a timely manner. It is likely that shortcomings in the data flow should be readily apparent, so evaluation and iterative improvement should likely occur as the pilot progress and anomalous water quality events, actual or speculative, arise.

9.1.2 Event Detection

Event detection can apply to any of the monitoring and surveillance components of the WS-CWS, albeit with different levels of sophistication. Due to the varying and sometimes complex nature of the data streams, computerized algorithms as well as human judgment and interpretation should likely be necessary for WS event detection. For example, relatively simple ‘event detection’ procedures for consumer complaints and enhanced security monitoring could involve simple decision trees, set points, or SOPs. For more complex data streams such as those from water quality sensors or public health surveillance system, a sophisticated, computerized algorithm may be a better choice, and perhaps the only choice. An algorithm is the mathematical operation or statistical technique that is performed on the data received (e.g., signals sent by water quality sensors) and is incorporated within the event detection software or tool that interfaces with sensors, other data streams, and other utility software. Event detection algorithms are applied to the data to filter out the anomalies that normally occur, or which have known causes, and signal only those events that are likely to be possible contamination incidents.

Evaluation criteria. Regardless of the method of event detection, there are a number of metrics that can be used to evaluate how well the particular type of event detection worked. These metrics include the following:

- **Interpretability/Integratability of event detection.** WS relies on the flow, management, and integration of data, ultimately resulting in correct interpretation and accurate communication of information about the potential incident. Thus, a critical criterion for evaluation of an event detection system is whether the results from this system can be readily interpreted and integrated with other information available to the users of the information, such as decision makers and responders.
- **Resource requirements.** This measure applies to the costs incurred as a result of time, labor, and consumables expended during the installation, and operation and maintenance of the event detection system, and in responding to an event trigger. This metric can also be used to track the costs associated with the execution of the event trigger protocol to determine whether the expenditures were commensurate with cause of the trigger (e.g., an event trigger that leads to a discovery by the utility that a sensor calibration problem is the cause without the implementation of a drastic response action like a ‘do not use’ order is indicative of good protocol because the resources expended were not excessive).
- **Ability to handle highly variable data.** The monitored data streams are influenced by many factors (e.g., seasonal factors, source water, and treatment variables) and baselines should show significant change daily, weekly, and seasonally. Event detection system tools and/or algorithms should have the ability to handle these highly variable data to be effective across time ranges.
- **Adaptivity.** This parameter represents the extent to which the system can learn on its own, as opposed to having a need to be re-trained over time. Adaptivity is valuable in a system because it reduces the amount of off-line re-training or adjustment needed.
- **Sensitivity.** In the context of event detection systems, the sensitivity of a test is related to the proportion of contamination incidents detected by the event detection system relative to all the contamination incidents that occurred during a given time. In terms of false positives and negatives:

  Sensitivity = (number of true positives) / (number of true positives + number of false negatives)

- **Specificity.** In the context of event detection systems, the specificity is related to the proportion of time the system is detected to be without contamination relative to the time the system is free of contamination (excluding false negatives). In terms of false positives and negatives:

  Specificity = (number of true negatives) / (number of true negatives + number of false positives)

- **F-measure.** The F-measure relates sensitivity and specificity in a single measure of performance. The F-measure is the harmonic mean of sensitivity and specificity; that is:

  F = (2 x sensitivity x specificity)/ (sensitivity + specificity)

- **Timeliness of data.** This refers to the ability to provide meaningful information in a timeframe appropriate for implementing response actions.

This more detailed evaluation plan for event detection systems has been developed as part of the pre-selection process to provide a basis for selection of EDSs that should be evaluated as part of the WS-CWS pilot. Many of these same aspects also should be considered in the evaluation of other elements and components of the WS-CWS.

Evaluation methodology. Some event detection systems can be evaluated through model simulations, or even live simulations (see Section 3.4 for a discussion of evaluation for online water quality sensor networks). However, due to the large number of event detection systems and evaluation criteria, it is not efficient to discuss each combination here. Regardless of how they are evaluated, the evaluation methodology should focus on the type of data, i.e., quantitative or qualitative, that is inherent to each criterion. For example, the four criteria of interpretability/integratability, the ability to handle highly variable data, timeliness, and adaptivity should likely produce a quantitative result in terms of their capability to deliver an answer. However, a more thorough evaluation would involve a qualitative investigation to elucidate the causes of the success or failure of the system. Only in this manner can any necessary improvements be made. For example, careful evaluation of actual operations should likely elucidate correctable bottlenecks impacting timeliness that could be easily overlooked.

Some evaluations should be essentially quantitative, such as those for resource requirements, sensitivity, and specificity. Of these, resource requirements are the most straightforward because the metrics of sensitivity and specificity are quantitative and inherently linked. One valuable tool for helping evaluating the relationship between the two is through the use of receiver operating characteristic (ROC) curves. The performance and reliability of an event detection system depends on the ability to minimize the number of erroneous ‘detections’ of a contamination event (i.e., false positives) while avoiding the erroneous ‘non-detection’ of a contamination incident that has actually occurred (i.e., false negative). For example, for water quality sensors, false negatives are associated with such factors as improper sensor selection and placement, lack of instrument sensitivity at low contaminant concentrations, interference caused by background noise, and insufficient data analysis capability. False positives are associated with oversensitive data streams that generate an indication of contamination when none exists. They can also be caused by the presence of interferences that mimic actual contaminants within the sensor or by inappropriate event detection system algorithms.

The generation of ROC curves is a means of visualizing the likelihoods of false negatives and false positives from an event detection system. These curves are produced by plotting sensitivity versus specificity. An ideal event detection system would have zero false negatives (i.e., 100% sensitivity) and zero false positives (i.e., 100% specificity). In reality, such an ideal situation cannot be achieved. For example, the use of low detection limit sensors would represent a situation where the sensitivity approaches 100% (i.e., minimal false negatives because the ability to detect has been sharpened), but this heightened ability to detect increases the likelihood that a non-contaminant would trigger the sensor (i.e., a false positive) and as the number of false positives increase, the specificity would drop. Because the consequences are much greater if an actual event is missed (i.e., a false negative), a certain percentage of false positives should be acceptable. However, the consequences of a false alarm can be significant, particularly if they result in substantial response actions. Thus, the false positive rate should be minimized to the greatest extent possible.

At a conceptual level, the ROC curve shows that the ability to detect contamination incidents and the level of false alarms are inextricably linked, and have a positive and usually non-linear relationship. The construction of a ROC curve requires that a set of events exists in a form that can be used to test the event detection algorithms. The actual ability to construct a ROC curve from WS pilot data may be a formidable challenge and may not be possible due to the complexities of the variables, in addition to obtaining enough data from contamination threats and incidents to produce a statistically valid result. Nonetheless, it is a worthwhile component of the WS evaluation, and even if it should not be as productive as hoped, the data gathered to perform the evaluation may themselves point to the optimal approach for evaluating the event detection element of WS.

9.1.3 Credibility Determination

At first glance, evaluation of the credibility determination element of WS would simply seem to be based on its success in answering the question 'Does a credible threat exist?' The appeal of a yes-no answer discounts the complexity of the overall process of managing the evaluation of a threat. The following simple model describes the credibility determination process in terms of input, evaluation, and output:

- Input = all available information relevant to the contamination threat.
- Evaluation = systematic evaluation of the collective information to determine whether or not the water supply could have been contaminated. It is important to consider all available information as a whole such that any one individual piece of information does not drive the entire decision process.
- Output = conclusions of the threat evaluation (i.e., has something actually happened?).

Credibility determination is a progressive process that is considered in three stages (or decision points); '*possible*,' '*credible*,' and '*confirmed*.' It is also an iterative process in which the credibility of threat is re-evaluated as additional information becomes available.

Evaluation Criteria._WS does not provide an automatic mechanism for managing a threat; rather, it can provide additional information to help make a credibility determination. If WS is providing high quality data streams and these streams can be interpreted optimally, the credibility determination ideally would be made more quickly and with greater confidence. The evaluation of the credibility determination process in the context of WS should mainly focus on the application of this process in the presence of additional information collected from the WS-CWS data streams. It should be the quality of these data streams, and the ability to quickly and effectively integrate the information from multiple data streams, that ultimately determine the reliability and performance of the credibility determination element of WS. Important criteria in this regard include:

- Measurement of response times between event trigger and credibility determination.
- Measurement of response time between credibility determination and event confirmation.
- Evaluation of the efficacy of data integration and the ability of this integration to inform response decisions, and possibly some assessment of the 'correctness' of the credibility determination. The latter is important for evaluating the overall 'false positive / false negative rate' of the entire WS-CWS.

Evaluation Methodology. Effective credibility determination would best be demonstrated through actual or simulated incidents. These incidents need not include just intentional contamination, but could arise from unintentional contamination or changes to the water system the may indicate the need for changes in the water system operations. The later reflects the potential for 'dual use' benefits, such as a previously undiscovered need to boost chlorine levels in parts of the system during certain times of the month. Conducting tabletop exercises and drills should also be necessary to exercise the pilot utility's process for credibility determination. Some evaluation of these drills in terms of how well the credibility determination element performed should be necessary. The results of these drills should improve the credibility determination process that takes place for actual incidents.

9.1.4 Response

Response actions within the context of WS are depicted in Figure 1-3 in the areas of operational response, public health response, and risk communication. Appropriate response actions vary with the stage of the threat evaluation. The evaluation of the response and the application of 'lessons learned' through the evaluation is perhaps of greater importance when response actions are needed during the 'credible' phase of the threat evaluation, as compared to the 'confirmed' phase. In the former case, it is not necessarily known with as high a level of confidence if data from WS do indeed indicate the presence of actual contaminants. Accordingly, response actions should be chosen carefully to avoid unnecessary alerts to the public when there is no confirmed contamination, which if too frequent, would cause the public to loose confidence in the CWS and the drinking water utility. Some response to contamination threats is warranted due to the public health implications of an actual contamination incident. However, a utility could spend a lot of time and money over-responding to every contamination threat, which would be an ineffective use of resources. Furthermore, over-response to a contamination threat carries its own adverse impacts, like a loss of confidence in the CWS by partners (public health agency, etc).

Evaluation Criteria. Although response actions are conceptually different from credibility determination, the two are operationally linked. Therefore, some of the same evaluation criteria described in Section 9.1.3 should be used. The evaluation of response actions should be largely qualitative and focus on how appropriate and timely these responses were, given the nature of the incident and the stage of the threat evaluation. For example, if the incident involved contamination that potentially impacts a substantial portion of the population, did it provide optimal public health protection? On the other hand, if the incident reflects a disturbance in plant operations that impacts water quality, but not short-term public health, did the response convey this condition to the public in a proper means and context so as to not diminish public confidence? It is difficult to generalize in advance the specifics of the evaluation of this element of WS, because the specific nature of the incident cannot be predicted.

Evaluation Methodology. As with the evaluation of 'credibility determination', the evaluation of 'response actions' should likely be based on a mixture of actual or simulated incidents, along with table top exercises and drills. The evaluation of response actions taken during the credible phase should occur in the context of the processes and procedures identified in the consequence management plan. The results of the evaluation, particularly of responses during the pilot program, should likely serve to inform local government about response actions in the context of water contamination threats and incidents.

9.1.5 Remediation and Recovery

Even in the absence of a confirmed contamination event, activities viewed broadly as 'remediation and recovery', may be required following the more possible situations of highly credible false alarms, unintentional contamination, or 'upsets' to the water system which indicate the need for changes in the water system operations. Regardless of what necessitates the remediation activity, the remediation process involves a sequence of activities including: system characterization; selection of remedy options; provision of an alternate drinking water supply during remediation activities; and monitoring to demonstrate that the system may be returned to normal operation. The goal of remediation and recovery is to return the water supply system to service as quickly as possible, while protecting public health and minimizing disruption to normal life (or business continuity).

Evaluation Criteria. Evaluation should be based on whether the situation involved intentional contamination, unintentional contamination, water system upsets, etc. The remediation and recovery approach, in terms of the involvement of law enforcement in particular, should be different for intentional versus unintentional contamination. For any case, relevant criteria such as the efficacy of the decontamination technologies, the quality of the sampling and analysis, and the process by which the water system is deemed fit to return to normal operation should all be evaluated. Another criterion common to all remediation and recovery approaches is the rate of the activities. While rapid recovery of the system is crucial, the evaluation should take into account that it is equally important to follow a systematic process that establishes remedial goals acceptable to all stakeholders, implements the remedial process in an effective and responsible manner, and demonstrates that the remedial action was successful.

Evaluation Methodology. Like the evaluation methodology discussed in the two previous subsections, the evaluation of this element should likely be based on a mixture of actual situations, along with table top exercises and drills. The evaluation methodology should vary based on the model for remediation employed. For instance, if intentional contamination is involved, it may be useful to perform the evaluation in light of the probable model for remediation and recovery, which may resemble a Superfund remedial response program, although a contaminated water system probably would not be classified a Superfund site, per se. However, some of the same principles involved in evaluation Superfund site clean-ups may apply here. Part of the evaluation of this phase, if necessary, should involve looking for the ability to apply the Superfund model—or other existing, remedial plans—to the remediation of water systems.

On the other extreme, WS may detect confirmed incidents that primarily affect system operation and not public health. Often, techniques to implement required changes in system operation are known, so the remediation model largely resembles routine maintenance or system optimization. Accordingly, the evaluation should center on the appropriateness and timeliness of the remedial action, in the context of the role that WS played in it. For instance, if WS data streams suggest a confirmed, inadvertent cross-connection, the remediation and recovery actions should be correlated with the data streams. This is not really an evaluation of the WS data streams themselves; rather, it is an exploration of how they contributed to the remediation process. For instance, did they help pinpoint the source of the cross-connection, saving utility resources in manually locating it?

Given the impossibility—due to resource, response, and technology limitations—of fulfilling the ideal performance goal of zero exposures, effectiveness of the WS-CWS should be defined along more pragmatic objectives. EPA's contamination incident timeline analyses, for example, use endpoints of 1 percent fatalities and 50 percent of exposures to evaluate the timeliness of its simulated CWS. A key output is determining the percentage decrease in exposures and fatalities that occurs as a result of the warning system. EPA intends that these endpoints serve only to guide the Agency as it seeks to evaluate, in the design phase, the components of a contamination warning system. Ultimately, while EPA expects to provide general guidance to utilities and communities in the design and implementation of effective CWSs, the process of balancing the resources versus the performance goals of the system should rest with the utility and the community. Additional considerations as part of the programmatic evaluation of WS are discussed in Section 9.2

9.2 Programmatic Evaluation of WaterSentinel

Section 1.1.2 briefly summarizes the overall objectives of the WS program. The objectives can actually be thought of as collectively representing the needs of the many parties who would participate in the WS pilot program as well as those involved in the promotion of CWS implementation beyond the pilot stage. The evaluation discussed below is based on the projected perspectives of several of these parties. There are other interested groups that may also have different perspectives, and the ones selected below may sufficiently encompass many other groups.

9.2.1 EPA Perspective

Like the technical evaluation discussed in the section above, the evaluation of the success of WS at the program level is an iterative process, allowing for continual improvement of the program. Thus, the programmatic evaluation should not occur just at the end of the pilot period. Rather, the WS pilot should need to be systematically evaluated in terms of results, accomplishments, limitations, sustainability, cost-benefits, and other such metrics that may become apparent during the course of the pilot. Evaluations should be in the context of the WS implementation and operational paradigm, but should also include comparative evaluations with other programs related to water quality monitoring, water security, public health protection, syndromic surveillance, and critical infrastructure protection.

This evaluation should include an evaluation of each individual element of WS in addition to a holistic evaluation of the overall program that is more than just a sum of the evaluation of the individual elements. This evaluation should accordingly consist of the following:

- A Pre-implementation Evaluation Plan that describes the framework for the overall evaluation of WS, including its ultimate goals, measures of success, limitations, and capabilities from technical, programmatic, and policy perspectives.
- Midway through the pilot, evaluate the WS against several benchmarks, such as: 1) to what extent progress has been made on the types of issues revealed in the Pre-implementation Evaluation Plan; 2) emerging issues not identified in the WS Pre-implementation Evaluation Plan; and 3) progress and developments in these or other appropriate areas relative to WS evaluation.
- A comprehensive quantitative and qualitative analysis of and development of recommendations about the overall system design and implementation, using both the issues identified in the WS Pre-implementation Evaluation Plan as well as any other developments that have occurred during the pilot period, in any relevant technical, programmatic, or policy area.

This holistic evaluation is mainly related to the goal of WS stated in Section 1.1.2, namely an investigation through a pilot demonstration project of the CWS concept, i.e., the timely warning of potential water contamination incidents through enhanced and integrated monitoring and surveillance. However, the ultimate goal of WS pilot project is develop a CWS model that can be adopted and implemented by drinking water utilities of all sizes and with varying characteristics. Accordingly, EPA is inherently interested in the evaluation of the program from the perspectives of utilities and other stakeholders, which relate to the six specific objectives bulleted in Section 1.1.2. These six objectives encompass a number of perspective-related issues, as discussed below.

9.2.2 Utility Perspectives

Much information should be generated from the WS program that may impact the ability of the pilot utility to continue operation of the WS-CWS, and for other utilities to implement their own CWS, as alluded to in Figure 1-2. The evaluation of the WS program from the utility perspective should focus on issues of key importance to drinking water utilities operating WS or any other monitoring and surveillance program, for that matter. These issues would include the following:

- **Management.** This portion of the evaluation should focus on the management structures and priorities that affect the ability of a utility to operate a CWS. This may range from availability of human resources to the ability to commit funding for monitoring and surveillance programs outside of the realm of compliance monitoring. The challenge is managing competing priorities, e.g., regulatory compliance, infrastructure replacement and upgrades, consumer rate base, etc. Effective management in this regard may involve a site specific analysis of the compatibility of WS with other requirements and programs (e.g., can some WS monitoring also meet certain regulatory monitoring requirements?). This gets to the heart of the desire to make the WS-CWS a dual-use application, with benefits that extend well beyond just security.
- **Analytical capability/capacity.** Section 4.4 focuses on the evaluation of the WS Sampling and Analysis Program from a technical standpoint. Utilities may also be very interested in an evaluation of how implementation of a CWS impacts their overall analytical capability and requirements, both in the laboratory and in the field, especially with regards to their regulatory compliance programs. In this respect, it is appropriate to note the following: historically, many utilities have made the business decision to contract out much of their analytical work, not due to technical challenges, but rather due to the overall cost-effectiveness of this approach. This has

important ramifications for the sustainability of the WS program which relies on rapid turn around of laboratory analysis for contaminants that are not of routine interest to most utilities and which are infrequently sampled.

- **Government and community relations.** This relates to the ability of the utility to interact local government and community partners to support a CWS program. Effective interaction with the public as a partner and as a customer is another important consideration in the evaluation of the WS-CWS in terms of government and community relations. This evaluation may be of additional value to the utility as operation, maintenance, and sustainability of a comprehensive WS-CWS is dependent on organizations and programs outside of the control and management of the utility. Local government and community partners should remain engaged through public health surveillance, consequence management, training, and evaluation to support an active and protective CWS.
- **Operability/sustainability.** Evaluation of the operability/sustainability of the WS program from the management perspective may greatly aid other utilities with implementing WS. This evaluation should contain specific cost-benefit results, enabling to the utility to implement a sustainable CWS that meets their anticipated needs. This could also be characterized as the manner in which a WS-CWS fits into the business model of the modern public (or private) utility.
- **Scalability.** The evaluation of WS at the pilot city is, in some respects, site specific. Many aspects of this specificity are discussed above. An additional aspect is the ability to scale the CWS model to different sized utilities and communities. This evaluation should be largely qualitative, but should broadly address scalability in terms of factors such as population served, geographically region served, hydraulic regions present, along with the many other factors that tend to make water systems unique.

9.2.3 Stakeholder Perspectives

There are a number of stakeholders deeply interested in and potentially affected by the WS program. A few are included below, along with the type of, and possible measures for, evaluation perhaps appropriate for each:

- **Drinking water consumers.** Aside from the interaction of water utilities with the public, the public perspective of a CWS program monitoring the drinking water in their community should be evaluated. Examples of factors that may be evaluated include public confidence in the government to protect them and benefits/problems reported by consumers as a part of the program. It should be useful to evaluate the means of effectively conveying the potential costs and benefits of the program to the public such that they can make an informed decision regarding their willingness to support it.
- **Emergency Responders and other Local Government Services.** The emergency response community, and others within the local community, would likely be impacted the WS program. Accordingly, an evaluation of the impact of the WS program on their activities should be very useful as other water systems implement a CWS. A key aspect of this evaluation should entail a thorough understanding of the maintenance of emergency response and governmental services upon which WS relies, such as the ability to perform response activities related to consequence management.
- **Public Health community.** WS represents a new level of complexity for the public health community and operations in terms of coordination with drinking water utilities. An important aspect of this is the maintenance of public health syndromic surveillance programs, which are part of the WS-CWS. In addition, coordination with the public health community in terms of response also should be evaluated.
- **Drinking Water Trade Associations.** These groups actively represent the various interests of drinking water utilities at the local, state, and national levels with respect to the development and

implementation of drinking water programs. A thoughtful evaluation of the program with their needs in mind should prove critical for the longer-term viability of the WS-CWS program.

- **Water Quality Researchers and Technology Developers.** These groups are interested in aspects of the WS program, mainly to focus their efforts on needs in their respective areas. The effective evaluation of the program in terms of the science and technology supporting the program should help meet their research and business objectives.

Section 10.0: References and Resources

Note: In addition to references cited throughout the document, this section also will include a summary of other documents available based on the list of system architecture documents developed for the WS Team Retreat. Documents will be listed as 'limited distribution' where appropriate.

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Appendix A: Acronym List

API	application program interface
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
BSL	biological safety level
CCSP	Consumer Complaint Surveillance Program
CDC	Centers for Disease Control and Prevention
CDF	cumulative distribution function
CEO	chief executive officer
CIS	customer information system
Cl	Chlorine residual
CMP	Consequence Management Plan
ConOps	concept of operations
COO	chief operating officer
CWS	contamination warning system
DHS	Department of Homeland Security
DOD	Department of Defense
DPD	a testing reagent
DQO	data quality objectives
DSL	Digital Subscriber Line
DSS	distribution system simulator
DSS	Decision Support System
EASI	Estimate of Adversary Sequence Interruption
ebXML	electronic business extensible markup language
EC	electrical conductivity
ECBC	Edgewood Chemical Biological Center
EDS	Event detection system
EDXL	Emergency Data Exchange Language
eLRN	Environmental Laboratory Response Network
EMS	emergency medical services
EPA	U.S. Environmental Protection Agency
ER	emergency room
ESSENCE	Electronic Surveillance System for the Early Notification of Community-Based Epidemics
FDA	U.S. Food and Drug Administration
FERN	Food Emergency Response Network
FTP	file transfer protocol
FY	fiscal year
GAO	Government Accounting Office
GC/MS	gas chromatography/mass spectrometry

GIS	Geographical information systems
HIPAA	Health Insurance Portability and Accountability Act
HL	health level
HSC	Homeland Security Council
HSPD	Homeland Security Presidential Directive
JBAIDS	Joint Biological Agent Identification and Diagnostic System
JHU-APL	John's Hopkins University Applied Physics Laboratory
LC/MS	liquid chromatography/mass spectrometry
LIMS	laboratory information management systems
LRN	Laboratory Response Network
MCL	maximum contaminant level
MDL	method detection limit
NEDSS	National Electronic Disease Surveillance System
NEMA	National Electrical Manufacturers Association
NEMI-CBR	National Environmental Methods Index – Chemical, Biological, Radiological Methods
NHSRC	National Homeland Security Research Center
NRDM	National Retail Data Monitor
NTU	Nephelometric Turbidity Units
NYC	New York City
NYC DOHMH	New York City Department of Health and Mental Hygiene
O&M	operations and maintenance
ORP	oxygen reduction potential
OTC	over-the-counter
PCR	polymerase chain reaction
PDA	personal digital assistant
PE	performance evaluation
PH	Public Health
PHIN	Public Health Information Network
PHS	public health surveillance
PLC	Programmable Logic Controllers
PPS	physical protection system
PSI	pound per square inch
PT	proficiency testing
QA	quality assurance
QC	quality control
RHIO	Regional Health Information Network
RIO	remote input-output
ROC	receiver operating characteristic
RODS	Real-time Outbreak and Disease Surveillance
RPTB	Response Protocol Toolbox
RSD	relative standard deviation
RTCC	Real Time Clinical Connections

RTU	remote terminal unit
SAM	Standardized Analytical Methods for Use During Homeland Security Events
SAVI	System Analysis and Vulnerability to Intrusion
SCADA	supervisory control and data acquisition
SOP	standard operating plan
SRMD	Standards and Risk Management Division
SS	syndromic surveillance
T&E	EPA's Test and Evaluation
TCR	Total Coliform Rule
TDS	total dissolved solids
TEVA	Threat Ensemble Vulnerability Assessment
TOC	total organic carbon
TTEP	Technology Testing and Evaluation Program
UPC	Universal Purchase Code
UPS	Uninterrupted Power Supply
USDA	U.S. Department of Agriculture
VA	Veterans Administration
WATERS	Water Awareness Technology Evaluation Research and Security
WCIT	Water Contaminant Information Tool
WLA	Water Laboratory Alliance
WQ	water quality
WS	WaterSentinel
XML	extensible markup language

Appendix B: Glossary

Working Draft for Discussion

Agency. A division of government with a specific function, or a non-governmental organization (e.g., private contractor, business, etc.) that offers a particular kind of assistance. In the incident command system, agencies are defined as jurisdictional (having statutory responsibility for incident mitigation) or assisting and/or cooperating (providing resources and/or assistance).

Analytical Approach. A plan describing the specific analyses that are performed on the samples collected in the event of a water contamination threat. The analytical approach is based on the specific information available about a contamination threat.

Analytical Confirmation. The process of determining an analyte in a defensible manner.

Automation. Ability of the monitoring/field technology, analytical method, or surveillance system to provide notification with limited analysis or interaction.

Availability. Identifies whether the technology, method, or surveillance system is available for implementation in the pilot or requires additional research and/or validation.

Baseline. Background levels of specific contaminants; normal ranges for water quality parameters; incidence of disease, consumer complaints, security breaches, or reports of information. Depending on the source of information, baseline can be site or system specific and may have a seasonality component.

Bias. A systematic or persistent distortion of a measurement process that results in a measurement different than the sample's true value.

Concept of Operations (ConOps). Identifies routine, day-to-day operations for maintaining the WaterSentinel contamination warning system at a water utility and public health agency to detect and respond to a contamination event. The ConOps provides the broad context from routine monitoring and surveillance activities to recovery from an event.

Confirmed. In the context of the threat evaluation process, a water contamination incident is 'confirmed' if the information collected over the course of the threat evaluation provides definitive evidence that the water has been contaminated.

Confirmatory Stage. The third stage of the threat evaluation process from the point at which the threat is deemed 'credible' through the determination that a contamination incident either has or has not occurred.

Consequence. The adverse outcome resulting from a drinking water contamination incident. In the context of the threat management process, the consequence considers both the number of individuals potentially affected as well as the severity of the health effect experienced upon exposure.

Consequence Management Plan. Provides a decision-making framework that governs when, how, what, and who will be involved in making decisions in response to contamination threat warnings to minimize the response timeline and implement operational or public health response actions appropriately.

Consequence Management. Refers to the process and procedures for implementing response actions that are initiated upon detection of a ‘possible’ contamination event and continues through determining if the threat is credible and confirming the contamination threat. An initial trigger indicating possible contamination could come from single or multiple monitoring and surveillance information streams. Indication of possible contamination will prompt the water utility to conduct follow up actions such as site characterization, triggered sampling, analysis for unknowns, notifications, and precautionary actions to reduce consequences should the event be later determined credible or confirmed. As the information from the initial response actions and/or additional detection information is collected from or coordinated with the water utility, additional response actions will be considered and implemented as the event is assessed for credibility. This process of continuous information collection followed by assessment and action will be performed by the water utility and others from the local to State to Federal levels of various agencies to respond to the event, mitigate the consequences, provide internal and external notifications, bring in additional resources for response and analysis, and manage all related emergency response requirements associated with the specifics of the event.

Contaminant Classes. WS contaminants can be categorized into 12 categories based on their ability to be detected by routine sampling, online monitoring, consumer complaints, and public health surveillance.

Contamination Warning System (CWS). Active deployment and use of monitoring technologies/strategies and enhanced surveillance activities to collect, integrate, analyze, and communicate information to provide a timely warning of potential water contamination incidents and initiate response actions to minimize public health impacts.

Consumer Complaint Surveillance. Consumer complaints regarding unusual taste, odor, or appearance of the water are often reported to and recorded by water utilities which conventionally use them to identify and address water quality problems. Using an appropriate methodology, WS could track and analyze these complaints to look for unusual trends that may be indicative of a contamination incident.

Credible. In the context of the threat evaluation process, a water contamination threat is characterized as ‘credible’ if information collected during the threat evaluation process corroborates information from the threat warning.

Credible Stage. The second stage of the threat management process from the point at which the threat is deemed ‘possible’ through the determination as to whether or not the threat is ‘credible’.

Credibility Determination. Detected events will be considered ‘possible’ indications of contamination and will be validated through the process of credibility determination. Based on this analysis a decision will be made to return to normal operations or move to the credible stage and implement consequence management and response actions. It is critical that the systematic approach for assessing credibility in response to contamination threat warnings ensures that all available information is analyzed in a timely and efficient manner to minimize both false alarms and over-response to a trigger that has not been determined to be credible.

Data Management. Manages, analyzes, and interprets different data streams in a timely manner to recognize potential contamination incidents in time to respond effectively.

Design Basis. The range of conditions and events taken explicitly into account in the design of a facility, according to established criteria, such that the facility can withstand them without exceeding authorized limits by the planned operation of safety systems.

Detection Time. The time for water contaminated with detectable concentrations to reach each 'sensor' in the network (i.e., an opportunity for a detection event). Travel times to each 'sensor' will be predicted by TEVA as a time series.

Distribution System. A network of pipes that distribute potable water to customers' plumbing systems.

Dual Use. Application of contamination warning system components to routine operations.

Emergency Operations Center. A pre-designated facility established by an agency or jurisdiction to coordinate the overall agency or jurisdictional response and support to an emergency.

Emergency Response Plan. A document that describes the actions that a drinking water utility would take in response to various emergencies, disasters, and other unexpected incidents.

Enhanced Security Monitoring. Security breaches, witness accounts, and notifications by perpetrators, news media, or law enforcement can be monitored through enhanced security practices.

Event Detection. Event detection is defined as a signal from monitoring and surveillance activities that is indicative of a possible contamination incident. This signal could be a pattern of unusual water quality, a cluster of unusual consumer complaints, or unusual symptoms picked up by a public health surveillance program. Event detection algorithms are applied to the data to filter out the anomalies that normally occur, or which have known causes, and signal only those events that are likely to be possible contamination incidents. In short, the purpose of the event detection algorithms is to reduce the false positive rate without missing potential events.

False Positive. (1) Rate at which a contamination warning system incorrectly indicates a contamination incident. (2) Rate at which the technology, analytical method, or surveillance system detects a contaminant, class of contaminants, or change from the baseline when the contaminant or contaminants are not present.

False Negative. (1) Rate at which a contamination warning system fails to detect a contamination incident. (2) Rate at which the technology, analytical method, or surveillance system does not detect a contaminant, class of contaminant, or change from the baseline when the contaminant or contaminants are present.

Field Safety Screening. Screening performed to detect any environmental hazards (i.e., in the air and on surfaces) that might pose a threat to the site characterization team. Monitoring for radioactivity as the team approaches the site is an example of field safety screening.

Health Care Provider. Any individual or organization involved in the care of patients. Health care providers include physicians and hospitals.

Homeland Security Presidential Directive 7 (HSPD 7). HSPD 7 – Critical Infrastructure Identification, Prioritization, and Protection – designated EPA and other agencies as the sector-specific agencies for critical infrastructure areas. EPA was designated as the agency responsible for protection activities for the Nation's drinking water and wastewater infrastructure. A key component of this responsibility is the hardening of drinking water and wastewater system infrastructure to address vulnerabilities.

Homeland Security Presidential Directive 9 (HSPD 9). HSPD 9 is the directive that charges EPA and other agencies, using existing authorities, to build upon and expand current monitoring and surveillance programs to develop robust, comprehensive and fully coordinated surveillance and monitoring systems to provide early detection and awareness of water contamination. In order to support the monitoring and response to an incident, HSPD-9 also directs EPA to develop nationwide laboratory networks that integrate existing federal and state laboratory resources.

ID_{50}. The dose that results in infection in 50% of the population exposed to that dose.

Incident. A confirmed occurrence that requires response actions to prevent or minimize loss of life or damage to property and/or natural resources. A drinking water contamination incident occurs when the presence of a harmful contaminant has been confirmed.

Incident Command System. A standardized on-scene emergency management concept specifically designed to allow its user(s) to adopt an integrated organizational structure appropriate for the complexity and demands of single or multiple incidents, without being hindered by jurisdictional boundaries.

LD_{50}. The dose that results in death in 50% of the population exposed to that dose.

Laboratory Information Management Systems (LIMS). Sophisticated software packages that track and analyze laboratory information. Interfacing with laboratory instruments and personnel at the front end and databases at the back end, LIMS provide information management at the integrated laboratory level.

Laboratory Response Network (LRN). The LRN is charged with the task of maintaining an integrated network of state and local public health, federal, military, and international laboratories that can respond to bioterrorism, chemical terrorism and other public health emergencies.

Latency Period. The period of time that elapses between exposure of an individual to a causative agent and the appearance of signs or symptoms of disease.

Monitoring and Surveillance. Element of the WS-CWS to provide a standardized set of information streams to detect contamination events.

Online Water Quality Monitoring. Sensors located within the treatment and distribution system can potentially detect an identifiable change from an established water quality baseline, such as chlorine residual, pH, conductivity, turbidity, etc., and serve as an indicator of potential contamination in the WS-CWS.

Possible. In the context of the threat evaluation process, a water contamination threat is characterized as ‘possible’ if the circumstances of the threat warning appear to have provided an opportunity for contamination.

Possible Stage. The first stage of the threat management process from the point at which the threat warning is received through the determination as to whether or not the threat is ‘possible’.

Precision. The degree to which a set of measurements obtained under similar conditions conform to themselves. Precision is usually expressed as standard deviation, variance, or range, in either absolute or relative terms.

Public Health. The health and well being of an entire population or community. Public health does not specifically address the health of individuals.

Public Health Surveillance. Ongoing, systematic collection, analysis, and interpretation of health-related data essential to the planning, implementation, and evaluation of public health practice (Sosin, 2003). Syndromic surveillance by the public health sector as well as reports from emergency medical service (EMS) runs, 911 call centers and poison control hotlines might serve as a warning of a potential drinking water contamination incident if there is a reliable link between the public health sector and drinking water utilities.

Quality Assurance. An integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the client.

Quality Control. The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the client; operational techniques and activities that are used to fulfill requirements for quality.

Rapid Field Testing. Analysis of water during site characterization using rapid field water testing technology in an attempt to tentatively identify contaminants or unusual water quality.

Reliability. For a contamination warning system (CWS), reliability can be considered from at least two perspectives: system operation and system performance. System operation refers to factors such as CWS component downtime and maintenance requirements. System performance is defined as the ability of the system to provide information that leads decision makers to successfully infer that contamination has or has not occurred.

Remediation and Recovery. The goal of remediation and recovery is to return the water supply system to service as quickly as possible while protecting public health and minimizing disruption to normal life (or business continuity). During the remediation and recovery stage, the immediate urgency of the situation has passed, and the magnitude of the remedial action requires careful planning and implementation. While rapid recovery of the system is crucial, it is equally important to follow a systematic process that establishes remedial goals acceptable to all stakeholders, implements the remedial process in an effective and responsible manner, and demonstrates that the remedial action was successful.

Response Decisions. Part of the threat management process in which decisions are made regarding appropriate response actions that consider: 1) the conclusions of the threat evaluation, 2) the consequences of the suspected contamination incident, and 3) the impacts of the response actions on drinking water customers and the utility.

Response Guidelines. A manual designed to be used during the response to a water contamination threat. Response Guidelines should be easy to use and contain forms, flow charts, and simple instructions to support staff in the field or decision officials in the Emergency Operations Center during management of a crisis.

Response Protocol Toolbox (RPTB). These modules provide a framework to guide the response to contamination threats and incidents and establishes the foundation for the primary steps, or phases, for consequence management as part of the WS-CWS

Response Time. The time to decide on an appropriate response action and mobilize resources to implement that action once an event is determined to be credible (as defined in EPA's Response Protocol Toolbox).

Robustness. The ability of an instrument to sustain performance under field conditions (e.g., a research-grade instrument may have excellent precision and bias specifications, but have poor robustness, and would be unsuitable for deployment).

Routine Sampling. Water samples can be collected at a predetermined frequency to establish a baseline or in response to a trigger and subsequently analyzed by the application of a robust unknowns protocol to establish a baseline and serve as preparedness and training for response to a possible contamination incident. This unknowns protocol would provide coverage for specific, priority contaminants, but may also detect some non-target analytes if the analytical techniques used in the routine monitoring program are sufficiently robust and if the analysts are trained and encouraged to investigate tentatively identified contaminants.

SCADA Systems. SCADA stands for Supervisory Control And Data Acquisition. It is not a full control system, but rather focuses on the supervisory level. It is a software package that is positioned on top of the hardware to which it is interfaced, in general via Programmable Logic Controllers (PLCs), or other commercial hardware modules.

Security Breach. An unauthorized intrusion into a secured facility that may be discovered through direct observation, an alarm trigger, or signs of intrusion (e.g., cut locks, open doors, cut fences). A security breach is a type of threat warning.

Security Surveillance. Ongoing, continual monitoring and investigation of security breaches, witness accounts, notifications by perpetrators, news media, or law enforcement.

Site Characterization. The process of collecting information from an investigation site in order to support the evaluation of a drinking water contamination threat. Site characterization activities include the site investigation, field safety screening, rapid field testing of the water, and sample collection.

Stakeholders. WaterSentinel stakeholders include water utilities, laboratories, states, emergency responders, public health officials, law enforcement, Federal agencies, technical experts, among others.

Surrogate. Utilizing general water quality parameters such as temperature, residual chlorine, pH, turbidity, etc. as an indication of a contamination event.

Surveillance Systems. Systems that collect and analyze morbidity, mortality, and other relevant data and facilitate the timely dissemination of results to appropriate decision makers (Bravata, et al., 2004).

Sustainability. Sustainability of a contamination warning system (CWS) considers factors that influence the ability of an entity, such as a drinking water utility, to operate and maintain the CWS over an extended period of time and in the face of competing priorities that could siphon resources away from the program. In most cases, the analysis of sustainability for a CWS will entail a cost-benefit analysis.

System Architecture. WaterSentinel system architecture provides a framework for developing a contamination warning system (CWS) in support of the WS program. The WS system architecture will define the conceptual approach for the WaterSentinel contamination warning system (WS-CWS) and document the most effective combination of CWS components to yield a sustainable program that can be adopted and implemented by drinking water utilities.

Technology Testing and Evaluation Panel (TTEP). Office of Research and Development program for analysis of technologies that could be candidates for deployment in a contamination warning system. Through TTEP, EPA will continue to evaluate existing detection and sensor equipment, as well as data management integration software, among others, to determine which technologies would have application for WaterSentinel.

Threat. An indication that a harmful incident, such as contamination of the drinking water supply, may have occurred. The threat may be direct, such as a verbal or written threat, or circumstantial, such as a security breach or unusual water quality.

Threat Ensemble Vulnerability Assessment (TEVA). An NHSRC research program that is a central element in the design of the WS-CWS. TEVA uses an ensemble approach to sensor placement by simulating contaminant insertion at all accessible nodes within a distribution system. The sensor placement algorithm tries to minimize the overall public health impacts across all scenarios, which favors detection of attacks that occur at nodes that produce the greatest impact.

Threat Evaluation. Part of the threat management process in which all available and relevant information about the threat is evaluated to determine if the threat is ‘possible’ or ‘credible’, or if a contamination incident has been ‘confirmed.’ This is an iterative process in which the threat evaluation is revised as additional information becomes available. The conclusions from the threat evaluation are considered when making response decisions.

Threat Management. The process of evaluating a contamination threat and making decisions about appropriate response actions. The threat management process includes the parallel activities of the threat evaluation and making response decisions. The threat management process is considered in three stages: ‘possible’, ‘credible’, and ‘confirmatory.’ The severity of the threat and the magnitude of the response decisions escalate as a threat progresses through these stages.

Threat Warning. An unusual occurrence, observation, or discovery that indicates a potential contamination incident and initiates actions to address this concern.

Timeline Analysis. Contamination incident timelines illustrate the time over which consequences resulting from a drinking water contamination incident would develop in a population, and the time at which various detection and intervention strategies might be effective, thus providing a rational basis for the WS-CWS design.

Vulnerability Assessment. A systematic process for evaluating the susceptibility of critical facilities to potential threats and identifying corrective actions that can reduce or mitigate the risk of serious consequences associated with these threats.

Water Contamination Incident. A situation in which a contaminant has been successfully introduced into the system. A water contamination incident may or may not be preceded by a water contamination threat.

Water Contamination Threat. A situation in which the introduction of a contaminant into the water system is threatened, claimed, or suggested by evidence. Compare water contamination threat with water contamination incident. Note that tampering with a water system is a crime under the Safe Drinking Water Act as amended by the Bioterrorism Act.

Water Laboratory Alliance (WLA). A network of laboratories with extensive capability for the analysis of water samples for a wide range of potential contaminants. It is proposed that the WLA integrate existing water quality labs with the existing Laboratory Response Network, established by CDC to support analysis of potential biothreat agents.

WaterSentinel. WaterSentinel is a robust, comprehensive monitoring and surveillance program that integrates elements of a contamination warning system (CWS) to inform response decisions and minimize public health and economic impacts.

Witness Account. A threat warning may come from an individual who directly witnesses suspicious activity, such as trespassing, breaking and entering, or some other form of tampering. The witness could be a utility employee, law enforcement officer, citizen, etc.

Appendix C: Overview of Related Projects

EPA anticipates that WS would build on and integrate water security activities and programs developed by EPA's Water Security Division and National Homeland Security Research Center (NHSRC) to enhance the design and implementation of the WS-CWS at a pilot utility. Key EPA programs and projects that plan to be leveraged to support the WS program are described below.

In addition to these efforts, EPA is working closely with stakeholders and partner organizations to identify and participate in projects related to elements of CWS design and implementation. Information from these efforts has been and continues to be considered throughout the various phases of the WS program. Examples of related CWS efforts include the following:

- AWWA Utility Users Group
- California Utilities Contamination Warning System Workgroup
- California Space Authority Water Monitoring Project
- AWWA Consumer Complaint Management
- Water Quality Monitoring and Event Detection Project (Charleston, SC)
- Wireless Underwater Telemetry System for Surface Water Quality Monitoring (Water Telemetry work)
- NJ American/Rutgers/USGS Consortium
- Region III Security Project 'Drinking Water Distribution System Early Warning Monitoring System for the District of Columbia'
- Hydra Remote Monitoring System
- Department of Homeland Security (DHS) Study of the Municipal Water System

Threat Ensemble Vulnerability Assessment (TEVA) Research Program

NHSRC's Threat Ensemble Vulnerability Assessment (TEVA) research program has been a central element in the design of the WS-CWS, particularly the online monitoring aspects of the system. TEVA is a suite of software tools for water security that can be used to assess the consequences of contamination events in distribution systems, design online monitoring networks, and evaluate mitigation strategies. TEVA uses an ensemble approach to sensor placement by simulating contaminant introduction at all accessible nodes within a modeled distribution system. The sensor placement algorithm uses an optimization routine to minimize the overall public health impacts across all scenarios, which favors detection of attacks that occur at nodes that produce the greatest impact (Murray, et. al., 2004).

TEVA's computational framework integrates an extended period simulation hydraulic model, exposure models, fate and transport models, disease transmission models, and numerous detection models. The program's approach to distribution system modeling for the purpose of sensor placement is ideally suited to the development of a CWS. In developing the general system architecture for WS, EPA used TEVA to simulate the consequences of a large number of different contamination scenarios, which were subsequently analyzed to evaluate the timing of detection and response, through various CWS strategies. These timelines were used to assess which strategies potentially provided the greatest opportunity for intervention in a drinking water contamination incident. In addition, the cost-benefit algorithm in TEVA would be used during design and implementation of the WS-CWS at the WS pilot utility to maximize the benefit in terms of increased protection per unit cost (Murray, et. al., 2005).

The TEVA Program has partnered with AWWA's Water Utility Users Group in order to ground truth the software tools on real drinking water distribution systems. When the WS project evolves to promote the design and implementation of CWSs at other utilities, the TEVA tools can be applied to the distribution system of each utility to establish the number and location of sensor and sampling locations. EPA expects that the experience gained from TEVA would also aid in the development of utility-specific contamination incident timelines to better understand the consequences of a drinking water contamination incident over time in a population, and the time at which various detection and intervention strategies might be effective, thus providing a rational basis for the WS-CWS design.

Directly in support of WS design and implementation and as Phase 2 of the TEVA research program, NHSRC is designing a comprehensive field study to assess the utility-specific system architecture design for the CWS, and verify performance. EPA anticipates that the field study would be implemented at the participating pilot drinking water utility to support the evaluation and implementation of the WS-CWS components at the pilot utility, including measures of online monitoring system performance, consumer complaint assumptions, and the effectiveness of the sampling and analysis protocols for routine and triggered monitoring.

Design of the field studies would be reviewed by subject matter experts before implementation, and the results of the studies documented and evaluated thoroughly to address any need for refinements of the utility-specific system architecture design or the implementation of the various components.

Public Health Syndromic Surveillance Pilots

Design and implementation of the WS program's public health surveillance component is aided by pilot programs in this area being led by EPA's NHSRC. The Center currently is conducting a multi-year, multi-phase demonstration project to integrate water quality and consumer complaint data from drinking water utilities with municipal syndromic surveillance data (Clayton, et. al., 2005). The goal of the pilots is to assess the value of these additional data streams in detecting accidental and intentional drinking water contamination events, which directly supports this aspect of the WS program, as well. EPA is conducting this project by working with pilot cities that already use nationally recognized public health syndromic surveillance systems, including Real-time Outbreak and Disease Surveillance (RODS) and Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE).

EPA anticipates that the public health syndromic surveillance demonstration project would consist of the following elements:

- Development of system interfaces to display integrated data for use by local water utilities and local public health officials to review and evaluate signals
- Sharing of anomaly alerts between a water utility and all public health agencies within the utility's service area
- Integration of near real-time data from the drinking water utility potentially including: water quality data, security incidents, and consumer complaints into existing public health surveillance systems
- Evaluation and analysis of results, as well as guidance for future integration efforts

EPA expects that results of these demonstration projects would inform the integration of water quality and syndromic surveillance data during the WS pilot. Participants in these projects should also inform aspects of data analysis, credibility determination, and consequence management as they relate to public health. Their analysis should help define and validate detection and response assumptions related to coordination and integration with the drinking water utility and local public health department.

Technology Testing and Evaluation Program (TTEP)

The EPA NHSRC's Technology Testing and Evaluation Program (TTEP) aims to provide independent assessments of water-security related technologies considered for use in WS. The program tests and reports on the performance of technologies for use by the water industry, including technologies specifically related to water security. In support of WS, it is anticipated that TTEP would develop a standardized approach for the evaluation of commercially available event detection software and would evaluate promising software for inclusion in the WS pilot and further evaluation. TTEP would also conduct additional water quality sensor evaluations for technologies that could be integrated into future iterations of the WS-CWS. Additional studies evaluating the impact of various contaminants on the target water quality parameters would also be conducted through TTEP. Continued evaluation of other monitoring technologies and field test equipment should support various WS components and site characterization activities. EPA anticipates that the results of these studies would be available on TTEP's website and can be used by utilities to select the technologies appropriate to each individual system.

Water Quality Sensor Studies

This is a program led by NHSRC to evaluate the sensitivity of water quality sensors and the potential use of water quality parameters to indicate the presence of a contaminant in water is being leveraged to support the selection of sensors and parameters for WS. EPA initiated the program in 2003 to investigate online sensors that monitor for standard drinking water parameters that could be used to trigger a contamination event within a drinking water distribution system and support CWS approaches being considered by water utilities. Research is conducted under this program on a pilot-scale system using a recirculating, pipe-loop distribution system simulator (DSS). The simulator is located at the Water Awareness Technology Evaluation Research and Security (WATERS) Laboratory within EPA's Test and Evaluation (T&E) Facility in Cincinnati, Ohio.

Water quality parameters evaluated through this program include pH, free chlorine residual, oxidation/reduction potential (ORP), dissolved oxygen, specific conductance, turbidity, total organic carbon (TOC), chloride, ammonia, and nitrate. Based on initial research, free and total chlorine residual, TOC, ORP, specific conductance, and chloride were consistently able to indicate a change in water quality due to injections of various contaminants into the pipe-loop (Hall, et al, 2005). In support of the WS program, additional research should be conducted to evaluate the effects of WS baseline contaminants on water quality parameters (USEPA, 2005h).

Sampling Guidance

EPA's WSD is developing detailed guidance for the sampling of chemical, radiological, or biological agents in drinking water to address all activities associated with sampling for chemical, radiological, and biological agents in drinking water, including sample collection and sample handling for samples collected in response to a trigger from one or a combination of CWS information streams (sample guidance). The guidance would describe the steps for sampling all potential WS baseline contaminants and contaminant classes.

The sampling guidance is aimed at individuals directly involved in collecting samples for analysis. The methods contained in the guidance would apply to both non-emergency uses, such as routine monitoring, determining background concentrations of WS baseline contaminants; as well as emergency response related to a possible breach of security. The guidance may supplement a utility's emergency response plan to provide more detailed sampling procedures for drinking water utility personnel during a possible contamination event.

Protocol for Analysis of Samples that Contain Unknown Contaminants (Unknowns Protocol)

EPA's WSD is developing a protocol for the analysis of samples that contain unknown contaminants that can help any water utility in their incident response activities, as well as the WS pilot utility, if a potential contamination incident is investigated (USEPA, 2005f). EPA anticipates that the 'unknowns protocol' would present staged analyses for chemical, radiological, and/or biological agents in drinking water to help narrow down, and ultimately identify, the contaminant(s) in the sample. The protocol can also be used to develop laboratory practices and standard operating procedures during contamination events.

The unknowns protocol is aimed at the individuals directly involved in analyzing the samples, and would provide a common-sense management approach to laboratory activities that need to be considered during investigation of a drinking water contamination incident. The protocol for analyzing water samples suspected of containing an unknown contaminant should be robust enough to detect WS baseline contaminants and contaminant classes as well as other contaminants that could be introduced into the drinking water system through intentional or unintentional means.

Although the analytical protocol described should be able to detect WS baseline contaminants and contaminant classes as well as other contaminants, EPA has recognized that not all laboratories would have all of the instrumentation listed in the protocol. EPA anticipates that guidance would be provided on how to prioritize in-house analytical capabilities and determine what steps can be taken in the event of a contamination incident.

Water Laboratory Alliance

EPA's WSD worked with technical experts and stakeholders in the drinking water community to design a conceptual framework for the Water Laboratory Alliance, a laboratory network that would support the WS-CWS and provide surge capacity in the event of a water contamination threat or incident (USEPA, 2004b). EPA plans to integrate the Water Laboratory Alliance with the existing Laboratory Response Network (LRN) to supplement the network's existing clinical analysis capability with environmental analysis capability, including presumptive analyses by utility laboratories. EPA anticipates that the Water Laboratory Alliance would also be integrated with EPA's eLRN to leverage aspects of their toxic industrial chemical and chemical warfare capability and laboratories. In addition to working closely with existing laboratory programs, as part of the Water Laboratory Alliance program development, EPA plans to develop a protocol for availability and access to standards and reagents, implementation of performance evaluation (PE)/proficiency testing (PT), and training programs and laboratory drills.

Method Development and Validation for Pathogens

In response to the need for monitoring and detection of pathogens and based on the WS contaminant selection process, the EPA WSD is standardizing and validating culture-based and molecular methods for five pathogens (*Bacillus anthracis, Burkholderia pseudomallei, Francisella tularensis, Salmonella typhi, and Vibrio cholerae*) and is working with NHSRC, the U.S. Army's Edgewood Chemical and Biological Center (ECBC), and CDC to leverage new methods being evaluated at ECBC and current techniques used by CDC. EPA WSD is already standardizing the culture-based methods concurrent with an on-going evaluation of method detection limits for these same methods at ECBC. Independent validation studies would be conducted on the standardized methods to verify the procedures' performance at laboratories representative of those that would use the methods during the WS pilot and in overall water security support.

In addition to ongoing assessments of the suitability of the molecular methods for these five pathogens being developed at ECBC, EPA WSD is also evaluating commercially available molecular method options. Evaluation criteria include performance, ease-of-use, and ability to implement for use as part of the WS pilot. After the assessments are complete, WSD aims to move forward with method standardization and validation, similar to the process already underway for the culture-based methods.

Method Development and Validation for Chemicals and Biotoxins

EPA's WSD is developing methods for chemicals and biotoxins for which no validated drinking water methods currently exist. EPA anticipates that these methods would respond to the need for monitoring and detection of hazardous contaminants that would result in high mortality rates or have the potential for major public health impacts. As part of this program, EPA WSD plans to expand the list of contaminants already validated for existing drinking water methods to include contaminants of concern identified by WSD, thereby simply expanding proven analytical techniques currently used by environmental laboratories to include WS baseline contaminants where these are not already included in the scope of the method.

EPA anticipates that single laboratory validation and lowest concentration minimum reporting limit studies for these methods would begin after the study plans are finalized.

Water Contamination Information Tool

The Water Contaminant Information Tool (WCIT) is a secure, online database under development to provide information on contaminants of concern for water security. As a planning tool, WCIT can be used to help create and update vulnerability assessments, emergency response plans, and site-specific response guidelines. As a response tool, WCIT can be used to provide real-time data on water contaminants to help first responders (including utilities) make better decisions. In addition, EPA anticipates that WCIT would help determine what information about priority contaminants is missing, which would direct future research efforts. Contaminant specific information contained in WCIT can be used in support of the WS pilot implementation in areas related to monitoring and surveillance, laboratory analysis, and consequence management. For example, a utility could use WCIT as a tool to identify tastes and odors associated with a particular contaminant. Also, if a utility receives a notification from public health related to certain symptoms, WCIT could be used as a tool to assist in the credibility determination process to identify contaminants associated with these symptoms based on exposure to contaminated drinking water.

NEMI-CBR

The National Environmental Methods Index–Chemical, Biological, Radiological (NEMI-CBR) developed jointly by the EPA Standards and Risk Management Division (SRMD) and the U.S. Geological Survey is an additional source of information on analytical methods that could be used to support WS sampling and analysis activities. NEMI-CBR is a web-based database for locating, evaluating, comparing, and retrieving analytical methods for chemical, biological, and radiological-related contaminants in water. NEMI-CBR includes methods for both screening and confirmation and provides multiple methods for the same analyte, where applicable. The companion Expert System, CBR Advisor, is linked to NEMI-CBR and provides advice (based on EPA's *Response Protocol Toolbox*) for evaluating threats, safely collecting samples, and selecting the best method for a given situation, even when the contaminant identity is unknown. NEMI-CBR is designed to be used as a planning and training tool by laboratories in preparation for an intentional or accidental contamination event from chemical, biological, and radiochemical agents.

SAM

EPA's *Standard Analytical Methods for Use During Homeland Security Events* (SAM) compendium also provides yet another resource for analytical methods and considerations for implementation that could be leverage to support WS sampling and analysis activities. SAM provides pre-selected methods (validated and non-validated) that could be used in a terrorism event in which multiple laboratories would be involved. SAM specifies one method per contaminant/matrix combination to enable sample loads to be shared among laboratories while maintaining data comparability and to simplify the task of outsourcing analytical support to the commercial laboratory sector. The single-method approach also would improve the data validation efficiency. SAM includes only confirmatory methods for analytes in a number of matrices (solid, oily-solid, aqueous/liquid, drinking water, air, surface, and dust) and is intended to be used when the agency responsible for managing response to an incident determines that multiple laboratories are needed for sample analysis during an event. The current version of the SAM document can be found at: http://www.epa.gov/ordnhsrc/pubs/reportSAM092905.pdf.