Water Security Initiative: Cincinnati Pilot Post-Implementation System Status

Covering the Pilot Period:
December 2005 through December 2007

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Executive Summary

The Water Security (WS) initiative is a U.S. Environmental Protection Agency (EPA) program that addresses the risk of intentional contamination of drinking water distribution systems. Initiated in response to Homeland Security Presidential Directive 9, the overall goal of WS is to design and deploy contamination warning systems for drinking water utilities. EPA is implementing the WS initiative in three phases: (1) development of a conceptual design that achieves timely detection and appropriate response to drinking water contamination incidents; (2) demonstration and evaluation of the conceptual design in full-scale pilots at drinking water utilities; and (3) issuance of guidance and conduct outreach to promote voluntary national adoption of effective and sustainable drinking water contamination warning systems.

This report addresses the second phase of the program, specifically a description of the initial pilot as implemented in Cincinnati, Ohio. EPA's objectives for this initial pilot were to demonstrate the conceptual design for a contamination warning system and to gain experience that would support the development of guidance and tools for other drinking water utilities. As shown in this report, these objectives are being achieved.

ES.1 Contamination Warning System Conceptual Design

The Cincinnati contamination warning system was designed to detect contamination incidents, both intentional and accidental. Such incidents are presumed to be extremely rare and uncertain with respect to contaminant type, location, time, and duration. These factors required the system to be designed around the following robust set of objectives:

- Detect a broad spectrum of potential contaminants that could cause harm to the public or cause disruption in service
- Provide spatial coverage of the entire distribution system
- Detect contamination incidents in sufficient time for implementation of response actions that reduce public health and economic consequences
- Reliably indicate a contamination incident with a minimum number of false-positives
- Provide a sustainable architecture to monitor the distribution system for general water quality objectives as well as detection of potential contamination incidents

Consideration of these objectives resulted in a multi-component approach to contaminant detection, as shown in **Figure ES-1** and briefly described below:

- **Online water quality monitoring** involves monitoring for typical water quality parameters throughout the distribution system, and comparison with an established baseline to detect possible contamination incidents.
- **Sampling and analysis** involves the collection of distribution system samples that are analyzed for various contaminants and contaminant classes for the purpose of establishing a baseline of contaminant occurrence (contaminants detected, levels detected and frequency of detections) and method performance, and for investigating suspected incidents.
- **Enhanced security monitoring** includes the equipment and procedures that detect and respond to security breaches at distribution system facilities.
- **Consumer complaint surveillance** enhances and automates the collection and analysis of calls by consumers reporting unusual water quality concerns and compares trends against an established baseline to detect possible contamination incidents.
- **Public health surveillance** involves the analysis of health-related data sources to identify disease events that may stem from drinking water contamination.

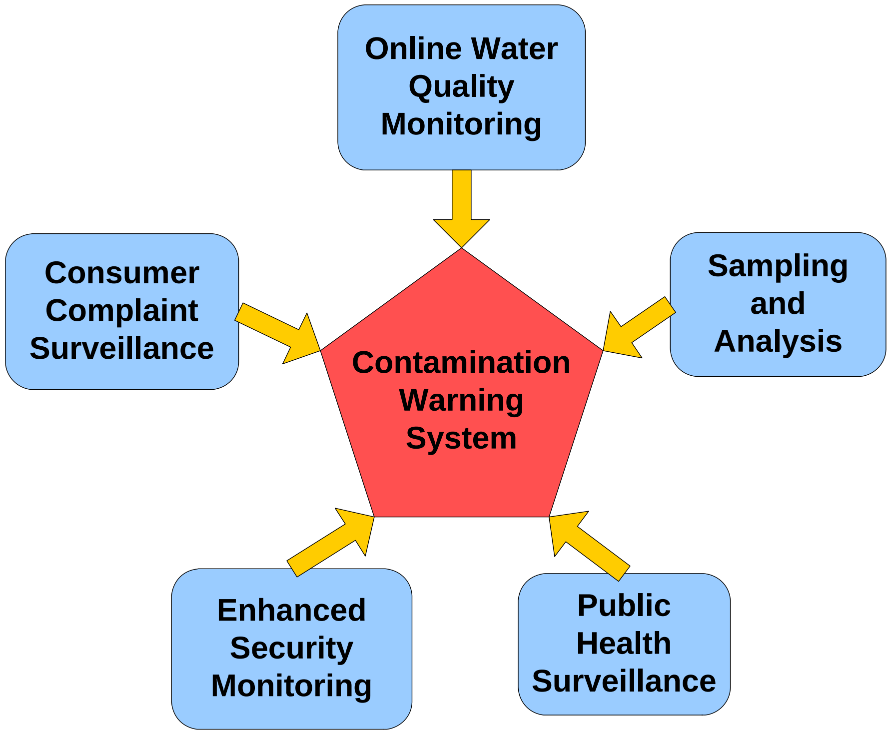

Figure ES-1. Multi-Component Approach to Contamination Warning System Design

These monitoring and surveillance strategies have a history of use in the utility industry or public health sector. While application of these strategies to drinking water contamination warning systems is a new concept, use of familiar systems and equipment provides a sustainable platform for contamination warning system design. Furthermore, integration of data from multiple, independent data streams increases contaminant and spatial coverage, timeliness of detection, and reliability of information from the system.

The WS system architecture also includes extensive consequence management planning that describes procedures for investigating and responding to possible contamination incidents detected through routine monitoring and surveillance. Once a possible contamination incident has been identified, the consequence management plan defines a process for establishing the credibility of the suspected incident. This plan also describes response actions that may be taken during and following the investigation to minimize public health and economic consequences and ultimately restore the system to normal operations.

ES.2 Process for Pilot Deployment

The process for deploying the initial pilot is illustrated in **Figure ES-2** and includes stages for planning through evaluation and refinement. This report describes the status of the initial pilot following completion of the implementation stage. Planning and pre-design activities for the Cincinnati pilot began in December 2005. Significant implementation activities were completed in July 2007, with additional activities continuing for some components through December 2007 in preparation for preliminary testing of the system.

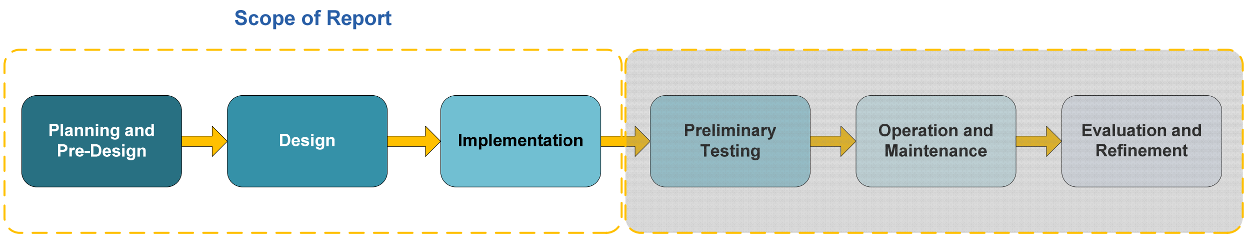

Figure ES-2. Deployment Process for the WS Contamination Warning System Pilot in Cincinnati

Because there was no experience base for deployment of a comprehensive contamination warning system at a drinking water utility, EPA had an active and direct role in the design and implementation of the first pilot. To facilitate this role, a Cooperative Research and Development Agreement was established between the City of Cincinnati and EPA. This Agreement allowed the pilot to be developed as a joint effort between the City and EPA, and provided an opportunity for EPA to evaluate the system and compile lessons learned to the benefit of the drinking water industry.

Design and implementation of the Cincinnati pilot was coordinated through a joint management team including staff from the Greater Cincinnati Water Works (GCWW) and EPA. This team developed an overarching work plan and schedule to prioritize and coordinate activities across the many additional teams established to design and implement the components of the pilot. As shown in **Figure ES-3**, a number of local, state, and federal partners were involved in implementation of the pilot, and the integrated project management team helped coordinate work with these key partners.

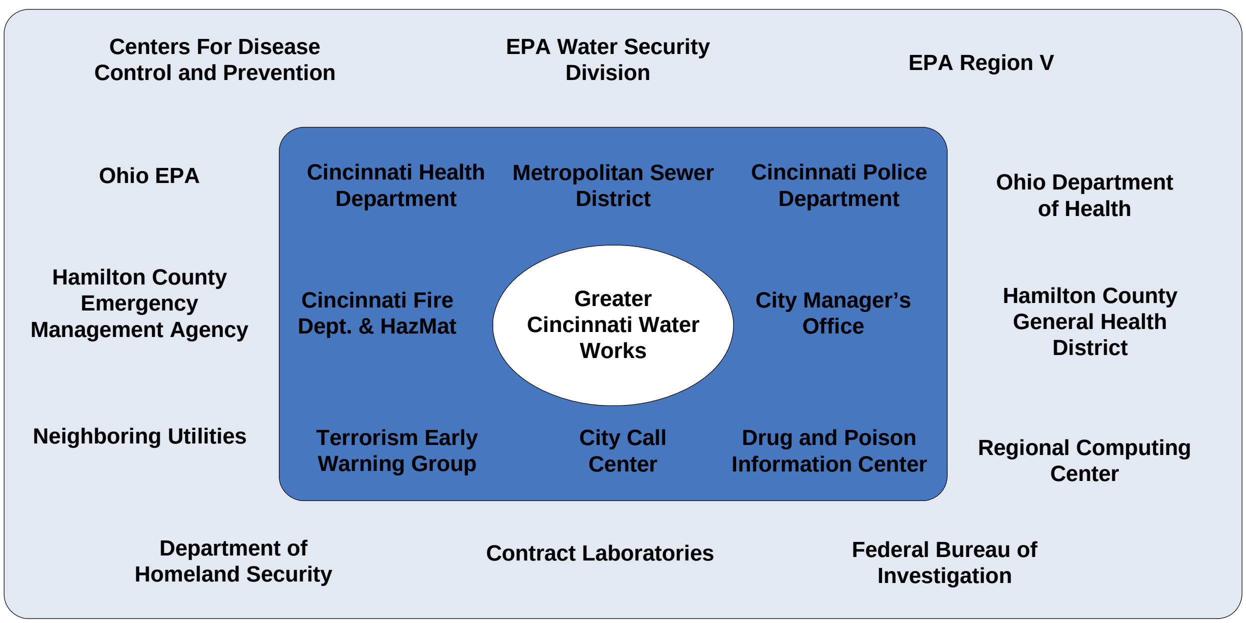

Figure ES-3. Partner Organizations Involved with Implementation of the Cincinnati Pilot

ES.3 Components of the Cincinnati Contamination Warning System Pilot

One of the overarching goals of the pilot was to integrate information across the various components to more effectively meet system design objectives (e.g., spatial coverage, contaminant coverage, timeliness of detection, etc.). To achieve this goal, operational procedures and information management systems were integrated across components whenever possible. Operational procedures took the form of a "concept of operations" that aligned alarm investigations with routine utility job functions. Information management was integrated by first identifying commonalities among component information technology requirements, and then implementing enhancements that met the collective requirements. Also, centralized database and application servers were deployed to serve multiple components. These system-level enhancements and coordination provided a foundation for developing the five (5) monitoring and surveillance components and the consequence management plan.

The online water quality monitoring component was designed to expand GCWW's existing monitoring capabilities to improve contaminant coverage, spatial coverage, timeliness of detection, and reliability. Four main design elements were addressed for this component:

- **Water quality monitoring equipment**. Each monitoring station is equipped with sensors for chlorine residual, total organic carbon, conductivity, pH, temperature, and oxidation reduction potential, which provides comprehensive coverage of contaminant classes considered in the WS design basis.
- **Water quality monitoring network**. Seventeen (17) water quality monitoring stations were installed throughout the GCWW distribution system to maximize the spatial coverage and timeliness of detection. Optimal monitoring locations were identified through application of the Threat Ensemble Vulnerability Assessment, Sensor Placement Optimization Tool.
- **Data management and communication**. A dedicated communication network and SCADA system were installed to enable the transmission, collection, and display of water quality data in near real-time to system operators. Communication equipment was installed at each site to transmit water quality data to the SCADA system via a digital cellular network.
- **Water quality event detection**. Two event detection systems were installed and trained/configured to continually analyze data from the seventeen (17) monitoring stations in order to detect anomalies that might be indicative of contamination. If an anomaly is detected, it is investigated in accordance with the concept of operations.

The sampling and analysis component of the Cincinnati pilot was designed to expand GCWW's ability to analyze for priority contaminants, as well as additional non-targeted contaminants during the investigation of a possible contamination incident. Three main design elements were addressed for this component:

- **Laboratory capability and capacity**. Through a combination of enhancements to GCWW's laboratory capabilities, partnering with the Ohio State Health Laboratory and local utility laboratory, and contracting with commercial laboratories, a laboratory network was established capable of analyzing for ten (10) out of twelve (12) priority contaminant classes.
- **Sampling and analysis**. A baseline monitoring program was designed and implemented to characterize contaminant occurrence (contaminants detected, levels detected and frequency of detections) and method performance in samples throughout the distribution system. Protocols for investigating possible contamination using the same methods implemented during baseline monitoring were also established.
- **Field screening and site characterization**. Site characterization procedures were developed, and local HazMat response teams were involved in the development of those procedures. Additional field screening equipment was provided to both GCWW and HazMat teams, and triggered sampling kits were assembled to allow for rapid response.

The enhanced security monitoring component was designed to provide early warning of intrusion at critical distribution system facilities, which could provide an opportunity for contamination of large quantities of water. Three main design elements were addressed for this component:

- **Physical security equipment**. Video cameras, motion sensors, and door contact switches were installed at three (3) large pump stations to enable visual identification of a potential intruder with intent to contaminate water. Ladder motion sensors were installed at seven (7) elevated storage tanks to detect potential intruders. Vent housings were installed on reservoirs and tanks.
- **Data management and communication**. A dedicated SCADA system was installed to collect and display security alarms and video clips in near real-time to system operators.

Communication equipment was installed at each site to transmit alarms and video clips to the GCWW control center via a digital cellular network.

- **Component response procedures**. Existing partnerships with local law enforcement agencies were leveraged to support the investigation of security breaches in accordance with the concept of operations.

The consumer complaint surveillance component built on GCWW's existing consumer complaint management system to improve the timeliness and reliability of detection of possible contamination incidents. Four main design elements were addressed for this component:

- **Comprehensive complaint collection**. GCWW already established a single number for all consumer calls; thus enhancements focused on procedures for funneling water quality calls received by other agencies into the GCWW call management system.
- **Electronic data management**. GCWW's work order system was enhanced to categorize customer calls related to water quality issues. Additionally, the interactive voice response system that greets all callers was enhanced to include a category for water quality issues.
- **Automated and integrated data analysis**. Event detection systems were deployed to continually analyze data from the interactive voice response and work order systems in order to detect anomalies that might be indicative of contamination. The work order system was also enhanced to spatially display water quality related work orders to provide more rapid identification of clustering events that may indicate contamination.
- **Component response procedures**. Procedures were established for timely identification of unusual water quality consumer calls and analysis of potential anomalies relative to an established base-state. The investigation of the anomaly is governed by the concept of operations.

The public health surveillance component leveraged existing syndromic surveillance programs operating in the area, added new data streams, and improved coordination among local partners. These enhancements extended contaminant and spatial coverage, while also improving timeliness of detection and reliability of indicators of potential water-related health episodes. Two main design elements were addressed for this component:

- **Public health data streams**. Existing syndromic surveillance systems for emergency room visits and sale of over-the-counter pharmaceuticals were leveraged for the pilot. Similarly, existing procedures for monitoring and analysis of poison control center calls were enhanced. In addition, systems were deployed to capture new data streams, specifically 911 calls and emergency medical service data applicable to drinking water exposure, in an effort to improve timeliness of detection
- **Communication and coordination**. To improve coordination among the many local health partners and GCWW, a Public Health User's Group was established and meets on a regular basis. Automated email notifications were implemented to notify all partners when a potential water-related health anomaly is detected. The investigation of the anomaly is governed by the concept of operations.

The consequence management component built on existing emergency response plans and partnerships to develop a consequence management plan with procedures that address the unique challenges associated with response to a drinking water contamination incident. Four main design elements were addressed for this component:

- **Contaminant incident response plans**. A Consequence Management Plan was developed to serve as a preparedness and response guide, and a Crisis Communication Plan was developed to guide public notification and risk communication procedures during all phases of a potential contamination incident.
- **Response partner network**. GCWW and response partners established a network to better integrate their roles and responsibilities in the event of a drinking water contamination incident.

- **Training and exercises**. Workshops, table-top exercises, drills, functional exercises, and full scale exercises were conducted to test the Consequence Management Plan and train participants on processes and procedures.
- **Equipment**. Eight 800 MHz hand-held radios were procured to improve communications between GCWW and response partners during field activities in response to a contamination incident.

ES.4 Cost of the Pilot Contamination Warning System

The overall cost for the design and implementation of the Cincinnati pilot, including labor and equipment, was approximately $12.3 million. **Figure ES-4** presents a breakdown of these implementation costs by component. When interpreting the cost data in this report, it is important to consider that this project was the first pilot of a contamination warning system, and that substantial costs were incurred as part of the research required to design and implement this prototypical system. It is expected that the cost to implement a contamination warning system according to the model documented in this report would be lower relative to the cost of the Cincinnati pilot.

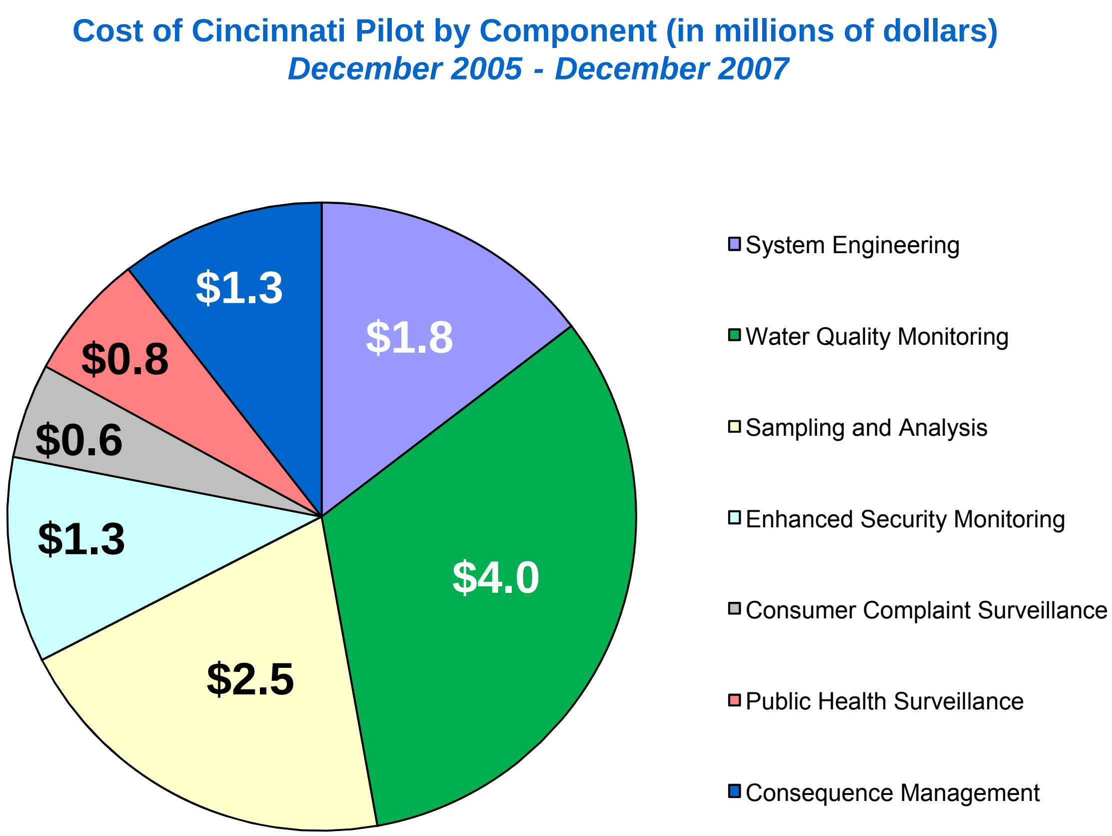

Figure ES-4. Cost Breakdown for Implementation of the Cincinnati Pilot

ES.5 Future of the Pilot Contamination Warning System

The drinking water contamination warning system in Cincinnati has been installed, is fully operational, and is currently generating data needed to establish baseline performance. Use of multiple monitoring and surveillance components provides broad contaminant coverage throughout the core GCWW retail service area, reduces the time for initial detection, and improves the reliability of information generated by the system. Furthermore, use of existing monitoring and surveillance systems that are integrated with routine utility operations provides many opportunities for dual-use applications, resulting in a sustainable system.

Evaluation of the Cincinnati pilot will quantify system performance, derive lessons learned, and assess the cost/benefit of deploying contamination warning systems at drinking water utilities. This information will be critical in development of guidance for drinking water utilities nationwide on effective and sustainable contamination warning systems.

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List of Acronyms

The list below includes acronyms approved for use in the System Status Report. Acronyms are defined at first use in the document.

CDC	Centers for Disease Control and Prevention
CL	Chlorine Residual (Total/Free)
CMP	Consequence Management Plan
COND	Conductivity
CUSUM	Cumulative Sum calculation
CSV	Comma Separated Value
DMZ	Demilitarized Zone
EARS	Early Aberration Reporting System
EDDIES	Event Detection, Deployment, Integration, and Evaluation System
EPA	Environmental Protection Agency
EMS	Emergency Medical Service
GCWW	Greater Cincinnati Water Works
GIS	Geographic Information System
HMI	Human Machine Interface
IVR	Interactive Voice Response
J2EE	Java 2 Platform, Enterprise Edition
LAN	Local Area Network
LOE	Level of Effort
NELAC	National Environmental Laboratory Accreditation Conference (standards)
NHSRC	National Homeland Security Research Center
ORD	Office of Research and Development
ORP	Oxidation Reduction Potential
PLC	Programmable Logic Controller
PTZ	Pan-Tilt-Zoom
RAM-W™	Risk Assessment Methodology – Water™ (Sandia Methodology)
RODS	Real-time Outbreak and Disease Surveillance
SCADA	Supervisory Control and Data Acquisition
SMTP	Simple Mail Transfer Protocol
TEMP	Temperature
TEVA	Threat Ensemble Vulnerability Assessment
TOC	Total Organic Carbon
TURB	Turbidity
UPS	Uninterruptible Power Supply
VOCs	Volatile Organic Compounds
WAN	Wide Area Network
WS	Water Security (initiative)
WSDR	Water Security Data Repository
WUERM	Water Utility Emergency Response Manager

Section 1.0: Overview

The Water Security (WS) initiative is a U.S. Environmental Protection Agency (EPA) program that addresses the risk of intentional contamination of drinking water distribution systems. Initiated in response to Homeland Security Presidential Directive 9, the overall goal of WS is to design and deploy contamination warning systems for drinking water utilities.

As shown in **Figure 1-1**, EPA is implementing the WS initiative in three phases: (1) development of a conceptual design that achieves timely detection and appropriate response to drinking water contamination incidents; (2) demonstration and evaluation of the conceptual design in full-scale pilots at drinking water utilities; and (3) issuance of guidance and conduct outreach to promote voluntary national adoption of effective and sustainable drinking water contamination warning systems.

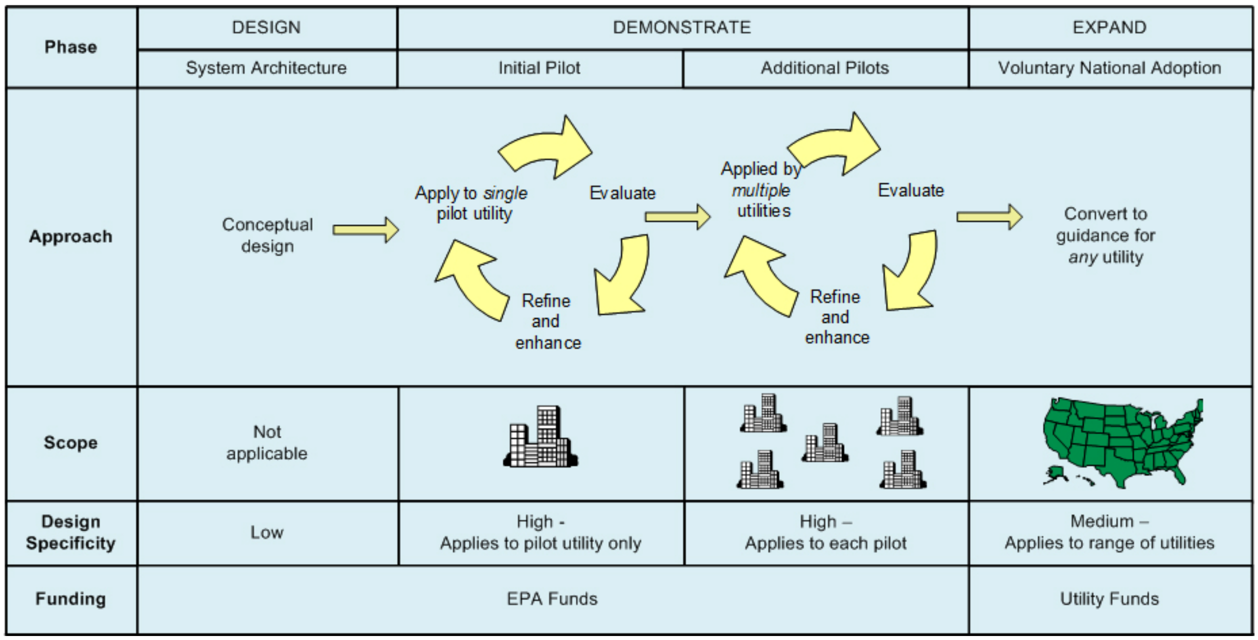

Figure 1-1. Overview of EPA's Water Security Initiative

Conceptual design of a contamination warning system began in 2004 and culminated in the development of the *WaterSentinel System Architecture* (USEPA, 2005a). In the second phase, Cincinnati, Ohio was chosen to demonstrate the initial pilot; implementation of the Cincinnati contamination warning system was complete in December, 2007. This document presents the post-implementation status of the initial pilot system and captures the effort invested to achieve this milestone.

To provide a context for the design of the initial pilot, the conceptual design developed during the first phase is briefly described in the following section. Additional detail on the conceptual design can be found in *WaterSentinel System Architecture* (USEPA, 2005a).

1.1 Conceptual Design of a Contamination Warning System

Significant contamination incidents in drinking water distribution systems are extremely rare, and their characteristics are uncertain with respect to contaminant type, location, time, and duration. Thus, a contamination warning system capable of detecting a wide range of contamination scenarios is designed around the following broad objectives:

- **Detect a broad spectrum of contaminant classes**. As part of the contamination warning system design basis, contaminants were prioritized and then binned into twelve (12) detection classes (USEPA, 2005b). Use of the detection classes to inform design provides more robust detection capability than analyzing for only a select number of contaminants and also avoids the challenge associated with designing a system around a list containing hundreds of potential contaminants.
- **Achieve spatial coverage of the entire distribution system**. Monitoring and surveillance strategies should be deployed throughout the distribution system in a manner that provides broad coverage on both a spatial and population basis.
- **Detect contamination in sufficient time for effective response**. The system should be designed in a manner to reduce the time to initial detection and thus increase the time available for implementation of response actions that reduce public health and economic consequences.
- **Reliably indicate a contamination incident with a minimum number of false-positives.** Information produced by the contamination warning system should lead decision makers to successfully infer that contamination has or has not occurred.
- **Provide a sustainable architecture to monitor distribution system water quality.** The contamination warning system should be designed as a dual-use application to benefit the utility in day-to-day operations while also providing the capability to detect intentional or accidental contamination incidents.

Consideration of these objectives resulted in the WS system architecture shown in **Figure 1-2**. The system is defined by two distinct operational phases: routine operation and consequence management. Routine operation includes the monitoring and surveillance components detailed below in addition to event detection systems designed to mine the large amounts of data produced by the system in order to identify patterns indicative of possible contamination. Consequence management is initiated once a possible contamination incident is identified and includes processes for investigating credibility of possible contamination, confirming an incident, and remediating a contaminated system.

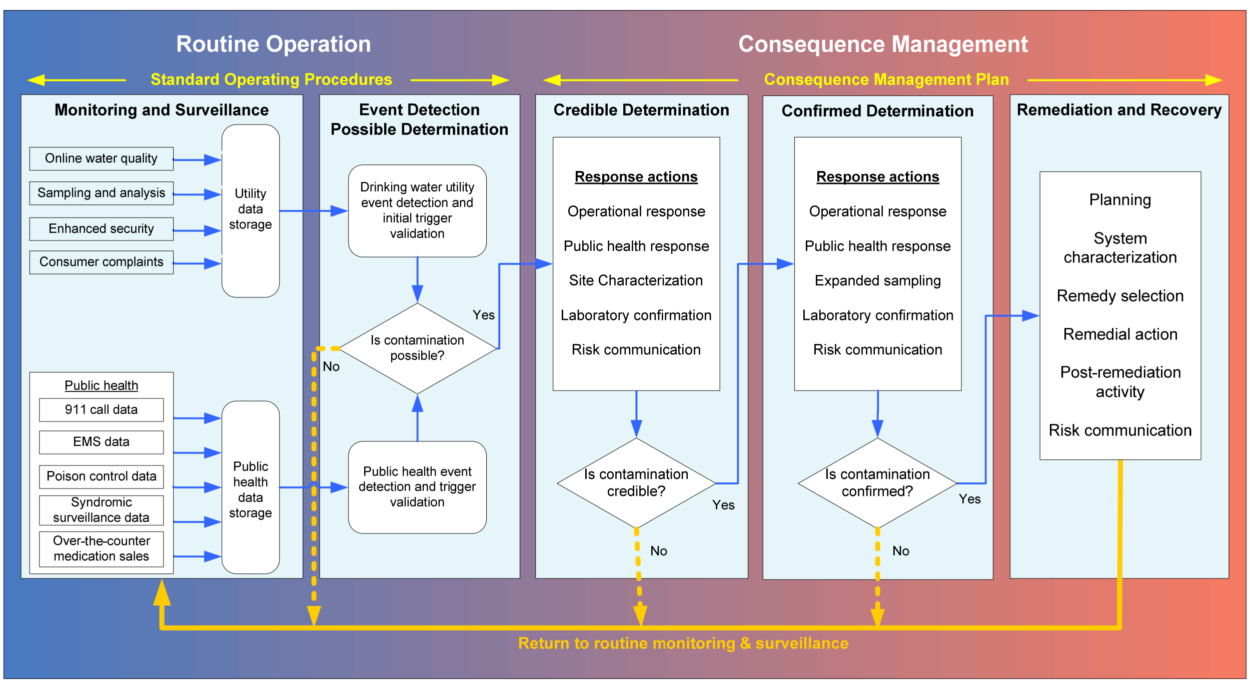

Figure 1-2. Architecture of the WS Contamination Warning System

Routine operation integrates the following multiple monitoring and surveillance components:

- **Online water quality monitoring** comprises stations located throughout the distribution system that measure multiple water quality parameters that have been shown to change in the presence of various contaminants (Hall, 2007a). Algorithms analyze the monitoring data to establish a water quality base-state. Possible contamination is indicated when a significant, unexplained deviation from the base-state occurs.
- **Sampling and analysis** involves the collection of distribution system samples that are analyzed for various contaminant classes as well as specific contaminants. Sampling is both routine to establish a base-state and triggered to respond to an indication of possible contamination from any of the other monitoring and surveillance components. Field and laboratory-based analyses are conducted for chemicals, radiochemicals, pathogens, and toxins using a team of utility personnel and a laboratory network.
- **Enhanced security monitoring** includes the equipment and procedures that detect and respond to security breaches at distribution system facilities. Security equipment may include cameras, motion activated lighting, door contact alarms, ladder and window motion detectors, area motion detectors, and access hatch contact alarms.
- **Consumer complaint surveillance** enhances and automates the collection and analysis of calls by consumers reporting unusual odor, taste, or visual characteristic of the drinking water. Algorithms analyze the call data to establish a base-state. Possible contamination is indicated when a significant, unexplained deviation from the base-state occurs.
- **Public health surveillance** involves the analysis of health-related data sources to identify disease events that may stem from drinking water contamination. Public health data may include over-the-counter sales of pharmaceuticals, hospital admission reports, infectious disease surveillance, emergency medical service (EMS) reports, 911 calls, and poison control center calls. Algorithms analyze the various data streams to establish a base-state and identify deviations from the base-state that could be indicative of a public health incident.

Data from each of these components are captured, managed, analyzed, and interpreted to identify potential contamination incidents. Information from the multiple components is used in combination to expand contaminant and spatial coverage, provide more timely detection, and improve reliability of detections. Furthermore, use of common or existing monitoring and surveillance systems improves acceptance and sustainability of the system.

Event detection is the process or mechanism by which an anomaly or deviation from the baseline or base-state is detected. The approach utilized for event detection may vary significantly from component to component and can range from analysis of data using sophisticated statistical algorithms to comparison of data against simple control limits. In many cases, event detection will also include manual investigation procedures to validate the alarm and establish whether or not contamination is possible. Once a possible contamination incident has been identified through routine monitoring and surveillance, operations shift to the first stage of consequence management – credibility determination.

Credibility determination procedures are performed using information from all monitoring and surveillance components, as well as available external resources. Through the credibility determination process, response partners may be notified and some preliminary response actions may be initiated to limit or minimize impacts of suspected contamination. If contamination is determined to be credible, additional confirmatory and response actions are initiated; if not, the system returns to routine monitoring and surveillance activities. In the confirmatory stage of consequence management, additional information is gathered and assessed in an attempt to provide definitive evidence of contamination. Once contamination is confirmed and the immediate crisis has been addressed through response, remediation and recovery actions defined in the consequence management plan are implemented to restore the system to normal operations.

1.2 Deployment of the Pilot Contamination Warning System

The initial WS pilot was designed according to the conceptual design described in Section 1.1 and illustrated in Figure 1-2. The process for deploying the initial pilot, summarized in **Table 1-1**, includes stages for planning through evaluation and refinement. Additional details on the contamination warning system deployment process are available in *Water Security Initiative: Interim Guidance on Planning for Contamination Warning System Deployment* (USEPA, 2007a). This document describes the status of the initial pilot following completion of the implementation stage in December 2007.

Table 1-1. Overview of the Deployment Process for the WS Contamination Warning System

Stage of Approach	Description
Planning and pre-design	Development of a core implementation team, definition of design objectives to guide implementation, and a preliminary assessment of existing capabilities relative to design objectives.
Design	Development of a preliminary concept of operations, and development of a detailed work plan and schedule to guide implementation.
Implementation	Implementation of enhancements, installation of equipment, and training according to the plan.
Preliminary testing	Operation of the contamination warning system for the purpose of collecting data necessary to understand system performance, and finalization of the concept of operations to optimize system.
Operation and maintenance	Operation of the contamination warning system for the purpose of monitoring for contamination incidents and other water quality issues.
Evaluation and refinement	Analysis of data and information generated during full operation to refine and optimize the system.

This document is intended to serve as a summary of the Cincinnati contamination warning system pilot. The intended audience for this document includes drinking water utility and public health managers and decision officials who wish to gain a broad yet comprehensive understanding of this initial contamination warning system pilot. It may also serve as a case study for contamination warning system implementation. However, this document does not provide detailed technical specifications on the various components, which are available through other documentation referenced throughout this report.

Sections 2 through 8 describe the various components of the initial pilot: overall system integration; each of the five (5) monitoring and surveillance components; and consequence management. For each of these components, the corresponding section describes the pre-existing capability of the initial pilot utility, Greater Cincinnati Water Works (GCWW), and partner agencies, the gap between existing capabilities and the design objectives for the pilot, and the post-implementation status that reflects enhanced capabilities realized through the pilot.

Section 2.0: Project Management and System Integration

The contamination warning system design involves the integration of information from multiple monitoring and surveillance components, coordination across multiple disciplines and organizations, and a planned transition from routine operations to consequence management. Such a complex system requires an integrated, interdisciplinary approach to design and implementation that extends beyond the basic tenets of project management in order to ensure that the components and procedures are integrated into a functional system that meets the design objectives discussed in Section 1.1. Furthermore, the contamination warning system should be implemented in a manner that is consistent with drinking water utility organization and procedures to promote adoption by the large number of staff with a role in its operation.

The desired outcome of the project is an integrated contamination warning system aligned with existing utility operations and partner organizations to the extent possible. To achieve this outcome, three overarching, system-level design objectives were defined for the Cincinnati pilot as shown in **Table 2-1**.

Table 2-1. System-Level Design Objectives

Project Element	Design Objective
1. Comprehensive Project Management	Establish an overarching project management structure to guide implementation, establish priorities, and ensure that project goals are met.
2. Integrated Operational Procedures	Develop procedures and define roles and responsibilities that guide routine monitoring and trigger investigation for each of the monitoring and surveillance components in an effective and efficient manner that is aligned with normal utility activities to the extent possible.
3. Integrated Information Management	Identify data needed for the investigation of alarms and credibility determination. Ensure that the data are available in a timely and effective manner (preferably in an electronic format). To the extent possible, integrate information from different sources to improve overall efficiency in the review process.

2.1 Pre-Implementation Status

The initial pilot was deployed in the City of Cincinnati, with GCWW as the principle local organization in the pilot effort. GCWW is a public drinking water utility serving retail and wholesale customers in the greater Cincinnati area, including wholesale customers in northern Kentucky. On average, GCWW distributes approximately 136 million gallons of water per day through 3,000 miles of distribution mains to approximately 1.2 million retail customers. GCWW operates two treatment plants to provide a reliable source of safe drinking water to all of its customers. The Richard Miller Treatment Plant treats surface water from the Ohio River and provides water to 88 percent of GCWW's customers. The remainder of GCWW's customers are served by the C. M. Bolton Treatment Plant, which treats ground water from the Great Miami Aquifer. Additional information about GCWW can be found at http://www.cincinnati-oh.gov/water/pages/-3026-/.

Prior to implementation of the contamination warning system, GCWW had a management structure in place for overseeing complex projects, procedures for guiding routine utility operations, and an extensive information technology infrastructure. These existing capabilities, described in more detail below, provided an excellent platform for implementation of a complex project such as a contamination warning system.

2.1.1 Comprehensive Project Management

GCWW has a standing Steering Committee chaired by the utility director with leadership from all utility divisions listed in **Table 2-2**. This committee provides a forum for establishing priorities for the utility and directing cross-divisional projects. Because of the multidisciplinary nature of contamination warning system deployment, the Steering Committee served a critical role in coordinating GCWW resources during WS pilot design and implementation. In addition, GCWW also had existing procedures that rely on partnerships with local agencies such as those from public health and law enforcement, some of which are described in Section 2.1.2. These existing partnerships provided a starting point for the development of many new cross-organizational relationships that were necessary for successful implementation of the pilot.

Table 2-2. GCWW Divisions and Responsibilities

Division	Responsibilities
Business Services	Houses the office of the Director, administrative staff, and clerical support; maintains the utility's vehicles, runs the internal storerooms for parts/supplies, and manages the total enterprise asset management system.
Commercial Services	Customer service and billing operations, manages the customer call center, responsible for meter reading and premises inspections; includes administrative and technical support personnel for these functions.
Distribution	Maintenance and repair of the distribution system; including underground water mains, service branches, valves, fire hydrants, and other appurtenances within the right-of-way; respond to leak investigations, low pressure or water quality complaints.
Engineering	Planning, design, and inspection of new and replacement lines in the system and at the treatment plants; also includes records management, survey, field investigation, and contract administration personnel.
Supply	24/7 operation and maintenance of both water treatment plants, and all pumping and storage facilities.
Water Quality & Treatment	Defines treatment at both plants 24/7, responsible for water quality at treatment plants and in distribution system. Performs studies and research to ensure high quality of water and compliance with all regulations at the treatment plants and throughout the distribution system; includes certified laboratory capabilities.
Information Technology*	Maintenance, upgrade and development of the software and hardware systems to support the IT needs of all divisions.

*The Information Technology Division was formed in 2007, during implementation of the pilot. An *Information Technology Roundtable* was in existence prior to the start of the pilot (see Section 2.1.3).

2.1.2 Integrated Operational Procedures

Procedures for routine utility operations within each GCWW division were well established, and many were applicable to contamination warning system operations. For example, GCWW had established procedures with local law enforcement agencies to support investigation of security breaches. This and other examples of existing GCWW procedures relevant to contamination warning system operations are listed in **Table 2-3**, while more detailed discussion of existing operational procedures relevant to component operations is included in Sections 3 through 8.

Table 2-3. Examples of Existing GCWW Procedures Relevant to Contamination Warning System Operation

Existing Procedure	Description
Investigation of Security Breaches	Close partnership established with local law enforcement agencies that had jurisdiction in areas where GCWW facilities were located to coordinate timely response to an investigation of security alarms at these facilities.
Cryptosporidium Action Plan	Plan developed in coordination with local public health agencies to respond to waterborne or water-related threats to public health.
Routine Sampling Routes	Plans and routes that were used for routine sampling and analysis of regulated drinking water parameters.
Daily Chlorine Level Trend Analysis	On a daily basis, staff from the water quality and treatment division would analyze trends in chlorine levels monitored at distribution system facilities (tanks, reservoirs and pump stations) to assess water quality and water age.
Customer Service Representatives	Consumer complaints relating to water quality were directed to specific, appropriately trained/knowledgeable personnel, and a threshold number of calls was established to indicate a possible water quality issue in the distribution system.

While the above procedures have some applicability to contamination warning system operation, they were not developed or optimized for rapid detection of contamination incidents of unknown origin. Nor were the procedures always integrated across divisions and local partners that may need to become involved in the investigation of possible contamination. However, a thorough understanding of these procedures facilitates integration of contamination warning system operations with routine utility operations.

2.1.3 Integrated Information Management

Effective information management and integration is at the heart of a contamination warning system, and thus information technology plays a key role. GCWW utilizes a number of information technology systems to support utility operations; however, many of these systems are isolated from one another making integration a challenge. GCWW recognized the importance of system interoperability for more efficient utility operations, and took steps towards this goal independent of the requirements of a contamination warning system. For example, an Information Technology Roundtable was formed with representatives from all GCWW divisions and information technology systems to improve coordination and planning for information technology related projects. In 2007, GCWW took this a step further and formed an Information Technology Division. GCWW also developed an *Information Technology Strategic Plan* (GCWW, 2006), with one key goal being improved information integration and system interoperability. While the goals of this master plan are consistent with those of a contamination warning system, the timeline for implementation of this plan was not aligned with the schedule for pilot implementation. Thus, a more modest integration strategy had to be developed for the pilot.

A number of existing GCWW information technology systems were leveraged to support the WS pilot; the relevant systems are briefly described in **Table 2-4**. While these systems were not fully integrated, GCWW had implemented a number of standards that made it easier to combine data from multiple systems to support the contamination warning system pilot. One such standard is the use of Oracle as the database platform for all information technology systems, which set the standard for data management in the pilot.

Table 2-4. GCWW Information Technology Systems Relevant to Contamination Warning System Operations

GCWW Information Technology System	Description
Information Technology Infrastructure and Networks	GCWW's information technology environment is served by a combination of Local and Wide Area Networks (LANs and WANs). Ethernet-based LANs are deployed in all major GCWW facilities to provide network services to user workstations and servers, permitting access to the databases for SCADA, EMPAC, and Banner, among others. Individual LANs are interconnected with a WAN operated and maintained by the Cincinnati Regional Computer Center behind a firewall that protects the content, function, and integrity of all systems operating on the WAN.
Water Quality Database	An Oracle database that collects, manages, and reports water quality data related to regulatory compliance, consumer water quality complaint investigations, and results from water quality and treatment studies. A separate Oracle Gas Chromatograph database, containing over 20 million records, stores laboratory analytical results.
Supervisory Control and Data Acquisition (SCADA)	GCWW's SCADA system provides real-time control and monitoring of the treatment plants, pump stations and storage facilities. During the pilot, the system underwent a major upgrade to a Citect system that runs on a Windows platform.
EMPAC	EMPAC is a software application that provides integrated functionality for work orders, inventory, and fixed asset management. The system interfaces with the utility billing system, the PeopleSoft financial system, the City's geographic information system (GIS), the City's human resources system, and the City's financial systems.
DWC / Hydra	DWC is a custom application that integrates GIS functionality with EMPAC, created to manage work in the distribution system not associated with a fixed asset, such as main repairs. The Commercial, Water Quality and Treatment, and Distribution divisions use DWC to create and search for work requests and work orders relating to maintenance of the GCWW distribution infrastructure. Hydra is a web browser user interface to the work order system that replaced DWC over the course of the pilot.
Banner	The Banner billing system is an Oracle-based, enterprise application that manages customer-based information and issues a combined utility billing statement for water, sewerage, fire, and stormwater. It is operated and maintained by the Commercial Services Division.

GCWW Information Technology System	Description
Geographical Information System (GIS)	GIS displays maps and models of the water distribution system that enables users to make better decisions by revealing trends and patterns that are not easily seen in other data presentation formats. GCWW runs ESRI ArcInfo 9x, ArcView 3x, and Gen7, but the ESRI application suite has been extensively customized by the Engineering Division. DWC/Hydra uses some of the shape files that are created by the GIS system, but beyond this there is no integration or direct interfaces between the GCWW GIS and the DWC/Hydra, Banner, and EMPAC applications and databases. GCWW also participates in the Cincinnati Area GIS consortium.

2.1.4 Summary of Identified Gaps

GCWW's existing programmatic and procedural capabilities coupled with an extensive information technology infrastructure provided a solid foundation for the system-level design and management of a contamination warning system; however, modifications and enhancements were necessary to meet the design objectives summarized in Table 2-1. To achieve comprehensive project management for contamination warning system deployment, plans needed to be developed, teams established, and mechanisms put in place to monitor progress and keep the effort aligned with the overarching goals of the pilot. While existing procedures were in place that addressed some elements of contamination warning system operations, they had not been optimized to include all relevant participants nor to resolve possible contamination incidents in a relatively short period of time (e.g., less than a day). GCWW had many information technology systems that were leveraged for the contamination warning system; however, many of these systems operated independent of one another and some lacked capacity or key functionality needed for the pilot. The specific gaps identified for each project element are summarized in **Table 2-5**.

Table 2-5. System-Level Gap Analysis

Project Element	Description of Gap
1. Comprehensive Project Management	A dedicated project management structure needed to be created to support deployment of a contamination warning system, including: developing a project plan and schedule, establishing project teams, establishing agreements, and tracking progress.
2. Integrated Operational Procedures	Existing procedures were not comprehensive for all monitoring and surveillance components and were not optimized for rapid investigation of possible signs of contamination. In many cases, multiple divisions and external agencies needed to be integrated into the operational procedures.
3. Integrated Information Management	Many information technology systems essential to operation of the contamination warning system were not interoperable. There was also a lack of standardization in some key areas, such as storage of geo-spatial information. Some information technology systems, such as SCADA, lacked capacity to support contamination warning system operations. There was not a central repository for contamination warning system information and there were no automated event detection systems.

2.2 Post-Implementation Status

The following section provides the post-implementation status of the contamination warning system pilot with respect to project management and system integration. The gaps identified at the conclusion of the previous section were addressed to the extent possible. The major products resulting from the system integration efforts include: integrated operational procedures, a dedicated data repository for the contamination warning system, and most importantly, an operational contamination warning system consisting of monitoring and surveillance components integrated through procedures that transition seamlessly to consequence management once a possible contamination incident is identified.

2.2.1 Comprehensive Project Management

Deployment of the first WS contamination warning system pilot was a cooperative effort between the City of Cincinnati, led by GCWW, and EPA. This working relationship was formalized through a Cooperative Research and Development Agreement between the City of Cincinnati and EPA (USEPA, 2006a). This agreement established overall project goals, expectations, and responsibilities for the project. The agreement vehicle also allowed EPA to provide equipment and assistance to GCWW, while collecting data from the pilot for use in evaluation and expansion of the program to the benefit of the entire drinking water industry.

As an addendum to this formal agreement a system-level work plan was developed, which established the scope of the project, approach to implementation, and a high-level schedule. While more detailed work plans were necessary for design and implementation of the individual components, this overarching work plan provided an effective means of coordinating, tracking, and prioritizing activities across the entire pilot.

Due to the magnitude of the project, dedicated teams were formed to design and implement each component. Parallel teams were formed by EPA and Cincinnati, and these teams were multidisciplinary to ensure that all aspects of component design and operation were considered. This was particularly important for the information technology elements of each component because many share common hardware or software, and inclusion of information technology representatives on each team helped to ensure that common systems met the needs of all components relying on those systems. For example, a SCADA system was installed parallel to GCWW's existing system to manage and display information for both the water quality and enhanced security monitoring components.

While the Cincinnati component teams were largely made up of staff and supervisors from the various GCWW divisions listed in Table 2-2, a number of local partners were involved in various aspects of pilot implementation. **Table 2-6** lists the partners with the most substantial involvement during design and implementation of the contamination warning system and provides a summary description of their roles. By far, consequence management involved the largest number of external partners; a more complete listing of these partners and their respective roles and responsibilities in consequence management is provided in Section 8.

Table 2-6. Local Partners Providing Support to GCWW during Implementation of the WS Pilot

Local Partner	Role in Contamination Warning System Implementation
Cincinnati Fire Department	• Host several water quality monitoring stations • Host sampling locations for the sampling and analysis component • Data provider for public health surveillance (911 and EMS data) • Supported development of the consequence management plan • Provide field response and HazMat support during consequence management
Cincinnati Health Department	• Informed design of public health surveillance systems to meet pilot objectives • Monitor public health surveillance systems and investigate anomalies detected by the systems • Supported development of the consequence management plan • Provide information and consultation during consequence management
City Call Center	• Implemented procedures to funnel water quality calls to GCWW's call center
City Council	• Approved the charter to enter into a cooperative research and development agreement with EPA to launch the first WS pilot
City Facilities and Maintenance	• Facilitated site selection and installation activities for water quality monitoring stations located at city facilities • Supported the installation of wireless routers at Cincinnati Fire Department stations for public health surveillance
City Manager's Office	• Entered the City of Cincinnati into the cooperative research and development agreement with EPA to launch the first WS pilot • Supported development of the consequence management plan • Provides support for risk communication during consequence management
Contract Laboratories	• Provide support and surge capacity for chemical analyses

Local Partner	Role in Contamination Warning System Implementation
Drug and Poison Information Center	• Data provider for public health surveillance • Informed design of public health surveillance systems to meet pilot objectives • Monitor poison control center calls and investigate anomalies as appropriate • Provide information and consultation during investigation of a suspected contamination incident
Greater Cincinnati HazMat Team	• Provide field response and HazMat support during consequence management
Hamilton County Emergency Management Agency	• Supported development of the consequence management plan • Coordinate alternate water supplies during consequence management
Hamilton County Public Health	• Informed design of public health surveillance systems to meet pilot objectives • Monitor public health surveillance systems and investigate anomalies detected by the systems • Supported development of the consequence management plan • Provide information and consultation during consequence management
Local Fire Departments	• Host several water quality monitoring stations
Local Law Enforcement Agencies	• Host one water quality monitoring station • Investigate reported security breaches at GCWW facilities • Supported development of the consequence management plan • Lead the criminal investigation and related support during consequence management
Metropolitan Sewer District	• Provide analytical support for baseline and triggered sampling • Supported development of the consequence management plan
Ohio Department of Health	• Perform analysis of baseline and triggered samples for select biological agents and radiochemicals • Supported development of the consequence management plan
Ohio EPA	• Supported development of the consequence management plan • Provide support for risk communication and remediation/ recovery issues
Regional Computer Center	• Reviewed and approved all information technology architecture using the City's wide area network • Supported the design and implementation of comprehensive call management for the consumer complaint surveillance component
Terrorism Early Warning Group	• Serve as a hub of law enforcement intelligence in the region, and provide support during credibility determination

During implementation of the Cincinnati pilot, a large amount of equipment was procured and installed throughout the GCWW service area. The project management team implemented a comprehensive tagging and tracking system to ensure that all equipment was accounted for as well as to assist in monitoring maintenance activities. Each piece of equipment with substantial value, typically over $1,000, was tagged with both EPA and GCWW property tags. The information for each piece of equipment was entered into a database used for periodic inventories. This information was also entered into GCWW's asset management system to facilitate transfer of ownership to Cincinnati.

More than 70 documents were developed during design and implementation of the Cincinnati pilot. They include assessment reports, requirements documents, design documents, as-built drawings, operating procedures, operations and maintenance guides, and training materials. In order to track and maintain version control of this extensive compilation of documentation, a document inventory / library was developed. The library serves as a valuable resource by allowing all GCWW and EPA personnel to quickly locate specific documentation and verify that the version is current.

2.2.2 Integrated Operational Procedures

To support routine operation of the Cincinnati pilot, it was necessary to develop an operational strategy that fulfilled the primary objective of a contamination warning system – timely detection of contamination incidents – that was also aligned with utility operational procedures. Consideration of typical utility operational procedures during development of a contamination warning system operational strategy will help to integrate the system into routine operations, which is essential to the long-term sustainability of the system. For the Cincinnati pilot, the operational strategy took the form of a document titled *Concept of Operations for the GCWW Contamination Warning System* (USEPA, 2007b).

The overarching objective of the Cincinnati concept of operations is to describe the processes and procedures involved in routine operation of the contamination warning system, including the initial investigation of alarms. To achieve this objective, it establishes specific roles and responsibilities, process and information flows, and checklists to support the systematic review of alarms. Process flow diagrams describe the sequence of activities that are performed during the detection and investigation of alarms and system anomalies. The information flow diagrams identify information technology systems, databases, and user interfaces used during routine monitoring and surveillance, event detection, and alarm investigation. Checklists were developed for each job function involved in contamination warning system operations and are intended to guide users through the investigation of alarms.

While the operational strategy does deal with monitoring and surveillance activities for individual components, the overall operational strategy had to be integrated across the entire system to ensure that investigational procedures and job functions were consistently defined throughout the system. This was achieved through a three-stage development process that included: 1) conducting a system-level resource assessment; 2) developing a concept of operations for each individual component; and 3) conducting a system-level review and revision to ensure that common elements of the concept of operations are consistent across all components.

Once the operational strategy for the Cincinnati contamination warning system was developed, training materials were developed and used to orient front-line staff and supervisors on system operations.

2.2.3 Integrated Information Management

One of the primary design objectives of the Cincinnati pilot was to provide information used in routine operations and alarm investigation in a timely and efficient manner to the end users. The requirements for the information technology systems supporting the pilot were derived in part from the information flows in the concept of operations, which identified key users and their information needs as well as existing systems that could be leveraged to support operations (see Table 2-4). Key gaps were identified with respect to information integration, limitations in functionality or capability of existing systems, and event detection. Many of these gaps were addressed at the component level, as discussed in Sections 3 through 8. Efforts at the system-level focused on coordinating data management across the components and filling key gaps in capability that could be best addressed from a broader perspective.

The contamination warning system pilot generates large quantities of new data continuously, in addition to mining data already collected by GCWW and other local agencies. To support data management for several components, two dedicated servers were installed on the GCWW LAN: one an application server and the other a database server. The application server hosts Oracle Application Server software and other custom application software to support event detection for consumer complaint surveillance and public health surveillance. The database server hosts Oracle Database Management System software and the Water Security Data Repository (WSDR), which supports data storage needs in cases where existing systems cannot serve this function for all monitoring and surveillance components. Additional detail on the design and operations of these centralized IT systems can be found in *Water Security Initiative Data Management at GCWW – Centralized Hardware and Software Operations and Maintenance Manual* (USEPA, 2007c). While these two centralized data systems do not achieve complete information integration across all components, they are an important step towards that objective, which may ultimately be realized through implementation of GCWW's *Information Technology Strategic Plan* (GCWW, 2006).

In addition to the application and centralized database servers, a number of existing systems were leveraged for the pilot. In cases where an existing system could not meet the requirements, new systems were designed and implemented. A comprehensive summary of all major information technology systems used in the Cincinnati pilot, including which contamination warning system component(s) each system supports, is presented in **Table 2-7**.

Table 2-7. Summary of IT Systems Used in the Cincinnati Contamination Warning System

Existing Systems and Tools Operated by GCWW						
System Name*	**WQM**	**S&A**	**ESM**	**CCS**	**PHS**	**Role in Contamination Warning System**
GCWW SCADA System	✓	✓	✓	✓	✓	A control system that collects and displays operational data and security alarms for distribution facilities. Provides information used in the investigation of any component alarm.
Water Quality Database		✓		✓		An Oracle database that serves as a repository of data for analytical results, field test results, and information related to water quality consumer complaints.
EMPAC and Hydra	✓	✓	✓	✓		EMPAC is an asset management system that is used to track work orders, which are accessed via a web application called Hydra that includes a GIS application for display of work orders. Used to track work orders created in response to customer water quality calls, and provides information about ongoing distribution system work, which is used in the investigation of component triggers.
Banner				✓		A customer information and billing system from which EMPAC draws customer premises data.
Avaya Interactive Voice Response				✓		A call menu routing system used to triage and direct customer calls. The menu was revised to facilitate tracking of customer water quality calls.
GIS				✓	✓	GCWW maintains its own GIS database using ESRI ArcInfo and ArcView, and this system is used with DWC for spatial display of customer water quality calls. The City of Cincinnati maintains a separate system, CAGIS, which is used for spatial analysis of data from public health surveillance.
Priority Dispatch					✓	When 911 calls are received with medical emergencies, Cincinnati Fire Department uses Priority Dispatch software to prioritize EMS runs. This software also serves to standardize information collected by dispatch. Call records are transferred from Priority Dispatch to the 911/EMS Database.
Emergency Medical Service Tablet					✓	EMS technicians enter run data on their handheld EMS tablet while in the field. The data are uploaded from the tablet to the 911/EMS Database via a wireless link when the vehicle returns to a Cincinnati Fire Department station.
Fireweb Database					✓	Database maintained by Cincinnati Fire Department for storage of 911 and Emergency Medical Service (EMS) data. Databases reside on the 911/EMS Cincinnati Fire Department Server. A replica database has been created to support WS data transfer and analysis.

Cincinnati Pilot Post-Implementation System Status

Existing Systems and Tools Operated by GCWW						
System Name*	**WQM**	**S&A**	**ESM**	**CCS**	**PHS**	**Role in Contamination Warning System**
Drug and Poison Information Center Systems					✓	Drug and Poison Information Center system alerts are phoned to Local Public Health. Data from these systems will be managed independent of the WS contamination warning system and will not be transferred to the WSDR.
National Retail Data Monitor					✓	National Retail Data Monitor alerts are sent by email to Local Public Health.
Real-time Outbreak Disease Surveillance					✓	Real-time Outbreak Disease Surveillance (RODS) system alerts are sent by email to Local Public Health.
Dedicated WS Systems and Tools						
System Name*	**WQM**	**S&A**	**ESM**	**CCS**	**PHS**	**Role in Contamination Warning System**
Water Security Data Repository	✓	✓	✓	✓	✓	The WSDR is an Oracle 10g database that stores data from all components of Cincinnati pilot. WSDR does not store all data for the system; rather, it stores data that are not stored in another utility or dedicated database.
Water Security Application Server				✓	✓	The WS Application Server is a general-purpose application server deployed to host custom applications developed for consumer complaint and public health surveillance.
Consumer Complaint Surveillance Event Detection System				✓		Algorithms deployed on the WS Application Server that continuously analyze customer water quality Interactive Voice Response (IVR) selection, work requests, and work orders in search of anomalies.
WS SCADA System	✓		✓			A control system that collects and displays data from water quality monitoring stations and enhanced security locations. Alarms for both of these components are displayed on an associated user interface. The system also includes remote clients that allow users outside of GCWW's control center to view alarm data from these two components.
EDDIES	✓					The Event Detection Deployment, Integration, and Evaluation System (EDDIES) is a custom application designed to broker data between event detection tools and a SCADA system. It hosts two event detection tools that continuously analyze data from the WS SCADA system in search of anomalies.
Early Aberration Reporting System Event Detection Tool					✓	Early Aberration Reporting System (EARS) event detection algorithms will reside on the WS Application Server at GCWW and will analyze EMS and 911 data received from the 911/EMS Database.
SaTScan™ Tool					✓	SaTScan™ spatial analysis program will reside on the WS Application Server at GCWW and perform cluster analysis on 911 call data received from the 911/EMS Database.

*System names: Water Quality Monitoring (WQM), Sampling and Analysis (S&A), Enhanced Security Monitoring (ESM), Consumer Complaint Surveillance (CCS), and Public Health Surveillance (PHS)

2.2.4 Summary of Post-Implementation Status

The drinking water contamination warning system in Cincinnati has been installed, is fully operational, and is currently generating data needed to establish baseline performance. A comprehensive project management strategy was implemented to guide and prioritize work across all components, track equipment, and compile supporting documentation. Integrated operational procedures were developed in the form of a concept of operations, which was aligned with routine utility function to the extent possible.

Data management activities were coordinated across components, and a centralized data system was deployed to fill critical gaps in existing capabilities. **Table 2-8** provides a summary of the post-implementation status of the system-level elements of the Cincinnati pilot.

Table 2-8. System-Level Post-Implementation Status

Project Element	Description of Implemented Element
1. Comprehensive Project Management	A cooperative research and development agreement was established between the City of Cincinnati and EPA. A dedicated project management structure was established for implementation of the contamination warning system pilot, including: a project plan and schedule, project teams, and mechanisms for tracking progress. Systems are in place for tracking equipment and documentation.
2. Integrated Operational Procedures	A comprehensive concept of operations was developed to guide routine operation of the contamination warning system and efficient investigation of alarms from any component. Procedures were integrated across components and with typical utility operations.
3. Integrated Information Management	A centralized data system was deployed to support data management activities for all components. Data management strategies for individual components were implemented in a coordinated manner that leveraged existing systems to the extent possible.

Figure 2-1 provides a summary of the level of effort associated with design and implementation of project management and system integration activities for the Cincinnati pilot. Comprehensive project management activities, as summarized in Table 2-8, relied on support from EPA, GCWW, and local partners. Local partners also contributed to the effort associated with integrated information management activities to ensure that the hardware, software, and supporting code deployed as part of the pilot did not introduce any vulnerabilities to the City's Metropolitan Area Network.

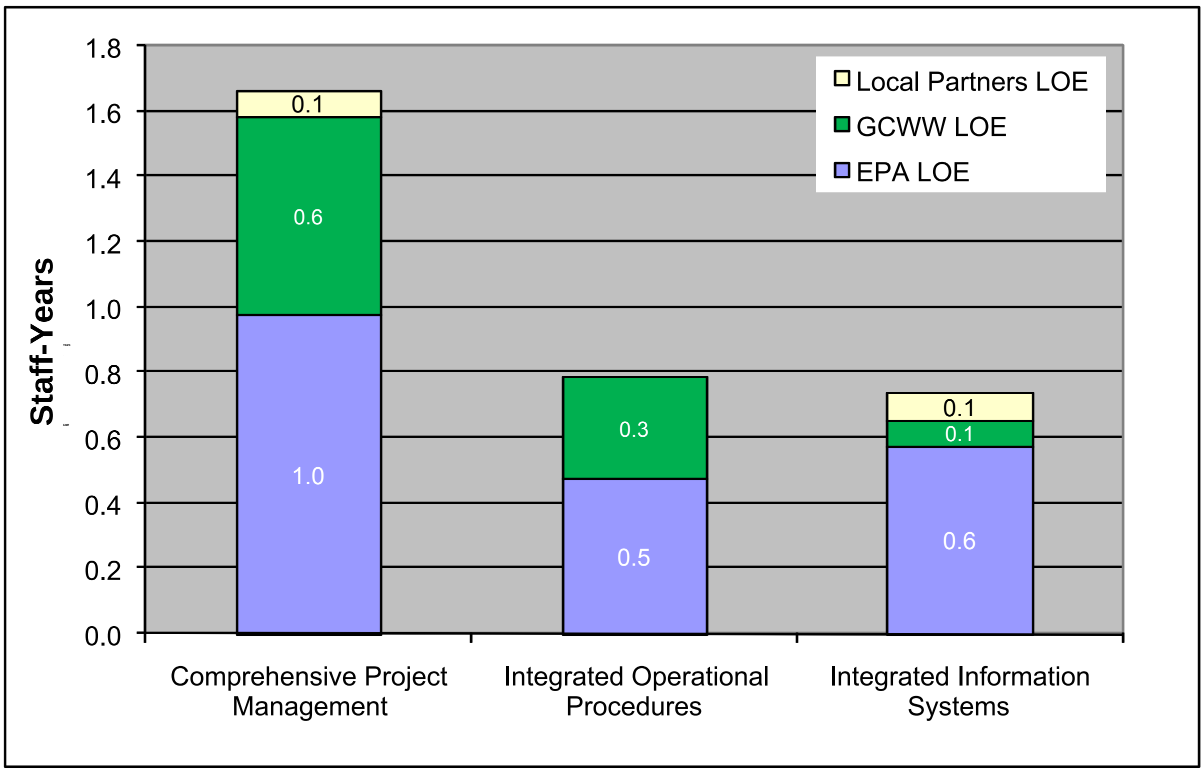

Figure 2-1. Level of Effort for the Cincinnati Pilot Project Management and System Integration Design and Implementation Activities (December 2005 – December 2007)

Figure 2-2 presents a summary of the costs associated with design and implementation of project management and system integration activities for the Cincinnati pilot. Extramural labor costs include contractor activities associated with coordination of system components and implementation of the centralized data system, including development of software, database applications, and hardware installation. Figure 2-2 also includes equipment and consumable supplies costs associated with the procurement of components of the centralized data system, as well as contracted services. Contractor travel costs were not included in these calculations.

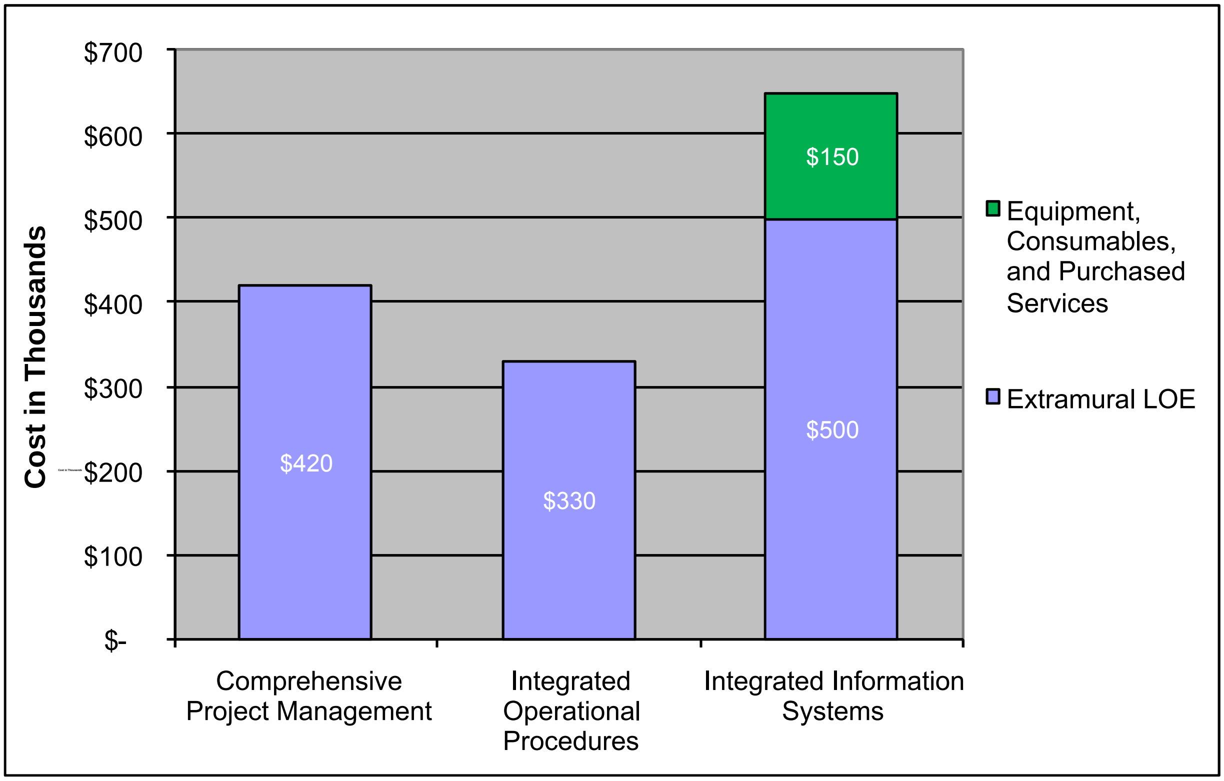

Figure 2-2. Extramural Costs Associated with Design and Implementation of Project Management and System Integration Activities (December 2005 – December 2007)

Section 3.0: Online Water Quality Monitoring

Online water quality monitoring is included as a component of the contamination warning system due to its demonstrated potential to rapidly detect contamination through changes in several commonly measured 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 concentration of total organic carbon) or from reactions with the disinfectant residual (e.g., oxidation of a reactive 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 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, as will be discussed below.

In the Cincinnati pilot, the following water quality parameters are monitored at seventeen locations (two entry points to and fifteen locations within the distribution system): chlorine residual (CL), total organic carbon (TOC), oxidation-reduction potential (ORP), pH, conductivity (COND), turbidity (TURB), and temperature (TEMP). Data from these monitoring stations are transmitted to the SCADA system at the utility's control center where an event detection system analyzes the data to monitor for water quality anomalies that might indicate a possible contamination incident. If the event detection system detects a water quality anomaly, it will generate an alarm to alert operators who initiate an investigation into a possible contamination incident.

The water quality monitoring component design objectives are shown in **Table 3-1**, and were derived from the overarching performance objectives of the contamination warning system as described in *WaterSentinel System Architecture* (USEPA, 2005a). GCWW's pre-existing capability with respect to each design element listed in Table 3-1 is summarized in Section 3.1.

Table 3-1. Water Quality Monitoring Component Design Objectives

Design Element	Design Objective
1. Water Quality Monitoring Equipment	Deploy monitoring stations consisting of a suite of water quality sensors that provide broad contaminant coverage. For water systems using free chlorine residual, current research shows that CL, TOC, ORP, and conductivity (COND) are the most reliable parameters for contaminant detection. The sensors and equipment used in the design of the water quality monitoring stations must function within specifications and consistently produce accurate data. Proper instrument maintenance and routine calibration are essential to meeting this design objective, and the effort required to maintain the equipment must be acceptable to the utility.
2. Water Quality Monitoring Network	Deploy several water quality monitoring stations at locations in the distribution system that optimize spatial coverage and timeliness of detection. This objective can be achieved through use of calibrated distribution system models along with sensor placement optimization tools.
3. Data Management and Communications	Deploy a communication system that transfers data from remote monitoring stations to a centralized data repository, such as a SCADA system, with minimal delay (i.e., less than two minutes from the time of measurement). The SCADA and communication network must be operational at least 99 percent of the time.
4. Water Quality Event Detection	Deploy an automated event detection system that continuously analyzes the large amount of water quality data produced by the monitoring network to search for anomalies that may be indicative of contamination. The event detection system will detect anomalies that are not due to contamination, and thus may be considered false positives that require some expenditure of resources. The rate of false alarms can be reduced by providing ancillary data to the event detection system, such as sensor alarms and tank/pump operational data. Furthermore, written procedures can guide the timely and systematic investigation of water quality alarms, which can further reduce the unnecessary expenditure of resources.

3.1 Pre-Implementation Status

Prior to installation of the contamination warning system, water quality monitoring equipment installed in the GCWW distribution system included only instruments commonly used for drinking water applications, such as CL analyzers. The sensors transmitted data, mostly using standard telephone lines, to the existing GCWW SCADA system located at the utility's operations center. Water quality plots were produced continuously and reviewed daily by staff from the Water Quality & Treatment Division, but there was no real-time event detection system deployed for early identification of water quality anomalies.

3.1.1 Water Quality Monitoring Stations

Pre-existing water quality monitoring equipment in the GCWW distribution system included forty (40) chlorine monitors, three (3) pH meters and two (2) turbidimeters. These sensors were located at twenty-two (22) sites across the distribution system. Twenty (20) of these sites were GCWW facilities and the remaining two (2) were utility boxes permanently installed alongside a public road in critical locations.

Each of the utility-owned storage facilities included one or more analyzers, monitoring residual chlorine levels at various points in the pump station flow stream. For example, multiple source feeds and discharge locations at one pump station require the use of multiple analyzers.

At the Miller and Bolton water treatment plants, water quality monitoring at the plant discharge conforms to standards for the industry and regulatory requirements. Specifically, the parameters monitored at the plant discharge are CL, fluoride concentration, pH, TURB, and TEMP.

All operations and maintenance of the online water quality monitors in the distribution system was performed by utility personnel, primarily consisting of monthly refilling of reagents for the CL analyzers, and calibration when necessary.

3.1.2 Water Quality Monitoring Network

The primary objective of the sensor network prior to contamination warning system implementation was to monitor chlorine residual levels at key transmission and storage facilities for water quality degradation as indicated by reduced chlorine residual levels. Monitors were first installed at the tanks furthest from the treatment plants based on the assumption that these locations had the oldest water. Recognizing the benefit of these sensors, and due to their successful application in the field, GCWW expanded the deployment of chlorine sensors in the early 2000's to include the installation of new sensors in all future tank and facility upgrades. By the commencement of the WS pilot at GCWW in 2006, twenty (20) of GCWW's storage tanks and pump stations were equipped with chlorine sensors. At that time, the utility also maintained two (2) additional sites that were deployed in stand-alone utility boxes permanently installed alongside the public road in critical locations. There were no water quality monitoring systems at non-utility owned sites, and thus there were no monitoring capabilities on distribution lines closer to consumers.

Water quality monitoring efforts prior to the implementation of the contamination warning system were supported by a hydraulic and water quality model of the utility's distribution system, which was built and evaluated using the widely-accepted EPANET software platform. The model was a skeletonized version of GCWW's distribution network, with 59 percent of the 3,000 miles of pipe in the system being represented. This included all pipes in the utility's retail distribution area that had diameters 12 inch and larger (as well as all significant 6 and 8 inch diameter pipes), and wholesale demands simply included at the hydraulically appropriate nodes. One version of this model was maintained by the Water Quality and Treatment Division personnel who used it to predict water quality parameters, particularly chlorine residual, in the distribution system. This informed the utility's efforts to deploy chlorine monitors at remote facilities.

3.1.3 Data Management and Communications

A well-developed data management and communication system was in place at GCWW primarily to support system operations and control, as well as monitoring water quality, flows, and pressures at select sites. The existing communications network included the following:

- Frame relay digital data telephone lines to remote terminal units at the Bolton Plant and major pump stations.
- Dedicated point-to-multipoint analog telephone lines with modulator/demodulator interfaces to remote terminal units at most other remote facilities.
- Unlicensed frequency hopping spread spectrum connections to several water storage tanks.

The analog telephone lines provide relatively low data transfer rates and are somewhat unreliable primarily because they are not monitored by the telephone company and are difficult and expensive to maintain. GCWW had previously conducted a tabletop radio path analysis based on their desire to migrate the existing analog telephone line network to a private radio network. This path analysis indicated that it would be economically challenging to deploy a private radio network throughout the distribution system due to the hilly topography of the greater Cincinnati area.

Data from the remote terminal units are transferred over the communications network to a centralized SCADA system. The SCADA system is located at the operations center, which is co-located with the Richard Miller Treatment Plant. At the start of the pilot, the existing GCWW SCADA system was in the process of being upgraded and migrated to a new Microsoft Windows based system, using Citect's graphical user interface application software. However, the communications links were not being upgraded. Therefore, GCWW determined early in the WS pilot that the existing communications network would not support the communications and data storage requirements of the project. The video communication and storage requirements of the enhanced security monitoring component of the pilot were a key consideration in GCWW's decision (see Section 5). Therefore, a separate or parallel SCADA network, complete with a separate communications network, was required for the WS pilot.

3.1.4 Water Quality Event Detection

In the context of the water quality monitoring component of a contamination warning system, an event detection system is defined as one or more algorithms that continually analyze water quality and related data to monitor for anomalous conditions. The application of event detection systems to near real-time water quality data is a relatively recent innovation, and thus has not been used in drinking water utilities with the exception of a handful of research and demonstration projects.

GCWW did not have an event detection system that met the requirements described above. However, the utility did have a method for identifying significant excursions from an expected range of water quality conditions, most notably CL. This included the establishment of process limit set-points configured in the local programmable logic controllers (PLC) which, when exceeded, activate alarms in GCWW's SCADA system. In addition, staff from the Water Quality & Treatment Division periodically performed retrospective analysis of water quality data from the distribution system monitoring locations to identify trends and methods of improving water quality, typically by reducing water age in storage facilities.

3.1.5 Summary of Identified Gaps

GCWW's existing water quality monitoring system was extensive and well designed for the purpose of monitoring and managing water age, as indicated by CL levels. This existing system provided a solid foundation and experience-base for the design of a contamination warning system; however, it did not meet the design objectives summarized in Table 3-1. Specifically, the pre-existing water quality monitoring system did not provide the required level of contaminant coverage, spatial coverage, timely detection of contamination incidents, reliable indication of potential contamination, or degree of automation necessary for near real-time detection. The specific gaps identified for each design element are summarized in **Table 3-2**. These gaps provided the design basis for enhancements to the GCWW water quality monitoring system, and the post-implementation status of the resulting system is described in Section 3.2.

Table 3-2. Water Quality Monitoring Gap Analysis

Design Element	Description of Gap
1. Water Quality Monitoring Equipment	• The existing network of monitors, consisting primarily of chlorine sensors, is insufficient to provide coverage of the contaminants of concern. • There was limited experience with other types of water quality sensors deployed for distribution system monitoring applications. Thus, there was insufficient information regarding the operating and maintenance requirements of water quality monitoring equipment necessary for a functional contamination warning system.
2. Water Quality Monitoring Network	• The existing monitoring network was based on utility-owned locations: primarily pump stations, reservoirs, and storage tanks. These facilities are typically located on large transmission lines; thus, spatial coverage of the distribution system was limited. • Existing monitoring locations were selected primarily to monitor chlorine residual as an indication of water age. Locations were not selected to optimize detection of contamination incidents and reduce the time to detection.
3. Data Management and Communications	• The utility was in the midst of a major SCADA upgrade at the time of the project, making it impractical to add a significant number of new monitoring locations under the schedule for the pilot. • The existing communication network was not being upgraded along with SCADA. While the existing network likely could have supported the expanded water quality monitoring network, it lacked the bandwidth to transmit video data that was essential to the enhanced security monitoring component.
4. Water Quality Event Detection	• The utility did not have an event detection system capable of rapidly detecting water quality anomalies that could be indicative of contamination. • The utility did not have a formal procedure for the timely and systematic investigation of water quality anomalies detected through online monitoring.

3.2 Post-Implementation Status

The design and installation of the water quality monitoring component of the contamination warning system was performed in two phases. Phase 1 included the design and installation of two types of water quality monitoring stations that allowed for comparison of sensors from different manufacturers. During Phase 1 a parallel communications network and SCADA system were deployed specifically to support both the water quality and enhanced security monitoring components of the contamination warning system. Phase 2 of the project utilized lessons-learned from Phase 1 to design and install a third type of water quality monitoring station that leveraged the best attributes of the two prototypes. The parallel communications network was expanded to include the additional stations, and data from all stations were continuously transmitted to the parallel SCADA system. Deployment of two event detection system and a custom interface application also occurred during Phase 2. The following subsections describe the post-implementation status of the: water quality monitoring stations; water quality monitoring network; data management and communication system; and event detection system.

3.2.1 Water Quality Monitoring Stations

Three types of water quality monitoring stations were designed and installed, which are referred to as Types-A, B, and C monitoring stations (see **Figures 3-1, 3-2,** and **3-3**). Specific sensors were selected based on the results of pipe-loop testing and evaluation studies (Hall, 2007a; Hall, 2007b), and GCWW experience. Additional design features of the monitoring stations were based on recommendations from the *Interim Voluntary Guidelines for Designing an Online Contaminant Monitoring System* (Pikus, 2004). The main difference among the three types is the manufacturer and model of installed instrumentation. All station types include instrumentation to measure the following water quality parameter: pH, TURB, COND, CL, TEMP, and TOC. Type-B and C systems also include sensors which measure ORP. During Phase 1 three (3) Type-A and five (5) Type-B systems were installed, while nine (9) Type-C stations were installed during Phase 2, resulting in a total of seventeen (17) water quality monitoring stations installed during the pilot. The specific sensors installed in each type of monitoring station are described in **Table 3-3** below.

Table 3-3. Water Quality Parameters and Equipment Selected for Water Quality Monitoring Stations

Parameter	Type-A	Type-B	Type-C
pH	Hach GLI pHD	US Filter Depolox 3+, YSI 6500 multiparameter probe	Hach pHD sc
COND	Hach GLI 3422	YSI 6500 multiparameter probe	Hach D3422C3
TURB	Hach 1720D	YSI 6500 multiparameter probe	Hach 1720E
ORP	-	YSI 6500 multiparameter probe	Hach pHD sc
TEMP	Hach GLI pHD	YSI 6500 multiparameter probe	Hach pHD sc
CL	Hach CL-17	US Filter Depolox 3+, YSI 6500 multiparameter probe	Hach CL-17
TOC	Hach 1950Plus	GE-Sievers 900	GE-Sievers 900

The Type-A system instruments, with the exception of TOC, were provided pre-configured on Hach WDMP monitoring panels. The Type-C system instruments, with the exception of TOC, were provided pre-configured on Hach WDMP-sc monitoring panels, which are updated versions of the panels included on the Type-A systems.

One each of the Type-A and Type-B systems also includes an S::CAN "carbo::lyser" TOC/TURB analyzer with "con::stat" transmitter. The carbo::lyser is an optical (visible-ultraviolet range) instrument, as contrasted with the standard, chemically-based methodology used by the Hach TOC instrument. It was provided as a redundant TOC analyzer so that its performance could be evaluated relative to the standard, yet more complicated, TOC instrumentation.

Each Type-A systems also includes a Hach Event Monitor. This is a stand alone computer which analyzes the measured water parameters and may register an Alert or Alarm locally. The event monitor alarm is transferred back to the SCADA system at the California Control Center to alert operators. The event detection systems are discussed further in Section 3.2.4.

Each Type-A station is equipped with an air compressor and a Parker-Balston gas generator. The gas generator removes carbon compounds (carbon dioxide, etc.) from the compressed air stream to provide carbon-free air to the Hach TOC analyzer, as required for its operation. Each compressor has an automatic drain valve which periodically purges condensed water from the air storage tank. Both the drain valve and the gas generator can be powered from the monitoring station uninterruptible power supply (UPS) convenience receptacle on the system. However, due to the starting load of the generator, and some associated experience with blown system fuses, the generator is powered from a separate power circuit, and not from the water quality monitoring station's electrical system.

The Sievers TOC analyzer does not require compressed air for operation, so air compressors are not provided with Type-B or Type-C stations. The Sievers instruments, however, are supplied with inorganic carbon removal systems to ensure that the resulting measurement is representative of only the organic carbon content.

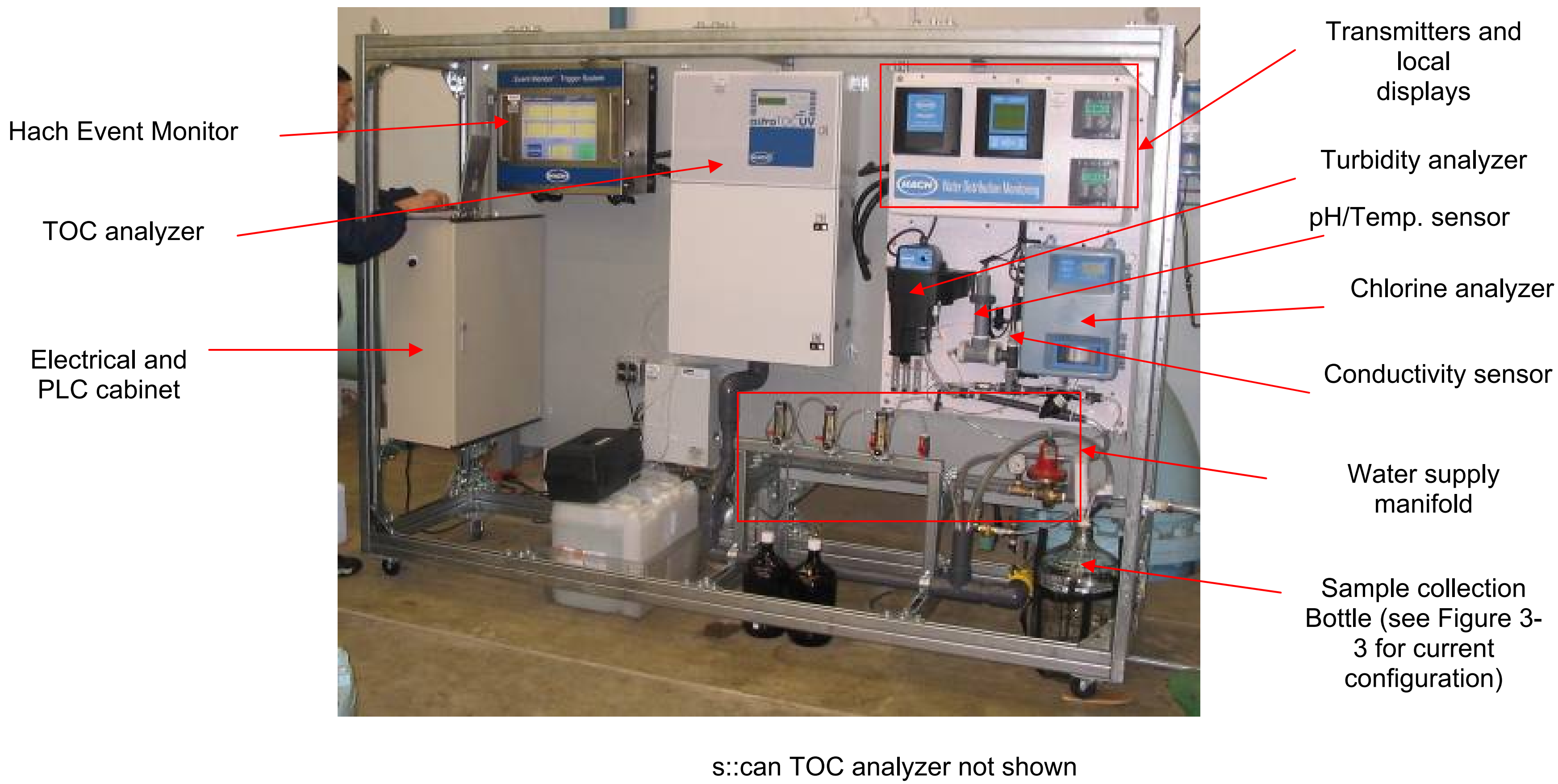

Figure 3-1. Type-A Water Quality Monitoring Station

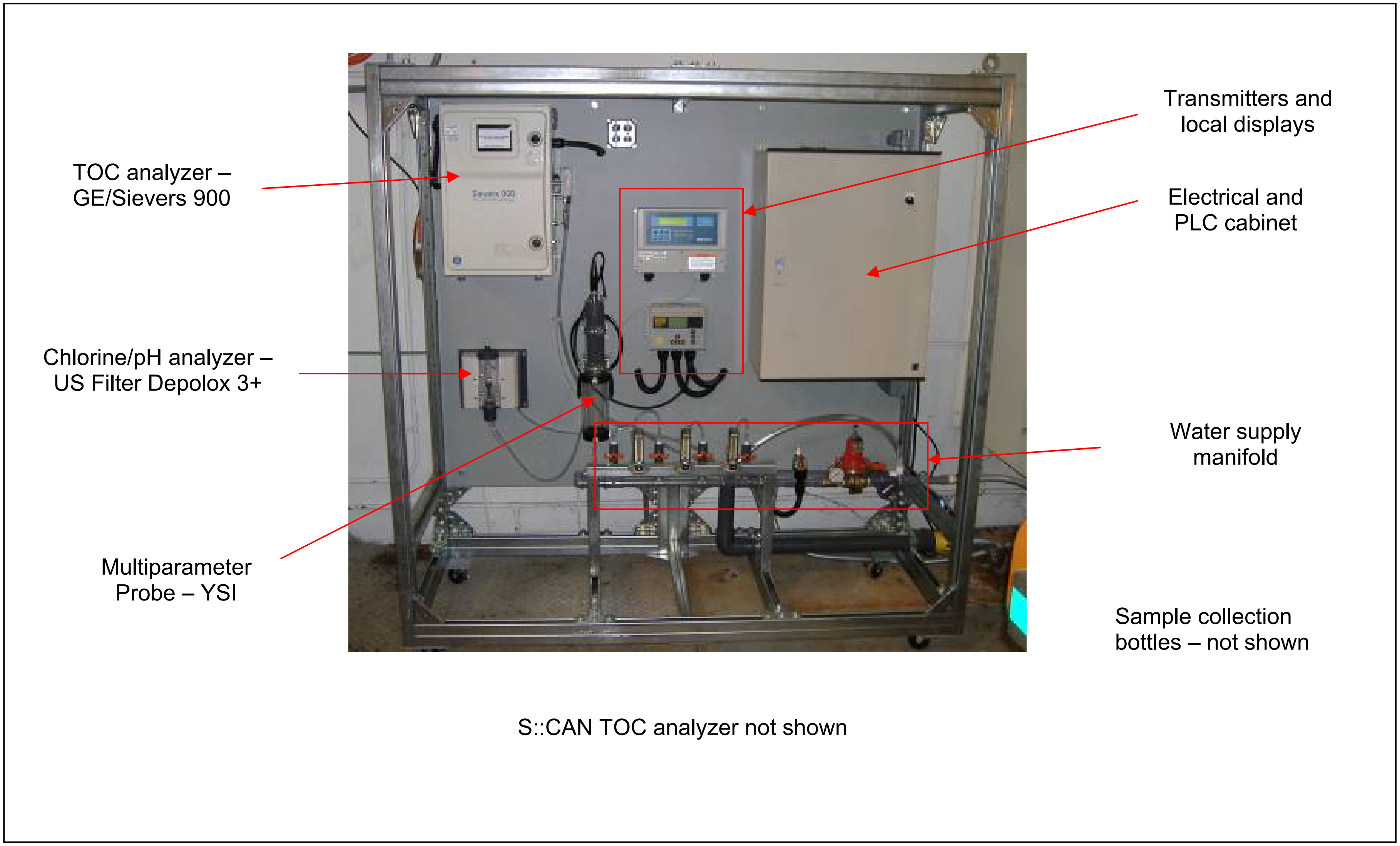

Figure 3-2. Type-B Water Quality Monitoring Station

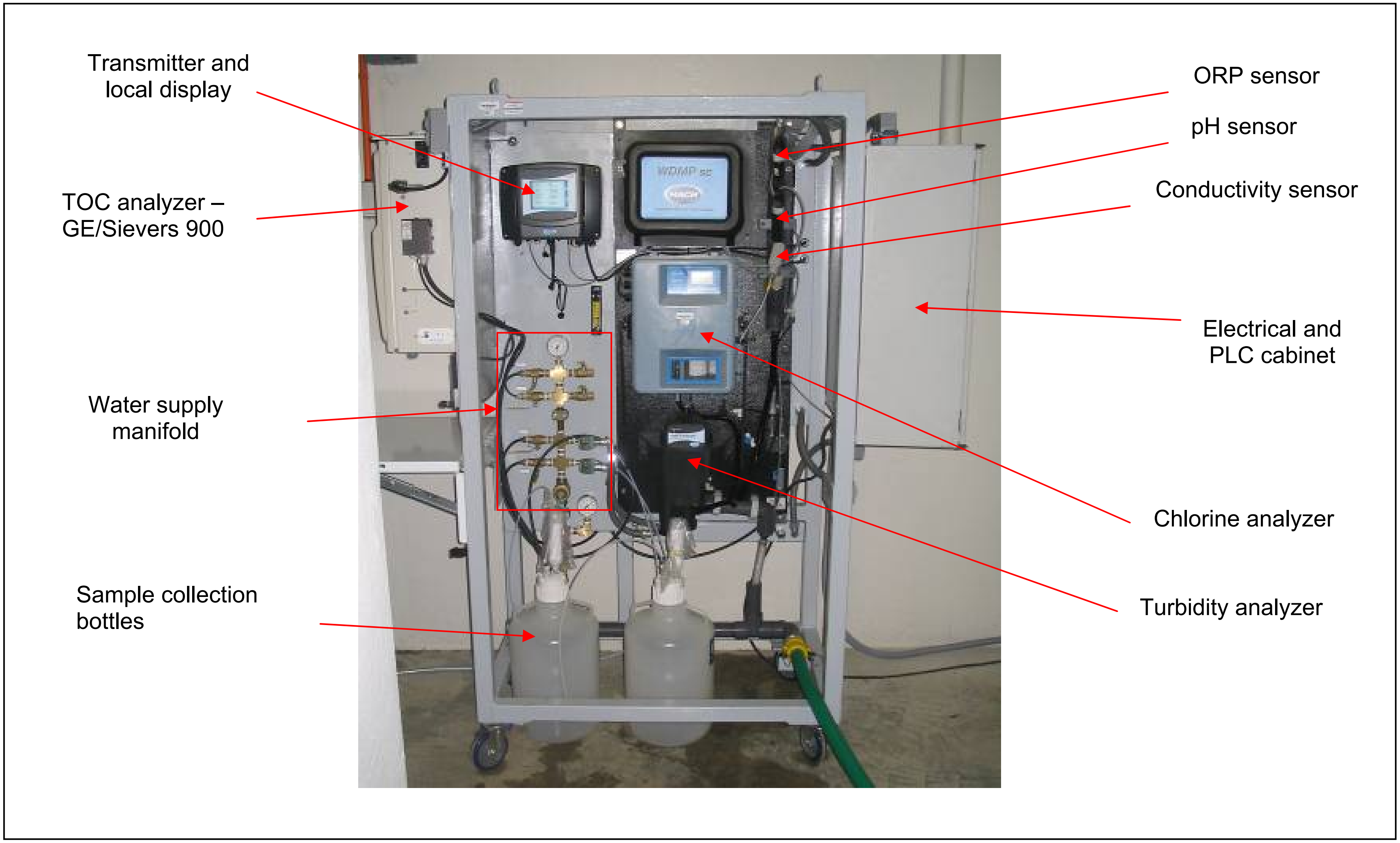

Figure 3-3. Type-C Water Quality Monitoring Station

The water quality monitoring stations are part of a demonstration pilot, and thus are configured as free standing systems mounted on casters for easy set-up and relocation. They are neither hard-wired to a power source nor hard-piped to a water source or drain. Each system includes an electric cord compatible with a standard 120 VAC power receptacle. Each system is powered from an UPS which provides approximately 24 hours of operation of all instruments, local PLC, and communication equipment in the event the main power supply fails.

Water supply and drains are routed through flexible hoses. Influent water flows through a Y-type strainer to prevent large particles from plugging the small diameter flow ports of some of the instruments. A regulator reduces the pressure from the distribution main to approximately 30 psig as verified through a pressure gauge (0-60 psig) mounted directly downstream of the regulator (Type-C units also include a 0-100 psig gauge upstream of the regulator). Water then flows through a pipe or manifold from which several ½ inch diameter branch connections are provided to carry water to each sensor. One of the branch connections is fitted with a manual ball valve and flexible tube to facilitate manual sample collection. Another connection with ball valve is provided at the end of the sample supply pipe/manifold, with a flexible hose connected directly to the system drain. This ball valve is normally closed, but may be opened temporarily to flush the supply header or left partially open as a bypass to reduce the residence time in the service connection between the distribution main and monitoring station. Two of the connections are used for the remote sampling systems discussed below.

Each monitoring station also includes two remote sampling systems, each of which consists of an automatically controlled solenoid valve and a 5-gallon bottle containing a small quantity of sodium thiosulfate to quench any CL, thus preserving chlorine sensitive contaminants. Each sampling system operates independently and only one of the two sample bottles may be filled at a time. A sampling event can be initiated through an operator command from the WS SCADA system, or when the event detection system alarms for a predetermined time interval. When a sample bottle has been successfully filled, the operator is notified through the WS SCADA system and another sample cannot be collected from that specific remote sampling system until the sample is retrieved and the solenoid valve is locally reset.

Bristol Babcock *ControlWave Micro* PLCs are used for collection and transmission of sensor data, and for control of the solenoid valves that are part of the remote sampling systems. This type of PLC was selected for compatibility with GCWW's existing equipment and is a model upgrade that GCWW plans to switch over to completely. The PLCs are housed in an electrical panel that also contains circuit breakers and fused terminal blocks for system isolation and protection as well as the UPS. Two- and four-outlet electrical receptacles are provided on the monitoring stations, some of which are used for ancillary equipment while others are available as convenience outlets for small electrical loads such as laptop computers. Digital cellular radios, with associated firewall protected Ethernet switches and UPS, are provided in separate enclosures.

Each water quality monitoring station is equipped with a Normal/Calibrate switch, which is used to indicate when a station is being serviced or calibrated. The state of this switch is transmitted back to the parallel WS SCADA, and alerts operators that the data from that monitoring location should be considered suspect until the status is returned to "normal." When the switch is in the "calibrate" position, the remote sampling systems are disabled, and the event detection system will not generate an alarm for that location.

Recommended calibration and maintenance activities and schedules for Types-A, B, and C systems have been provided to service technicians, and are included in manuals stored at each monitoring location as well as the GCWW service technician's office. Maintenance activities are provided in tabular format, with separate documents provided for each of the three monitoring station types. Each list includes maintenance activities for each instrument, along with recommended intervals noted as "monthly," "quarterly," "semi-annually," and "annually."

3.2.2 Water Quality Monitoring Network

As discussed in Section 3.1.2, existing monitoring locations within GCWW's monitoring network were selected based on objectives different from those that guide the design of a contamination warning system. For the pilot, the water quality monitoring network was designed to minimize average consequences to the public over thousands of possible contamination scenarios. The methodology used to develop the network design relies on an accurate model of the utility's distribution system, and uses a sophisticated, optimization process that is part of the Threat Ensemble Vulnerability Assessment (TEVA) software. The following three subsections describe: steps taken to validate the GCWW distribution system model, the TEVA methodology, and the process for finalizing the physical monitoring network.

3.2.2.1 Distribution System Model Validation

The TEVA software used to optimize the placement of monitoring stations relies on an accurate distribution system model. Thus, a significant part of the network design included efforts aimed at assessing and validating the accuracy of the GCWW distribution system model.

The methodology devised was to validate the utility's model by comparing its predictions of the mass transport of a conservative tracer through the distribution system to actual field data gathered during a tracer study. This approach required the planning and execution of complex field work to capture the movement of an injected tracer through the utility's distribution system followed by significant efforts to modify the GCWW model to match the operational conditions that existed during the field study. The final step involved analysis and comparison of the field study data to the model predictions. The goal was to gain confidence in the accuracy of the distribution system model, or to identify modifications to the model that were necessary to improve confidence that the monitoring network design would be as close to optimal as practical.

Following more than nine months of planning and preparation, the field activities collected data over an intense six-week timeframe in the fall of 2006. The tracer chemical (a calcium chloride solution injected at a concentration that doubled the background conductivity of the water) was injected at four locations, effectively testing the entire service area of the Richard Miller Treatment Plant, which serves approximately 88 percent of GCWW's customers. Each injection consisted of at least six, one-hour pulses over a 24-hour period to maximize data collection. The injections were done in series, approximately a week apart, and targeted specific regions within the Richard Miller Treatment Plant service area. Following each injection, specially designed conductivity meters were deployed to measure and record the conductivity signal at approximately forty (40) locations throughout each study region.

Before the field data was analyzed and compared, significant effort was spent modifying the utility's original model to reflect the exact distribution system conditions during the study, as captured in data from the GCWW SCADA system. Unfortunately, this effort yielded limited success. The field testing and model recalibration effort needed for this study to be successful was beyond the scope of this project. Instead, the field results were compared against the original model provided by the utility that had been calibrated for a typical summer day in 2005. Performance of the model was assessed using three metrics that characterized how well the model predictions matched measured values with respect to: 1) profiles of each pulse; 2) peak of each pulse; and 3) travel time to the monitored location in the distribution system. The complete analysis and results are summarized in the *Water Security Initiative Distribution System Studies and Modeling: Tracer Study Report* (USEPA, 2007d).

The results of the field study and subsequent data analysis uncovered two omissions in the model that had important impacts on the accuracy of model predictions. These items were incorporated into the model and this updated version was used in the second phase of network design. Additionally, the tracer study enhanced GCWW's knowledge of water quality and hydraulics in their distribution system. Finally, the tracer study results will also be used in a retrospective analysis of the water quality monitoring network design during evaluation of the pilot.

3.2.2.2 Overview of the TEVA Sensor Placement Optimization Tool

The TEVA Sensor Placement Optimization Tool was developed by EPA's National Homeland Security Research Center (NHSRC), Sandia National Laboratories, University of Cincinnati, and Argonne National Laboratory to address the challenge of optimally placing a limited number of sensors throughout a distribution system in order to protect public health (USEPA, 2007e). The TEVA Sensor Placement Optimization Tool uses a utility's distribution system model to simulate the transport of contaminants in the distribution system from the point of injection to consumers. Consequences of contamination are estimated by predicting exposure and the resulting public health impacts using contaminant-specific dose-response curves. In order to develop a robust design, TEVA uses an ensemble of thousands of potential contamination scenarios in which every distribution system node is considered a potential injection location (unless known physical constraints preclude injection at a specific node). The TEVA Sensor Placement Optimization Tool then uses the consequence assessment from this ensemble to place a pre-defined number of sensors at locations that maximize public health protection across all modeled scenarios.

Without constraints on monitoring station locations, the TEVA Sensor Placement Optimization Tool will select the optimal locations, even if those sites are impractical for installation. Therefore, the design was constrained to a pre-selected set of feasible installation sites and a maximum number of monitoring stations, as further described in the following section. The impact of these constraints on monitoring network performance was evaluated by comparison with the unconstrained design (in which a monitoring station could be installed at any node). Comparison between the two designs showed that the constrained design reduced the potential reduction in public health impacts from 49 to 44 percent.

3.2.2.3 Overview of the Monitoring Network Design Process

Design of the online water quality monitoring network followed a three-step process. The first step was to determine the number of monitoring stations that could be deployed within the allocated budget and identify feasible installation locations. The second step was to run the TEVA Sensor Placement Optimization Tool with the constraints identified under the first step to determine the optimal installation sites that maximize public health protection. The final step was to validate the site conditions and local hydraulics at each potential installation site identified through the second step. This three step process was applied in an iterative fashion until a complete, validated set of installation sites was developed. Additional details of the monitoring network design process are discussed in the *Preliminary Sensor Network Design for Greater Cincinnati Water Works* (USEPA, 2007f).

The monitoring network design for both Phase 1 and 2 followed the three-step process described above. During Phase 1, three (3) Type-A and five (5) Type-B prototype monitoring stations were installed and operated for approximately three months to collect data on the various equipment used in each prototype. As discussed in Section 3.2.1, this information led to the design of the Type-C monitoring stations, nine (9) of which were installed during Phase 2. These two phases of monitoring network design are described in more detail below.

During the first phase of sensor network design, GCWW identified a set of desirable installation locations. In addition to all GCWW-owned facilities, other municipal buildings to which GCWW personnel could gain 24/7/365 access were considered. This initial pool of potential locations included all police stations and fire stations in the county and many governmental and academic institutions. EPA personnel then translated the physical addresses of these potential locations to a specific node in the distribution system model. At this phase of the design, the number of monitoring stations that could be deployed was unknown, but based on experience with other monitoring network designs, it was decided that an upper bound of thirty (30) stations was reasonable for a distribution system of this size.

The TEVA Sensor Placement Optimization Tool was then used with the existing GCWW distribution system model to develop the first network design. Because all thirty (30) stations would not be installed in the first phase, the thirty locations in the design were ranked in order of importance. The intent of this approach was to determine an overall network design consisting of up to thirty (30) monitoring locations, and install them in phases. Note that ultimately only seventeen (17) monitoring stations were installed, but the initial network design was based on the upper bound of thirty.

Following the development of detailed cost estimates for the Type-A and B prototypes, it was determined that eight (8) monitoring stations could be fabricated and installed in Phase 1. Furthermore, it was decided that two (2) of the water quality monitoring stations would be installed at the two (2) water treatment plants to monitor the water quality entering the distribution system, which provides a benchmark for distribution system water quality. The remaining six (6) locations were selected from the prioritized list of thirty potential locations identified by the TEVA Sensor Placement Optimization Tool. In addition to the rank of each location, consideration was given to the expected variability of water quality at the monitored location. This would provide an opportunity to evaluate how event detection systems, as discussed in Section 3.2.4, would respond to different baseline water quality conditions.

Next, the hydraulic connectivity for each of the proposed installation locations was verified. Using GIS records available from GCWW, or plans provided by the facility owner, the physical location of the proposed site was compared to the model representation to ensure that the facility was actually being supplied water from the distribution system model node.

Finally, a site visit was conducted to locate the exact installation location within the facility, estimate the hydraulic residence time in the pipes from the distribution main to the monitoring equipment inside the building, and address any outstanding concerns with that specific location. Installation sites were also verified to confirm accessibility, physical security, available sample water and drainage, a reliable power supply, and data communications.

If at any point in this process it was discovered that a site being investigated was unsuitable, it was discarded and another site from the ranked list was evaluated. The result of Phase 1 deployment was a network of six (6) stations installed across the distribution system, in addition to the two (2) at the GCWW treatment plants, to provide broad protection as well as monitoring locations with different water quality variability.

During Phase 2 of water quality monitoring network design, the station location selection process followed a similar path, with a few modifications. To begin with, the pool of potential installation sites was further verified and refined from the pool used in the first phase. However, the facility types considered were still constrained to GCWW-owned facilities, police stations and fire stations in the county, city facilities, post offices, and many other governmental and academic institutions. This resulted in a pool of 193 potential installation locations.

It was also possible to define the precise number of monitoring stations to be installed under the pilot – seventeen (17). Furthermore, it was decided that the eight (8) monitoring stations installed under the first phase would remain at the same locations. Using these additional constraints, the TEVA Sensor Placement Optimization Tool was used with the updated GCWW distribution system model to identify potential installation locations for the nine (9) Type-C monitoring stations.

The suitability of potential installation was then verified through site visits, during which the hydraulic connectivity and physical constraints on installation were evaluated. If this review showed the potential installation site to be acceptable, it was included in the final monitoring network design. Any site that was found to be unsuitable was removed from further consideration, and the TEVA Sensor Placement Optimization Tool was re-run to determine optimal locations under the new set of constraints. For example, if the first four (4) locations were found acceptable but the remaining five (5) deemed unsuitable, the TEVA Sensor Placement Optimization Tool was re-run with the eight (8) original and four (4) new locations fixed so that the remaining five (5) locations could be optimized under these refined constraints. This process was repeated until nine (9) acceptable locations were identified for the Type-C monitoring stations. The end result was a water quality monitoring network that provides improved contaminant coverage, spatial coverage, and timeliness of detection.

3.2.3 Data Management and Communications

While GCWW's existing data management and communication system was able to support the existing water quality monitoring network, it was determined that a parallel system would be needed to support the water quality and enhanced security monitoring components of the contamination warning system pilot. As discussed in Section 3.1.3, this decision was driven by two considerations: 1) GCWW was in the process of updating its SCADA at the same time the water quality monitoring network was being deployed; and 2) the existing communication system was deemed inadequate to support communication of video data produced by the enhanced security monitoring component. Improvements to the data management and communications systems are discussed in the following subsections.

3.2.3.1 Remote Data Collection and Communication

Communication of data from sixteen (16) of the seventeen (17) water quality monitoring stations to the parallel WS SCADA system was established using digital cellular telephone links to the public telephone system. (As discussed in Section 3.2.2, one (1) monitoring station is located at the Richard Miller Treatment Plant and utilizes fiber optic cable for communications). This design uses digital telephone infrastructure, similar to that used by common cellular telephones, but optimized for use with data applications. It represents a substantial upgrade in both technology and reliability compared to the pre-existing analog telephone network.

The digital cellular network is composed of a Cincinnati Bell Telephone LAN Advantage wireline link and integrated service firewall/router connecting the WS SCADA to the digital cellular network. **Figure 3-4** shows the communication network with nodes for both water quality and enhanced security monitoring locations.

Each water quality monitoring station is equipped with a radio panel that includes an Ethernet switch with built-in firewall and security features to protect data stored on the PLC and during transmission to the WS SCADA system. Each radio panel is also equipped with an UPS which can power the Ethernet switch, radio, and other communication equipment for approximately 24 hours. Water quality parameter data collected at each water quality monitoring station are automatically communicated in two-minute intervals to the WS SCADA system.

While data are communicated to the WS SCADA system and stored on a local server, all measured data are also stored every two minutes in flash memory on the Bristol Babcock *ControlWave Micro* PLC. More than thirty days of data are stored in the flash memory on a chronological basis, and the oldest records are automatically overwritten by the newest records. This data file is available for download in the event that communication to the WS SCADA system is lost.

The enhanced security monitoring devices communicate with the WS SCADA network using the existing GCWW communications system. These new devices provide access alarming for reservoir and tank assets. The existing GCWW SCADA network and the parallel WS SCADA network are separated by a network security device, a firewall, to eliminate unwanted traffic.

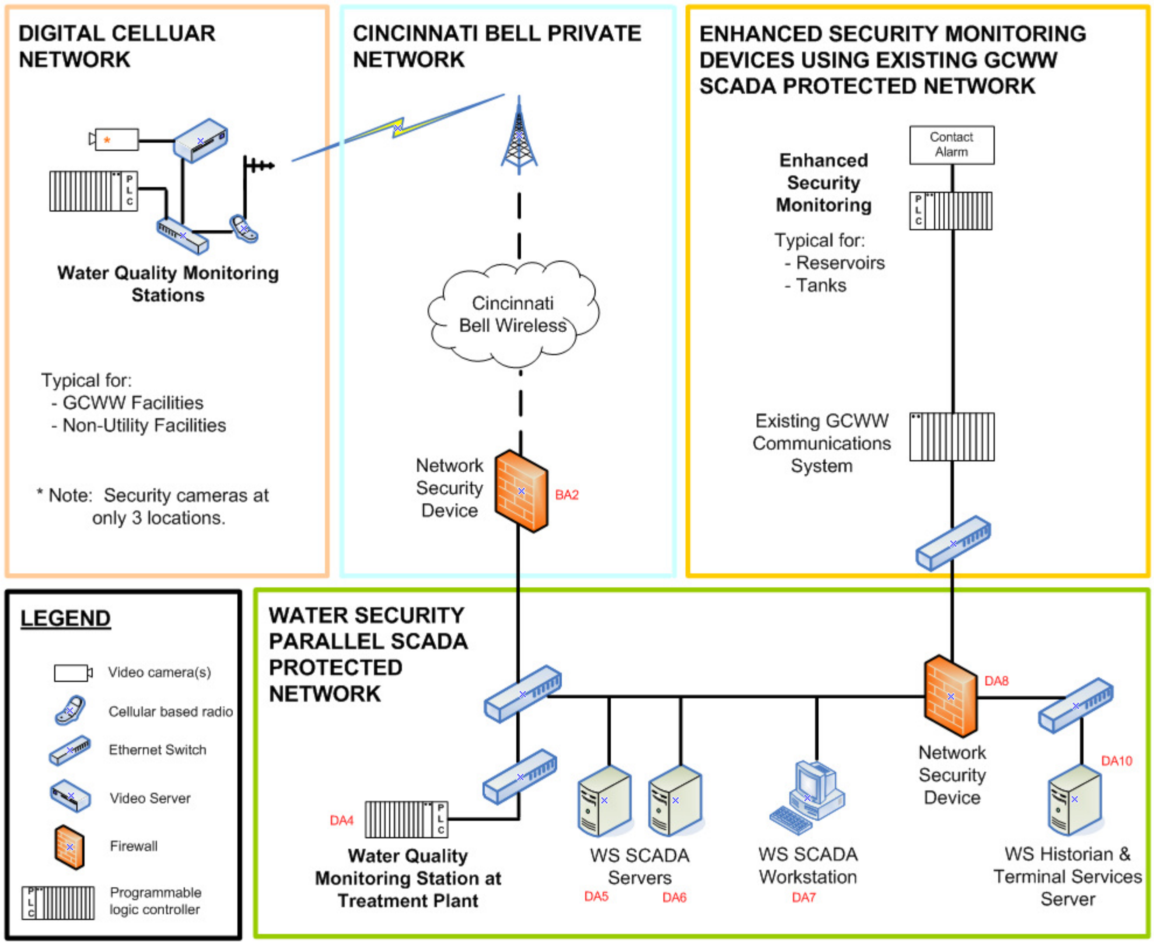

Figure 3-4. WS Water Quality and Enhanced Security Monitoring Communication Architecture

3.2.3.2 Data Management System Architecture

As discussed previously, a dedicated data management and communication system was developed to support the water quality and enhanced security monitoring components of the Cincinnati pilot. The data management system integrated existing GCWW systems with new systems designed specifically for the WS pilot. **Figure 3-5** is a block diagram showing integration of the existing and new systems into an architecture that would support SCADA and event detection systems used in the water quality monitoring component. The water quality data management system is made up of a group of components spanning six (6) computer networks: a pre-existing GCWW SCADA Protected Network, a GCWW and City of Cincinnati Network, a GCWW SCADA Demilitarized Zone (DMZ), an Event Detection Deployment, Integration, and Evaluation System (EDDIES) DMZ, a parallel WS SCADA Protected Network, and the parallel WS SCADA DMZ. These components consist of the servers, workstations, network switches, and firewalls shown in Figure 3-5.

The network design includes many network security devices such as routers, switches, and firewalls to route Ethernet traffic. Each device can limit traffic in different ways. Firewalls are used strictly to eliminate all traffic other than for very specific uses. In general, protected networks can only communicate out through firewalls to a DMZ or to a business network. This design follows industry standards, pushing data to DMZ servers and workstations for storage and reporting. Computers located in the public networks such as the GCWW and City Network can pull data from the DMZ computers for analysis and reporting purposes. In other words, the DMZ buffers traffic between public and private networks. The City's Regional Computer Center is responsible for managing traffic and security through these devices.

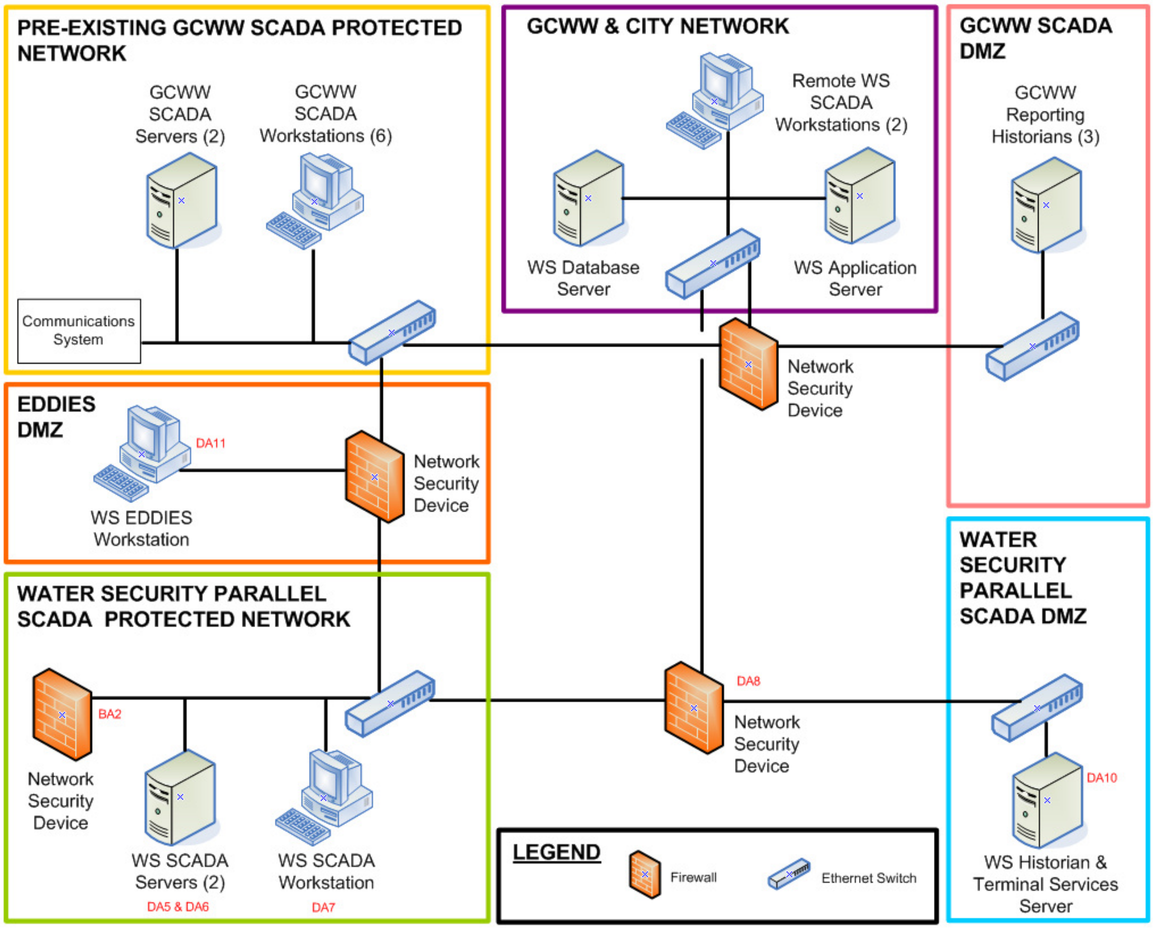

Figure 3-5. WS Water Quality Monitoring Data Management System Architecture

The pre-existing GCWW SCADA Protected Network consists of two (2) SCADA communication servers, six (6) SCADA workstations, and a communications system as depicted in Figure 3-4. The communications system communicates with all the GCWW assets that are off-site such as pump stations, reservoirs, and elevated tanks. Off-site SCADA data are constantly being polled by the SCADA servers and being displayed on the SCADA workstations. Operators use this information to monitor the entire GCWW water system and to make control changes.

The GCWW and City of Cincinnati Network consists of hundreds of workstations and servers used to provide business services to the city. These include email, file storage, and database engines. The WS project added two servers and one workstation to the network. The WS Database Server stores data from many components of the contamination warning system pilot, including SCADA data. The WS Application Server provides program services for some components, such as public health surveillance. The servers were installed on the business network to allow other systems on the City network easy access to data. A workstation located in the security guard shack and another in a GCWW water quality laboratory provides remote, read-only access to the WS Protected SCADA Network. These workstations can monitor data from individual water quality monitoring stations, analysis results from the event detection system, and enhanced security cameras and access controls.

The GCWW SCADA DMZ houses servers which archive GCWW SCADA data and summarize it for reporting purposes. The DMZ provides access to this data via public networks such as the GCWW and City Business Network. One of the reporting servers is used to temporarily hold operational data from the GCWW SCADA private network. It is later picked up by the WS Application Server and written to the WS Database Server for long-term storage.

The EDDIES network consists of one (1) firewall and one (1) workstation. The EDDIES workstation runs the EDDIES application and the event detection software. It receives SCADA data from both the WS and GCWW SCADA Protected Networks. A firewall is used to secure each SCADA Protected Network and ensure that no communication occurs directly between the two SCADA systems.

The water quality monitoring stations are monitored by the WS SCADA system. This system consists of two SCADA servers and one SCADA workstation. The SCADA servers communicate with the PLCs for each of the water quality monitoring stations, polling each for local data such as pH, TOC, and chlorine values. One of the WS SCADA servers also provides information to the Terminal Services server in the WS SCADA DMZ.

The WS SCADA servers host Human Machine Interface (HMI) software to monitor and control the water quality monitoring stations and event detection system via the SCADA workstations. The HMI software is written by Citect and provides the following functionality to users: monitoring of SCADA data, control of field devices, and alarming of values that are out of a specific range. The WS System HMI application provides user interfaces to view to following data representations of the system: a system map detailing the location and status of each monitoring system, real-time values and alarm status from each monitoring system, and event detection system results. The WS SCADA workstation also provides operators with the ability to initiate remote sample collection at any water quality monitoring location. For more information about the WS SCADA HMI application, reference the *WS SCADA HMI Users' Guide* (USEPA, 2007g).

The WS SCADA DMZ includes one (1) SCADA Historian and Terminal Services Server. This server provides the following services: file storage for water quality and enhanced security data; a tape backup device to archive data; and Terminal Services for providing SCADA information to remote users as described above. The WS SCADA DMZ allows for remote SCADA workstations, located on the GCWW and City Network, to view the WS SCADA system without compromising system security.

3.2.3.3 Data Flow

Data flow throughout the data monitoring and event detection system uses two standards, Object Linking and Embedding for Process Control and text files in comma separated value (CSV) format. As noted in Section 3.2.3.2 there are six (6) networks making up the data management system supporting the water quality monitoring component. In order to comply with industry and City of Cincinnati security standards, numerous network security devices were deployed. The City required the use of static port addresses in firewalls, which eliminated the possible use of Object Linking and Embedding for Process Control communications between networks. This required the use of CSV files to transfer data from one network to another. **Figure 3-6** illustrates the path of data flow between networks.

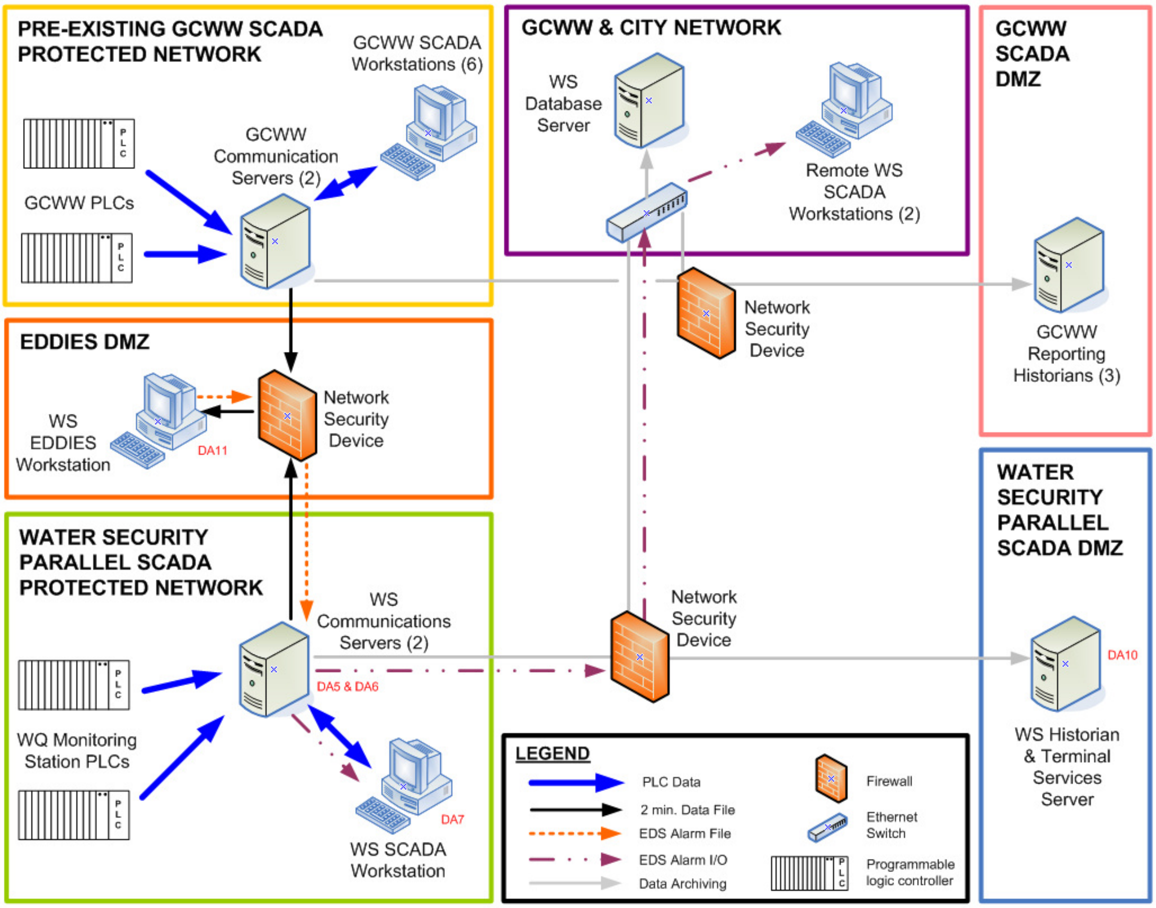

Figure 3-6. WS Water Quality Monitoring Data Flow Diagram

Each of the protected SCADA networks have private communication systems to talk to their SCADA devices, such as PLCs. Because these networks are private, they employ Object Linking and Embedding for Process Control as the communication standard. This line of communication is illustrated in Figure 3-6 by the bold blue arrows. Communication occurs in anywhere from millisecond to minute intervals depending on the device.

Each of the firewalls in Figure 3-6 require static port address and thus cannot use Object Linking and Embedding for Process Control communications. This requires SCADA data to be transferred using CSV files. CSV file movement is represented by gray, purple, orange and black lines.

On a two minute interval data are sent from both the GCWW and WS SCADA Communication Servers to the EDDIES workstation for processing by the event detection system. Once analyzed, EDDIES returns the status of each monitoring location to the WS Communication Server for display on the WS SCADA workstations, including the remote workstations in the GCWW and City Network.

Nightly, SCADA data, represented by gray lines, are moved from each of the protected SCADA networks to their respective DMZs. Then the WS Database Server, located on the GCWW and City Network, polls each DMZ for their SCADA data and archives it for long-term storage.

3.2.4 Water Quality Event Detection

As discussed in Section 3.1.4, GCWW did not have a pre-existing water quality event detection system that met the design objectives of a contamination warning system. For the pilot, three (3) event detection systems were deployed to allow for comparison among these new and novel technologies. Two (2) of these event detection systems were integrated with the WS and GCWW SCADA systems through a custom interface – EDDIES. An off-line study was performed to test the ability of these two event detection systems to detect simulated contamination incidents without producing an unmanageable number of false alarms. Finally, the two (2) systems were deployed for real-time operation at the utility using the EDDIES interface, and a concept of operations was developed to guide routine operations and the investigation of water quality alarms.

3.2.4.1 Event Detection Systems

In the context of the water quality monitoring component of a contamination warning system, an event detection system is defined as one or more algorithms that continually analyze water quality data, along with metadata such as sensor alarms and data quality flags, to monitor for changes in water quality triggered by abnormal conditions. Three (3) event detection systems were deployed as part of the GCWW contamination warning system pilot: the Event Monitor developed by Hach; Canary developed by Sandia National Laboratories; and H2O Sentinel™ developed by Frontier Technology Incorporated. The Hach Event Monitor is an ancillary piece of hardware that is compatible only with Hach sensors. As Hach's Event Monitor must be deployed at each monitoring location and ties directly into the Hach Distribution Monitoring Panel, it was not practical to include the Event Monitor in the offline evaluation study discussed in Section 3.2.4.3. For this reason, the focus was on the two centralized event detection systems, Canary and H2O Sentinel™.

Canary: The Canary event detection system, developed by the Sandia National Laboratories in cooperation with USEPA – National Homeland Security Research Center, uses three different algorithms to detect possible contamination events based on water quality values (Hart, 2007). The algorithms were developed and tested using empirical data relating water quality response to specific contaminants, as well as historic baseline data from large water utilities.

The three algorithms used in Canary are described below:

- Time Series Increment: This algorithm looks at the differences between successive values of each water quality parameter separately. This difference between the current parameter value and the previous is represented as *n* standard deviations, and an alarm is raised if *n* surpasses the set threshold. Differences across all water quality sensors can be fused to create a combined difference value.
- Linear Filter: For the linear filter algorithm, the expected value of a parameter for a given time-step is predicted based on a linear combination of its previous values in the time series. Similar to the time series increment algorithm, differences between the current water quality parameter value and the predicted value are recorded and compared to a threshold value. Also, differences across all sensors can be fused to create a combined difference value (Klise, 2006).
- Multivariate Distance: All parameters are considered together in this algorithm. The Euclidean distance in multivariate space between the current measurement vector and all previous vectors held in the moving time history is calculated, the minimum of all these distances is determined, and if this distance is above the set threshold, an alarm is raised.

A recent addition to the Canary tool is the Binomial Event Discriminator that takes the multiple, sequential outputs from any one of the event detection algorithms and determines whether or not an event is beginning based on those multiple results (McKenna et al., 2007).

H2O Sentinel™: The H2O Sentinel™ Event Detection System, developed by Frontier Technology Incorporated, is specifically designed to detect abnormalities in drinking water quality data. The software is an extension of NormNet™, the company's patented event detection technology. This technology uses a statistical / signal processing / pattern recognition approach (Frontier Technology Incorporated, 2006).

The training procedure for H2O Sentinel™ is fully automated. Training data that represents normal conditions is provided to the software, and multiple statistical models are built that capture a wide variety of normal operating conditions (Frontier Technology Incorporated, 2006). Each model combines current and past values of the input parameters to uniquely characterize sensor performance over a subset of the training data. These models are stored in a database and are later used to assess new water quality conditions as anomalous or normal.

Once the models are built, new data are automatically analyzed by selecting the best statistical model from the existing database using a rapid nearest neighbor search. Next, H2O Sentinel™ generates predicted values for each parameter that are compared with measured values. At each time-step, the tool produces a probability of anomalous water quality conditions.

3.2.4.2 Event Detection, Deployment, Integration, and Evaluation System

Canary and H2O Sentinel™ were designed as software applications that could be deployed at a central location and monitor data from water quality monitoring sensors produced by any manufacturer. To facilitate the evaluation of these two tools, as well and their integration with the SCADA systems discussed in Section 3.2.3, an interface application was developed: Event Detection, Deployment, Integration, and Evaluation System (EDDIES). Two versions of EDDIES were developed to facilitate and manage the evaluation and deployment of the two event detection systems.

- **EDDIES 2.0**: The off-line evaluation, discussed in Section 3.2.4.3, was conducted using EDDIES 2.0. Through EDDIES 2.0, test datasets were stored, managed, and provided to the EDS tools in simulated real-time. EDDIES 2.0 also managed the output from each event detection system, which was used in the evaluation of the event detection systems (USEPA, 2007h).

- **EDDIES 3.0**: Canary and H2O Sentinel™ were deployed at GCWW using EDDIES 3.0. This custom application manages the event detection systems, processes and stores data from the WS SCADA system in an Oracle database, makes it available to the event detection system in real-time, receives and stores event detection system output, and transfers the output back to the WS SCADA system in order to display alarm status. The supporting system architecture is shown in Figure 3-5. Similar to EDDIES 2.0, EDDIES 3.0 eliminates the need for event detection systems to read and write data from a variety of sources with disparate formats. EDDIES 3.0 is currently operational at the Cincinnati pilot, processing data and providing output to the WS SCADA system in near real-time (USEPA, 2007i).

3.2.4.3 Event Detection System Performance Evaluation

Two preliminary evaluations have been performed on Canary and H2O Sentinel™ using data from the Cincinnati pilot: an off-line evaluation was completed to support the selection of tool(s) for deployment at the pilot, and an on-line evaluation was performed to quantify the performance of the tools as they operate in near real-time at the Cincinnati pilot.

In spring of 2007, an off-line evaluation of Canary and H2O Sentinel™ was conducted using EDDIES 2.0. Data from GCWW was analyzed by each tool, both in its original state and with simulated contamination events, to test the tools' detection capability. Approximately thirteen (13) weeks of 2-minute data from early 2007 for each of the eight (8) water quality monitoring stations installed in Phase 1 was used for the evaluation. Superposition of simulated events on the original baseline data allows for the evaluation of the tools' detection capability in addition to the false alarm rate. Contamination events were simulated at each monitoring location, and were defined by the following parameters.

- **Contaminant concentration pattern**: Two (2) to three (3) patterns showing concentration as a function of time were chosen for each monitoring location. The patterns were obtained from a large-scale tracer study conducted at the pilot utility in fall of 2006.

- **Peak extension**: Two (2) peak extensions were used for each pattern. The patterns are made longer by extending the peak or plateau of the event.

- **Peak concentration**: Two (2) to three (3) peak concentrations were identified for each contaminant. The LD_{50} (the dose that would be lethal for 50 percent of the exposed population) of toxic chemicals (and infections dose for pathogens) was used as the benchmark for selection of contaminant peak concentrations in order to provide some equivalence among simulations.

- **Contaminant**: Eight (8) contaminants were selected for this evaluation based on EPA's analysis of contamination threats. Five (5) of the contaminants were identified by the EPA as contaminants of concern because of their ability to cause harm if injected into a water system, ability to be dispersed in water, and availability. In addition, this set of contaminants was chosen because they capture various combinations of water quality parameter responses. Laboratory data from pipe-loop studies and bench-top experiments was used to develop models for the change in water quality parameter values as a function of contaminant concentration.

- **Start times**: Four (4) event start times were used in the design of the simulations. Events may manifest quite differently depending on the time of day and background water quality variability at that time, and the four dates and start times selected each exhibit different baseline conditions.

The range of values for the above parameters was selected to create realistic events and as well as a wide variety of water quality changes. Every combination of these six (6) variables was simulated, producing an experimental matrix of 3,872 test datasets. More details on the evaluation can be found in the event detection system evaluation framework (USEPA, 2006b) and plan (USEPA, 2007j).

Once the event detection tools were executed on the test data, a variety of analyses were performed on the Event Detection System outputs. Performance measures calculated included false alarm rates, median time to detect, and sensitivity (ratio of events correctly identified). The results of this evaluation were very promising. At some monitoring stations, over 70 percent of the simulated events were detected at false positive rates (specificity of 0.004 translates to less than 3 false positives a day for this utility). Note that while this rate may seem high, these false positives are often grouped together into one false alarm, which would require only one investigation. In addition to the good detection performance at low false alarm rates, those detections occur in less than an hour, on average. More comprehensive results can be found in the *Evaluation of Tools to Detect Distribution System Water Quality Anomalies* (Umberg and Allgeier, 2007).

The on-line evaluation provided a summary of event detection tool performance at GCWW during the month of October 2007 using EDDIES 3.0 (USEPA, 2007k). As this was an on-line evaluation, only real-time, non-event data was used; thus, only false alarm rates could be evaluated, and no information was gained on how effectively the tools would detect contamination events. During this period, EDDIES 3.0 and Canary ran on all seventeen (17) stations with no errors or unexpected down-time. Also, both Canary and H2O Sentinel™ produced considerably fewer false alarms than was observed in the offline evaluation, with several stations producing fewer than eight (8) alarms during the entire month of October 2007.

3.2.4.4 Event Detection System Deployment

Deployment of the event detection system at GCWW involved training the tools, setting them up on a dedicated workstation, establishing data flows, and establishing procedures to investigate and respond to water quality alarms.

Approximately three (3) months of water quality data from each of the seventeen (17) monitoring stations was used to train the event detection system tools. The event detection system developers used this data to establish baseline water quality and determine normal variability at each location. Each tool was optimized for each monitoring station by developing location-specific settings tuned to the water quality variability and patterns present in the training data for that location.

These "trained" tools, along with EDDIES 3.0, were installed on a dedicated workstation at GCWW. As discussed in Section 3.2.3, this workstation exists on a DMZ that is only connected to the GCWW and WS SCADA systems. EDDIES 3.0 facilitates the processing of data from both SCADA systems for use by the event detection tools.

For each timestep, the running event detection tool processes the data provided by EDDIES 3.0 and outputs two values for each location after analyzing the water quality data for that timestep. First, it outputs the probability that conditions are anomalous as a value between 0 and 1 (with higher numbers indicating greater cause for alarm). A definitive *Alarm* / *No Alarm* indicator is also produced. In the case of an alarm, additional information is given as to which water quality parameter(s) triggered the alarm. EDDIES 3.0 then sends the Event Detection System results back through the WS SCADA system to be displayed on the SCADA HMI. In addition to visual alarms on the screen, the system issues an audible alarm to alert operators in case they are away from the graphical user interface.

When an Event Detection System alarm indicates abnormal conditions for a particular monitoring station, GCWW implements the concept of operations that guides the initial investigation into potential causes of the alarm (USEPA, 2007b). The concept of operations includes steps that are intended to rule out benign causes. For example, system operations and ongoing distribution system work activities would be reviewed as potential causes. In some cases, the water quality monitoring station that produced the alarm may be investigated to determine if a sensor malfunction was the cause. If the initial investigation does not reveal an obvious cause, contamination is considered possible and the investigation is turned over to the Water Utility Emergency Response Manager (WUERM), who will take additional steps to determine whether or not contamination is credible.

3.2.5 Summary of Post-Implementation Status

The water quality monitoring system at GCWW has been installed, is fully operational, and is currently generating data needed to establish baseline performance. The water quality monitoring network includes a total of seventeen (17) monitoring stations placed at locations optimized to detect contamination events in a manner that will limit public health consequences. Three (3) monitoring station prototypes have been deployed to allow for comparison of different vendor technologies. A digital cellular network was designed and installed to transmit data back to a SCADA system developed specifically for the needs of this project. Three (3) event detection systems were deployed to provide for continuous analysis of the data produced by the monitoring network and provide early warning of anomalies that may be indicative of contamination. **Table 3-4** provides a summary of the post-implementation status of the water quality monitoring component of the contamination warning system.

Table 3-4. Water Quality Monitoring Post-Implementation Status

Design Element	Description of Installed Component
1. Water Quality Monitoring Equipment	• Each monitoring station includes sensors for chlorine residual, TOC, conductivity, pH, and temperature (fourteen (14) locations also monitor ORP). Collectively, these parameters provide broad coverage of potential contaminants. • Each monitoring station is equipped with two sampling devices that allow for remote sample collection in the event of suspected contamination.
2. Water Quality Monitoring Network	• A water quality monitoring network consisting of seventeen (17) water quality monitoring stations has been deployed and is operational. • Fifteen (15) monitoring stations have been strategically placed throughout the distribution system to optimize public health protection. • A monitoring station has been place at the finished water for each of the two (2) treatment plants, providing reference water quality values for the rest of the stations in the network.
3. Data Management and Communications	• Data collection and transmittal to central facility is operating using a secure, digital cellular system via public telephone utility. • Water quality is continuously displayed to system operators, including real-time parameter values, instrument alarms, and event detection alarms.

Design Element	Description of Installed Component
	• Data are formatted and transmitted to a dedicated workstation for use by the even detection system. • Data are automatically archived for historical data analysis and easy recall.
4. Water Quality Event Detection	• Two (2) event detection tools, Canary and H2O Sentinel™, are installed and operational on all seventeen (17) water quality monitoring stations. • A comprehensive performance evaluation of the two (2) event detection tools has been completed. • EDDIES manages real-time data transfer between the SCADA network and the event detection system providing continuous monitoring for anomalies. • A concept of operations has been developed and guides the day-to-day operation of the component at GCWW.

Figure 3-7 provides a summary of the level of effort associated with design and implementation of the online water quality monitoring component for the Cincinnati pilot. Implementation of the online water quality monitoring component, as summarized in Table 3-4, relied on support from EPA, GCWW, and local partners. Much of the effort associated with the design element "water quality monitoring equipment" involved the design, implementation, and shakedown of the monitoring stations. For design of the water quality monitoring network, most of the level of effort was expended in the design, implementation, and analysis of the tracer study. The local partner effort associated with data management and communications resulted from reviews and approvals necessary for deploying new systems on Cincinnati's Metropolitan Area Network. A significant portion of level of effort for the water quality event detection design element was associated with integrating two software tools – H2O Sentinel™ and Canary – with the GCWW and parallel SCADA systems, and training both tools on the water quality base-state at each of the seventeen (17) monitoring stations.

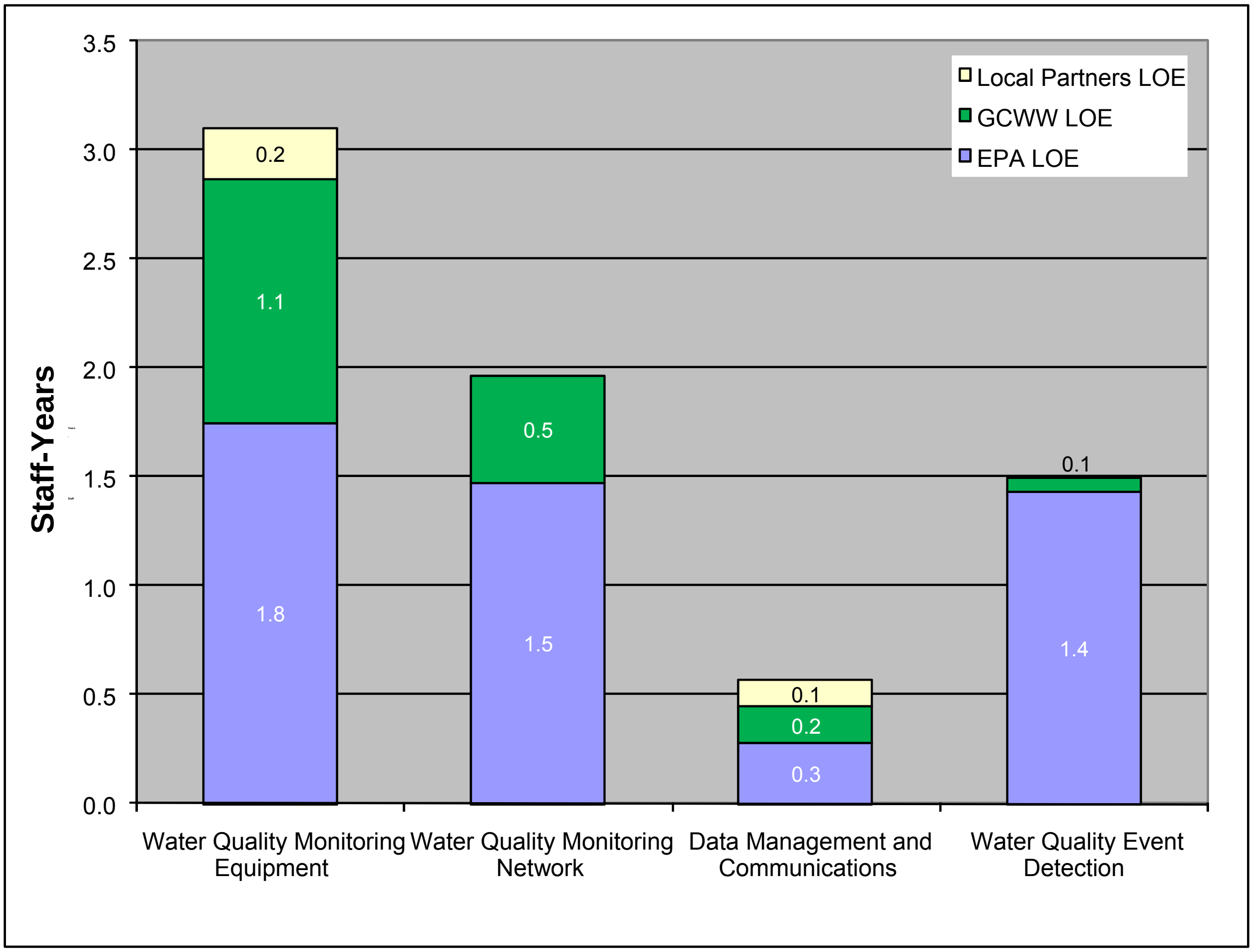

Figure 3-7. Level of Effort for Design and Implementation of the Online Water Quality Monitoring Component (December 2005 – December 2007)

Figure 3-8 presents a summary of the extramural costs associated with design and implementation of the online water quality monitoring component for the Cincinnati pilot. The most significant extramural labor costs include contractor activities associated with design, procurement, and installation of the water quality monitoring stations. Purchased services include costs associated with routine maintenance and repair of the online water quality monitoring stations, as well as the licensing and technical support contract for the H2O Sentinel™ software. Another event detection system, Canary, was developed by EPA's NHSRC, and is being used as part of the Cincinnati pilot. As this software is available in the public domain, no procurement costs were incurred. Costs associated with contractor travel were not included in this calculation. The majority of the equipment and extramural LOE costs for the water quality monitoring network design element were associated with the large-scale tracer study. Forty (40) portable conductivity and ten (10) chlorine monitors had to be procured and fabricated to support this study, in addition to the equipment and supplies necessary to inject the tracer. The extramural costs attributable to data management and communications were expended primarily on the parallel WS SCADA system deployed to support online water quality and enhanced security monitoring.

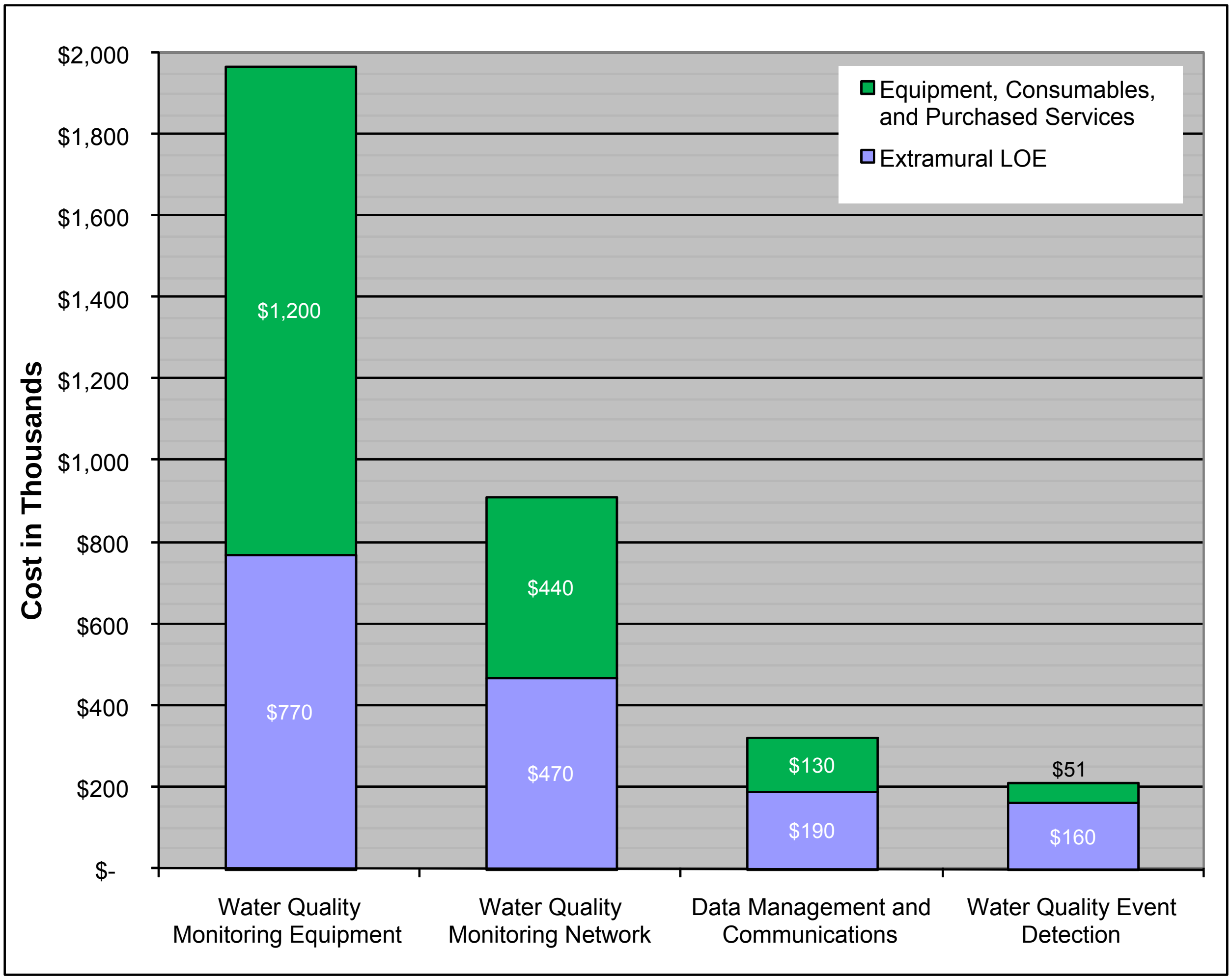

Figure 3-8. Extramural Costs Associated with Design and Implementation of the Online Water Quality Monitoring Component (December 2005 – December 2007)

The cost breakdown in **Table 3-5** is intended to provide additional details regarding the total implementation costs for the water quality monitoring equipment deployed at the Cincinnati pilot. Specifically, Table 3-5 focuses on the costs for fabrication and installation of the three water quality monitoring station prototypes described in Section 3.2.1, including the local electrical, data storage, and communication system installed with each station.

Table 3-5. Comparing Implementation Costs for Each Type of Water Quality Monitoring Station *(reference 3.2.1 and Table 3-3 for Water Quality Monitoring Station Specifications)*

Activity	Description	Type A Costs	Type B Costs	Type C Costs
Administrative Support	Procurement support, equipment tracking, and contractual services	$3,000	$3,000	$3,000
Procurement: Primary Components	**TYPE A**: Hach WDMP ($12,400), Hach Astro TOC ($18,450), Hach Event Monitor ($8,300) **TYPE B**: YSI 6500 ($10,700), USF Depolox 3+ ($3,700), GE TOC 900 ($24,950) **TYPE C**: Hach WDMPsc ($14,950), GE TOC 900 ($24,950)	$39,150	$39,350	$39,900
Procurement: Other	PLC, UPS, radio panel, sampling system, misc. electrical and plumbing connections	$10,500	$10,500	$10,500
Design	Selection of primary/secondary components, and arrangement of components onto a portable frame	$3,500	$3,500	$3,000
Fabrication	Placement of components on frame, materials for frame, assembly of radio panel, routing of interior plumbing and electrical wiring, and WQM delivery	$17,000	$17,000	$11,000
Fabrication: Technical Support	Development of fabrication specifications, and technical inspection/oversight of fabrication process	$4,000	$4,000	$3,500
Installation	WQM placement and connections to electricity, plumbing, and the communications network	$5,000	$5,000	$5,000
Installation: Technical Support	Development of installation specifications, and technical inspection/oversight of installation process	$2,000	$2,000	$2,000
Startup	Initial calibration/troubleshooting required to produce accurate WQ data, and cost of reagents/supplies	$4,000	$4,000	$4,000
Communications System	Field study, design, technical support, startup, and troubleshooting required to establish communication link	$2,500	$2,500	$2,500
	TOTAL COST PER WQM STATION	$90,650	$90,850	$84,400

Cost savings in the areas of "Fabrication" and "Fabrication Technical Support" for the Type C water quality monitoring station can be attributed to the use of a local, lower-cost fabrication company in Phase 2. Type C stations also experienced cost savings in the area of "Design," primarily due to templates and processes that were developed during Phase 1.

These cost estimates are illustrative and not intended to inform future decisions regarding equipment selection for similar projects, which should be based on analysis of comprehensive life-cycle costs among the various options. The costs presented in this document do not include expenditures associated with routine operation and maintenance activities or depreciation of equipment.

Section 4.0: Sampling and Analysis

Sampling and analysis plays a critical role in the contamination warning system due to the potential to detect contaminants in drinking water samples collected throughout GCWW's distribution system. During a suspected contamination event, water samples can be collected and analyzed with the goal of confirming or ruling out actual contamination. Though results from sample analyses may not be generated until several hours or longer after sample collection, results can supplement a triggered investigation of alarms from other components of the system.

Prior to implementation of the Cincinnati pilot, EPA compiled a list of high priority contaminants of interest to water security (USEPA, 2005b). From the high priority contaminant list, EPA identified a subset of chemical, radiochemical and microbiological contaminants to monitor during the Cincinnati pilot at GCWW. To supplement the in-house analytical capability of the GCWW utility laboratory, EPA identified a network of partner laboratories that would provide additional analytical support.

During implementation of the sampling and analysis component at GCWW, the initial phases of sample collection and analysis, referred to as 'baseline monitoring', were designed to establish a baseline of contaminant occurrence (contaminants detected, levels detected, and frequency of detections) and method performance in samples collected throughout the distribution system over a one year period of time. Additionally, baseline monitoring provided the opportunity to practice, under low-stress conditions, the methods and protocols that would be used in the high-stress scenario of a triggered sampling event in which contamination is possible.

Triggered samples are those collected and analyzed in response to "triggers" from any other component (e.g., public health surveillance, consumer complaint surveillance, online water quality monitoring, or enhanced security monitoring). Initially, triggered samples are analyzed using the same methods and protocols employed routinely during baseline monitoring. If a suspected contamination event occurs, the credibility determination would involve comparison of triggered sample results to baseline data to assess whether background levels have been exceeded or method performance has been compromised. This process will assist the utility to confirm or rule out a wide array of known contaminants or refer the sample for additional analysis. In special circumstances, it may be necessary to analyze triggered samples using methods not previously employed during baseline monitoring.

The sampling and analysis component design objectives are shown in **Table 4-1**, and were derived from the overarching performance objectives of the contamination warning system as described in *WaterSentinel System Architecture* (USEPA, 2005a). GCWW's pre-existing capability with respect to each attribute of the sampling and analysis component listed in Table 4-1 is summarized in Section 4.1 and the utility's capability after implementation of the contamination warning system is summarized in Section 4.2.

Table 4-1. Sampling and Analysis Component Design Objectives

Attribute	Design Objective
1. Laboratory capability and capacity	Build laboratory capability and capacity to perform screening and confirmatory analyses for a wide range of contaminants under routine and non-routine scenarios
2. Sampling and analysis	Select sampling locations, frequencies, quality assurance and data quality objectives for routine sampling and analysis to establish baseline data for contaminant occurrence in the distribution system and to evaluate method performance
3. Field screening and site characterization	Establish roles that will be assumed by the utility and others investigating a potential contamination incident and identify testing equipment that will be necessary to conduct field and safety screening

4.1 Pre-Implementation Status

This section describes the processes and tools that were used to evaluate existing sampling and analysis capabilities that could support the Cincinnati pilot and summarizes the findings. The evaluation included review of existing in-house sampling and analysis capabilities as well as areas where analytical support could be provided by partner laboratories and agencies.

Implementation of the sampling and analysis component at GCWW involved an assessment of existing capabilities and identification of potential enhancements to enable the detection of a wide range of contaminants from EPA's priority contaminant list (USEPA, 2005b). The primary objective was to determine if GCWW's existing system could support routine monitoring and triggered sampling and analysis objectives.

Gap analyses were used to determine appropriate enhancements and/or modifications to support implementation of the sampling and analysis component at GCWW and to identify key equipment or training to increase the utility's capability and capacity. Additionally, local partner laboratories or agencies that could provide support to sampling and/or analytical objectives were also identified. The assessment process demonstrated that method support laboratories would be needed for biological, radiochemical, and some chemical analyses. Also, local HazMat resources would be required during sampling events when hazardous materials were suspected to be present.

EPA used a multifaceted evaluation and assessment process to determine the sampling and analysis capabilities of the utility and local partner laboratories and agencies. On-site tours, interviews, cataloging of inventories, and surveys were used to assess the pre-implementation capabilities and resources of GCWW and other local resources. These activities included:

- Tours of GCWW, Metropolitan Sewer District, Cincinnati Health Department Laboratory, and Ohio Department of Health facilities, and interviews with staff
- Catalog of GCWW field and laboratory equipment and respective methods currently performed
- Review of current certifications held by GCWW
- Determination of GCWW chain of custody practices and data management capabilities through survey questions
- Determination of existing GCWW sampling routes, locations, and sampling frequencies that could be leveraged for baseline monitoring
- Review of existing GCWW response capabilities and plans
- Review of existing relationships between GCWW and the Cincinnati Fire Department and Greater Cincinnati HazMat Unit
- Determination of field capabilities of Cincinnati Fire Department and Greater Cincinnati HazMat Unit
- Determination of current Cincinnati Health Department Laboratory methods performed, equipment, and capabilities

The assessment process led to the identification of improvements or enhancements that were necessary to provide the broad level of contaminant coverage desired for the Cincinnati pilot.

4.1.1 Laboratory Capability and Capacity

Field and laboratory-based methods to detect a subset of contaminants from the priority contaminant list were identified and GCWW was assessed to determine if they possessed the capability (instrumentation and staff), qualifications (training, certifications and accreditations), and systems (Quality Assurance/Quality Control program, Standard Operating Procedures, protocols, data management) to implement the methods. Due to the sensitive nature of revealing specific detection capabilities at the Cincinnati pilot, **Table 4-2** presents only the contaminant classes for which capabilities were identified and implemented.

Table 4-2. Cincinnati Pilot Contaminant Classes and Method Types

Contaminant Class	Method Type
Free cyanide	Field and Screening Test Methods/Kits
Free chlorine	
pH and conductivity	
Turbidity	
Organophosphate chemical warfare agents and pesticides	
Radioactivity	
Volatile Organic Compounds	
Toxicity	
Metals	Laboratory-Based Chemical Methods
Polychlorinated biphenyls	
Organophosphate pesticides	
Carbamate pesticides	
Volatile Organic Compounds	
Gross alpha	Laboratory-Based Radiochemical Methods
Gross beta	
Gamma emitters	
Select Agents and Toxins	Laboratory-Based Biological Methods

Capabilities for routine monitoring and surveillance using the approaches listed in Table 4-2 were desired for the Cincinnati pilot so that a wide range of contaminants and classes could be ruled in or out by comparison of baseline data to triggered sample results. In the initial phases of a contamination threat investigation, triggered sampling and analysis protocols will be almost identical to routine sampling and analysis protocols. Unless there is specific evidence leading the investigation, the same methods used for routine sampling and analysis will be utilized during a triggered event.

For regulated chemical or radiochemical contaminants, EPA drinking water certification standards (USEPA, 2005c) or National Environmental Laboratory Accreditation Conference (NELAC) standards were used for assessment. NELAC standards were used for field methods, and Clinical Laboratory Improvement Amendments standards or Laboratory Response Network standards were used for biological contaminants. It was necessary to establish new standards for some contaminants and methods, as standards did not exist (e.g., ultrafiltration quality control recovery, field method quality control practices). The document *Assessment Report of Sampling and Analysis Activities at the GCWW WS-CWS Pilot* contains more detailed information regarding assessment criteria, pre-implementation status of sampling and analysis at GCWW and partner laboratories, and how existing gaps were addressed (USEPA, 2007l).

GCWW Pre-Implementation Sampling and Analysis Equipment and Capabilities

Prior to implementation of the Cincinnati pilot, GCWW's analytical capabilities were primarily associated with compliance monitoring and water treatment process monitoring. In general, compliance samples were analyzed by GCWW; however, some compliance monitoring samples (for semivolatiles and carbamates) were contracted to Mobile Analytical Services, Inc. Radiochemical analyses were conducted by the Ohio Department of Health in Columbus, OH.

One of the first steps conducted during the assessment process was a full inventory of sampling and analysis equipment at GCWW. The findings are summarized in **Table 4-3**. GCWW had sufficient staff and standard operating procedures for most analyses conducted in-house. For some of the portable instruments, the instruction manuals were used as the standard operating procedures, as indicated in Table 4-3.

Table 4-3. GCWW Pre-Implementation Equipment and Methods

Instrumentation	Model	Qty	Methods Used	SOP
Radiochemical				
Nuclear Radiation Monitor	Radalert 50	1	General scan	Yes
Inorganic				
Portable Colorimeter	Hach DR890	4	Chlorine Hach Method Cyanide CHEMetrics Vacu-vial Method	Yes
Portable pH	Fisher Accumet AP61	3	pH	No
Meter	920A	2	SM 4500 H Ammonia as Nitrogen	Yes
Conductivity meter	Orion 150AT	1	SM 2510	Yes
Graphite furnace AA	Varian SpectrAA 640Z	1	SM 3113-B Pb, Cu, Al, As	Yes
Flame AA	Varian SpectrAA 640	1	SM 3111-B Zn, Na	No
Cold Vapor Mercury Analyzer	Varian VGA 77	1	SM 3112-B Hg	Yes
Hot Block	Environmental Express	1	EPA 200.7 Digestion	Yes
Nitrate	Accumet AR 50	2	SM 4500-NO_3 D	Yes
Fluoride	920At	1	SM 4500-F C	Yes
O_2	Orion 97-08-00	1	SM 4500-O G	Manual
Portable Turbidimeter	Hach 2100P	1	Turbidity	Manual
IC- Conductivity detector	Metrohm 819 IC	1	EPA 314, 300	Yes
Amperometric titrator	Wallace and Tiernan	1	SM 4500 Cl D Chlorine residual by amperometric titration	No
Spectrophotometer	Hach DR 4000 and 5000	2	NH_3, PO_4, Fe, NO_3, UV254, SO_4^{2-}	Mfrs Method
Organic				
Fluorometer	10-AU Turner Designs	1	SM 10200H Chlorophyll	Yes
GC-FID	Varian 3400cx	1	EPA 502.2	Yes
GC-MS	Varian Saturn 2000	1	EPA 524.2	Yes
GC-PID AND ELCD	VARIAN 3400	2	EPA 502.2	Yes
GC/MS	Varian Saturn 2000	1	SM 6040D	Yes
TOC	TeledyneTekmar Phoenix 8000	1	SM 5310C	Yes

Instrumentation	Model	Qty	Methods Used	SOP
TOX	Rosemont Dohrman	1	SM	Yes
GC-ECD	Varian 3800	1	EPA 552.2	Yes
Biological				
Autoclave	Consolidated SSR38PB	1	Waste, media, and glassware sterilization	Yes
Water Bath	Lindberg BlueM 1110	1	Tempering agar	No
Incubator	Precision 6LM	3	SM 9223B Colisure® Presence/Absence	No
Refrigerator	LabLine Ambi-HiLo Chamber	1	Sample Storage	No
Class II Biosafety Cabinet	LabConCo Model 36208 / 36209 Type A/B3	1	N/A	Manual
Shaking Water Bath	Precision Scientific Model 50	1	SM 9218 B Endospores	No
Phase Contrast Microscope	Bausch & Lomb	1	N/A	No
Colony Counter	Quebec Colony Counter	1	Colony Counting	No
Dissecting Microscope	AO Spencer	1	N/A	No
Particle Counter	Met One 250	1	Manufacturer's Instructions	Yes

While some of the equipment and methods listed are not directly relevant for detecting the specific contaminants targeted for monitoring during the Cincinnati pilot, documenting GCWW's existing capabilities was essential for performing gap analysis and identifying necessary enhancements.

GCWW Pre-Implementation: Laboratory Methods and Certifications/Accreditations

The majority of the drinking water methods GCWW conducted were certified by Ohio EPA. Laboratory staff had access to fume hoods and biosafety cabinets and in some cases could analyze potentially hazardous samples. GCWW did not have capability to analyze for all the targeted priority contaminants (e.g., select agents, radiochemicals).

Table 4-4 contains a list of analytical methods for chemical and biological contaminants that GCWW was certified by the Ohio EPA to perform prior to implementation of the contamination warning system.

Table 4-4. Pre-Implementation Status of GCWW Laboratory Methods

Method Number	Title/Instrumentation	Analyte or Analytical Parameter
Methods with Certification from Ohio EPA		
502.2	VOCs by Purge and Trap Capillary GC with Photoionization and Electrolytic Conductivity Detectors in Series	Regulated volatile organic compounds (VOCs)

Method Number	Title/Instrumentation	Analyte or Analytical Parameter
524.2	Purgeable Organic Compounds by Capillary Column GC/Mass Spectrometry	Regulated VOCs
552.2	Haloacetic Acids and Dalapon by Liquid-Liquid Extraction, Derivatization and GC with Electron Capture Detector	Halogenated organic compounds
SM 5310-B	Total Organic Carbon by High-Temperature Combustion	Total organic carbon and dissolved organic carbon
SM 3113-B	Metals by Graphite Furnace Atomic Absorption	Certified for lead and copper
SM 9223-B	MMO-MUG Colisure®	Total coliforms and *E. coli*
SM 2130-B	Nephelometric Method	Turbidity
SM 4500-H+	pH Value	pH
SM 2320	Alkalinity	Alkalinity
SM 2330	Calcium Carbonate Saturation	Stability
SM 2340-C	Hardness	Hardness
SM 4500 F-C	Ion-Selective Electrode Method	Fluoride
SM 4500 NO_3-D	Nitrate Electrode Method	Nitrate
SM 4500 Cl-D	Potentiometric Method	Chlorine
SM 4500 Cl-G	Mercuric Thiocyanate Flow Injection Analysis	Chlorine
Methods without Certification from Ohio EPA		
SM 3113-B	Metals by Graphite Furnace Atomic Absorption	Monitoring for metals other than lead and copper
NA	In-line GC/FID monitoring of all water coming from the Miller Treatment Plant sampled every few minutes	VOCs
Various	Spectrophotometric methods	Various

Several contaminant classes [e.g., biological (select agent) and radiochemical contaminants] were not within GCWW's capability. EPA determined that partner laboratories would be necessary to provide analytical coverage for the targeted priority contaminants for routine and triggered sampling and analysis.

Laboratory Partners: Pre-Implementation Capabilities and Relationships with GCWW

During the assessment process, EPA evaluated the capability of various partner laboratories to process samples for targeted contaminant classes/methods outside of GCWW's laboratory capability. EPA also determined whether existing relationships were established between GCWW and the partner laboratories. The following partner laboratories were identified by EPA as entities that could provide analytical support to the GCWW utility laboratory.

Metropolitan Sewer District of Greater Cincinnati: Prior to the Cincinnati pilot, no formal arrangement existed between GCWW and Metropolitan Sewer District for sample analyses. Metropolitan Sewer District possessed capabilities to analyze samples for metals by inductively coupled plasma – mass spectrometry. Although Metropolitan Sewer District was not certified by Ohio EPA for drinking water compliance monitoring, however, they participate in the Discharge Monitoring Report Quality Assurance program and analyze performance evaluation samples on a quarterly basis. EPA determined that the laboratory's qualifications were sufficient to support baseline monitoring.

Ohio Department of Health Laboratory: All radiochemical analyses as required by National Primary Drinking Water Regulations were analyzed by the drinking water certified Ohio Department of Health Radiochemical Laboratory. The Cincinnati pilot did not require the use of different methods by Ohio Department of Health Laboratory for radiochemical analyses, however, the number of samples submitted for analyses increased significantly during the baseline monitoring phase.

GCWW did not have an established formal arrangement with the Ohio Department of Health Laboratory to conduct microbiological analyses for select agents and toxins. EPA noted that Ohio Department of Health Laboratory had the required experience to concentrate and analyze large volumes of drinking water using the BT Agent Screening Protocol through participation in the Laboratory Response Network Multi-Center Validation Study conducted in 2006.

Mobile Analytical Services, Incorporated: Mobile Analytical Services, Incorporated had provided analytical support to GCWW for several years. During the Cincinnati pilot, Mobile Analytical Services, Incorporated was contracted to analyze samples for carbamates using an EPA approved method. Mobile Analytical Services, Incorporated was certified by Ohio EPA to analyze drinking water samples using an EPA approved method.

Test America – Savannah, formerly Severn-Trent Laboratories: Prior to the pilot, no contract existed between GCWW and Test America-Savannah for chemical analyses. Test America-Savannah is certified to conduct drinking water analyses using a wide variety of EPA approved methods. Test America-Savannah was contracted to analyze samples as necessary using these methods.

4.1.2 Sampling and Analysis

Sampling and analysis encompasses existing sampling and analysis plan(s), including sample locations, frequencies, and procedures as well as roles and responsibilities. It also includes data management activities and appropriate Quality Assurance/Quality Control policies and procedures.

At the time of this assessment, GCWW performed routine sampling for all regulated drinking water parameters and had established sampling routes and plans. GCWW's routine sampling and analysis frequencies for each method or group of methods is provided in **Table 4-5**.

Table 4-5. Sampling and Analysis Frequency

Contaminants	Sampling and Analysis Frequency
Total coliforms and *E. coli*	80 samples per week
Method 524.2 VOCs	30 samples per week
Copper and lead	20 samples per week
Chlorine	2 samples per day at plant effluent plus 80 samples per week at microbiological distribution system locations
Wet chemistry parameters	1 sample per day

GCWW had developed a document called the "Section IIF4- Distribution Water Contamination Plan" which included sampling standard operating procedures for incidents if contamination of the water system was suspected. This plan addressed compliance monitoring sampling and sampling for unknowns, but did not address scenarios involving analysis for unknown contaminants. Additionally, this plan did not contain field screening procedures and only addressed sampling from taps. The pilot study consequence management team later developed a more comprehensive response plan to address the different possible warnings and responses to a contamination event.

Only a few GCWW employees had received 40 hour Occupational Safety and Health Administration HAZWOPER training prior to implementation of the Cincinnati pilot. GCWW planned to rely on the local HazMat units (e.g., Cincinnati Fire Department and Greater Cincinnati HazMat Unit) for sample collection during a potential contamination event. Although GCWW field personnel were experienced samplers, they did not have the appropriate training, expertise, or equipment to respond to a potentially hazardous contamination incident.

The GCWW laboratory was divided into inorganics, organics, microbiology, and wet chemistry sections; each section had a quality assurance plan and standard operating procedures. These quality assurance plans were reviewed and approved by the Ohio EPA auditor; therefore, EPA did not review them for completeness or accuracy, but did verify that specific laboratory procedures were documented in the quality assurance plan. GCWW did not have a quality assurance program or quality control practices for the new methods that would be implemented during the Cincinnati pilot (e.g., new field methods, laboratory-based chemical methods, or ultrafiltration). The document *Assessment Report of Sampling and Analysis Activities at the GCWW WS-CWS Pilot* contains a more in-depth discussion of quality assurance practices that were evaluated at GCWW (USEPA, 2007l).

Although GCWW did not have a laboratory information management system, an in-house database was used for data management. This water quality and treatment database captured all of the sampling parameters (date, time, location, sample identification, and technician/analyst) and analytical results. However, analytical quality control data are not captured in the database. All compliance data was required to be maintained and stored for at least 10-12 years. A questionnaire, "Data Management for Sampling and Analysis" was used by EPA for an initial assessment of GCWW capabilities. The results of this survey showed that GCWW uses hardcopy chain of custody forms. Analysts check the sample storage area daily to determine if new samples had arrived. It is the responsibility of the analyst to track the samples in the laboratory. All hardcopy records pertaining to sampling and analysis are kept for a minimum of ten (10) years.

4.1.3 Field Screening and Site Characterization

Table 4-6 describes GCWW's existing field screening and site characterization procedures, protocols, and equipment. It also includes equipment available through external partners.

Table 4-6. Summary of Pre-Implementation Field Screening and Site Characterization Capability

Organization	Description of Capability
GCWW field screening methods	• Cyanide analysis • Free chlorine, total chlorine, and iron analysis • pH testing • Turbidity analysis • Fluorometer to analyze for PCBs and fuels. However, these instruments were not used on a routine basis. • Existing SOPs for all screening equipment
Emergency response coordination with HazMat units	• Prior to the pilot study, GCWW had not developed a response plan that included the local HazMat teams affiliated with the Cincinnati Fire Department and the Greater Cincinnati HazMat Unit.
Cincinnati Fire Department	• Full OSHA Level B response capabilities, and possesses a wide variety of field screening instruments. • Possessed several multi-gas meters for confined space entry that contain detectors for VOCs, explosive gases, carbon monoxide, oxygen, and hydrogen sulfide.
Greater Cincinnati HazMat Unit	• Similar capabilities to Cincinnati Fire Department. • Field screening van that contains hundreds of different detection kits and instruments. An inventory of the equipment in this van was not provided.

4.1.4 Summary of Identified Gaps

Table 4-7 summarizes the gaps identified during the initial assessment of sampling and analysis capability at GCWW. Section 4.2 describes the post-implementation status for each of the attributes listed below.

Table 4-7. Sampling and Analysis Gap Analysis

Attribute	Gap Description
1. Laboratory capability and capacity	• GCWW did not have the in-house capability to conduct any biological analyses for select agents. GCWW would require instrumentation and training to conduct the LRN ultrafiltration procedure necessary to concentrate drinking water samples for analysis by ODH using the LRN BT Agent Screening Protocol. • GCWW did not have any significant capability to screen or analyze for radiochemicals. • GCWW did not have the in-house capability to perform carbamate pesticide analysis. Contract laboratory support would be required. • GCWW had personnel to perform GC/MS analysis, but did not have a GC/MS instrument dedicated to semivolatile organic compound analysis. Instrumentation would be required for this function. • GCWW did not have ICP-MS capabilities for metals analysis. • MSD did not have a turbidity meter to check turbidity of drinking water samples.
2. Sampling and analysis	• A QA program was needed for concentration of large volumes of water using ultrafiltration. • QC practices and standards needed to be developed for field methods. • A baseline monitoring program needed to be designed, including development of Sampling and Analysis Plans (SAPs). • Sample tracking equipment such as bar code readers was needed. • COC forms for baseline monitoring and triggered sampling and analysis were needed. • SOPs for special activities associated with routine and triggered sampling and analysis were needed (e.g., sample collection, packaging, and shipping procedures). • Additional data elements needed to be added to the WQ&T database. • A separate database was required for EPA to statistically analyze baseline data. CSC was contracted to establish and maintain this database.
3. Field screening and site characterization	• GCWW did not have the equipment or personnel necessary to mobilize multiple teams that could perform site (safety) characterization and field screening. Purchase of field equipment was needed. • The screening equipment possessed in-house at GCWW, CFD, and GCHMU were inconsistent. If each organization possessed the same basic screening instrumentation, then communication of field screening information between these organizations during a response event would be greatly improved. • CFD and GCHMU needed to gain familiarity with the potential sampling sites at GCWW. • Coordination of roles and responsibilities of GCWW, CFD, and GCHMU to conduct field screening and site characterization was needed.

4.2 Post-Implementation Status

This section provides a summary of enhancements to the sampling and analysis component which were implemented during the Cincinnati pilot. These enhancements include resource documents and sampling and analysis plans, training sessions, equipment purchases, standard operating procedures, and outreach to partner laboratories and agencies. The following sections also summarize the post-implementation status of laboratory capability and capacity, sampling and analysis, field screening, and site characterization for both baseline monitoring and triggered sampling and analysis.

Gap analyses described in Section 4.1 were used to determine the appropriate enhancements and modifications that would be required to implement the desired sampling and analysis capabilities. **Table 4-8** summarizes post-implementation status of the sampling and analysis component with respect to analytical capabilities for detection of potential drinking water contamination.

Table 4-8. WS Detection Classes and Current Sampling and Analysis Capabilities for the GCWW Pilot

Detection Class	Contaminant Class	Laboratory-Based Analytical Method(s)	Field-Based Screening Method or Rapid Field Test(s)
1	Petroleum products	√	√
2	Pesticides (chlorine reactive)	√	√
3	Inorganic compounds	√	√
4	Metals	√	Method not available
5	Pesticides (chlorine resistant)	√	Method not available
6	Chemical warfare agents	Method not available	√
7	Radiochemicals	√	√
8	Bacterial toxins	Method not available	Method not available
9	Plant toxins	√	Method not available
10	Pathogens causing diseases with unique symptoms	√	Method not available
11	Pathogens causing diseases with common symptoms	Method not available	Method not available
12	Persistent chlorinated organic compounds	√	Method not available

4.2.1 Laboratory Capability and Capacity

This section describes equipment and support laboratory enhancements implemented at GCWW. If enhancements were needed to provide the capability to analyze for targeted contaminants, GCWW determined if building in-house capability or capacity was sustainable. If in-house enhancements were deemed sustainable, then consideration was given to providing instrumentation and training to GCWW staff. Otherwise, a partner laboratory with relevant capability was identified to provide the analysis. **Table 4-9** contains a list of enhancements made at the GCWW laboratory.

Table 4-9. Sampling and Analysis Equipment Enhancements at GCWW

Equipment	Justification
Gas chromatograph / mass spectrometer and extraction equipment	• EPA and GCWW determined that it would be more beneficial to purchase a GC/MS and the associated extraction equipment and supplies rather than compensate a contract laboratory for semivolatile organic compound analyses. • Adequate laboratory space was available and GCWW personnel were familiar with the instrument. • This enhancement is sustainable because GCWW, once certified, can analyze its own compliance samples and possibly generate new revenue by providing analyses for other utilities.

Equipment	Justification
Ultrafiltration equipment	• EPA and Ohio Department of Health determined that ODH did not have personnel available to perform the ultrafiltration concentration procedure for baseline monitoring. • Transportation of large volume samples (up to 100 liters each) would be impractical. CDC agreed to allow GCWW use the LRN filter concentration protocol to concentrate samples and ship retentates to Ohio Department of Health for analysis. • GCWW identified staff to conduct the ultrafiltration procedure on-site and Ohio Department of Health provided training. EPA purchased two ultrafiltration units and associated supplies for the GCWW microbiology laboratory.
Incubator	• To support initial and ongoing proficiency demonstrations, EPA procured an incubator for Quality Control procedures requiring bacterial culture at 41°C.
Barcode reader	• The barcode reader was purchased for GCWW to help the laboratory incorporate electronic tracking of laboratory samples. Currently, laboratory staff are integrating barcode reading into their sample tracking procedures.

The addition of new equipment and the use of new methods at GCWW (i.e., ultrafiltration, and gas chromatograph / mass spectrometer semivolatile analysis) required training and instructional documentation. GCWW was already familiar with the gas chromatograph / mass spectrometer instrumentation and operation; however, EPA provided training for extraction and analysis of SVOCs in water.

GCWW did not have any prior experience with the ultrafiltration concentration procedure, so implementation of this capability required drafting standard operating procedures and training. The *Standard Operating Procedure for Routine Pathogen and Toxin Sampling, Packaging, and Shipping* (USEPA, 2007m) describes procedures for large volume sample collection (100 L), transport, packaging, and shipping of concentrated retentate. This document was developed in collaboration with Ohio Department of Health to support the use of the Laboratory Response Network ultrafiltration procedure at GCWW. This standard operating procedure provides guidance to GCWW staff collecting and preparing ultrafiltration retentates for shipment to Ohio Department of Health.

The *Standard Operating Procedure for the Demonstration of Capability Using the CDC/LRN Ultrafiltration Protocol: Determining Recovery of Enterococcus faecalis from Water* (USEPA, 2007n) describes the procedure used by GCWW to demonstrate initial and ongoing demonstration of capability using the filter concentration/ultrafiltration procedure. Proficiency is based on acceptable percent recovery (>50 percent) of *Enterococcus faecalis* spikes using the ultrafiltration procedure and EPA Method 1600. Ohio Department of Health, in conjunction with EPA, conducted training on the use of the Laboratory Response Network filter concentration procedure for GCWW personnel in May of 2006.

In order to analyze for additional contaminant classes, GCWW and EPA built a laboratory network to provide additional and contingency analysis during baseline monitoring and triggered response events. **Table 4-10** lists the partner laboratories that were identified to support analysis of samples and a description of the type of agreement that was utilized.

Table 4-10. Laboratory Contracts and Letters of Intent

Laboratory	Description of Agreement
Metropolitan Sewer District of Greater Cincinnati	The letter of intent between Metropolitan Sewer District and the U.S. EPA made it possible for GCWW to send samples to Metropolitan Sewer District for metals analysis during routine and triggered sampling, as GCWW could not perform these analyses in-house. In addition, a turbidity meter was purchased for Metropolitan Sewer District.
Mobile Analytical Services Incorporated	A contract with Mobile Analytical Services Incorporated allowed for analyses of samples for carbamate pesticides during baseline monitoring. GCWW could not conduct these analyses in-house.
Ohio Department of Health Radiochemical Laboratory	A contract with Ohio Department of Health allowed for analyses of samples for radiochemicals during baseline monitoring. GCWW could not conduct these analyses in-house.

Laboratory	Description of Agreement
Ohio Department of Health Laboratory Response Network Laboratory	A letter of intent with Ohio Department of Health and the U.S. EPA enabled the analysis of samples filtered by GCWW in accordance with the LRN ultrafiltration procedure by the LRN BT Agent Screening Protocol. The letter of intent also made available the necessary LRN reagents for this analysis.
Public Health Foundation Enterprises	A contract provided funding for overtime work in the event that laboratory analysts would have to complete analyses for BT agents at the Ohio Department of Health laboratory outside of normal working hours.
Test America – Savannah	A laboratory contract with Test America, Savannah was established in the event that other local partner chemistry laboratories could not analyze samples for any reason. Test America, Savannah is a large full service environmental laboratory that has a wide variety of drinking water certifications.
Cincinnati Health Department Laboratory	Real time PCR instrumentation was purchased and installed at the Cincinnati Health Department Laboratory to build detection and response capabilities for non-select pathogens (*Bordetella* spp., *Staphylococcus aureus*, norovirus). This is a longer-term project that can hopefully provide support in the second and third year of the pilot.

Contaminant class analytical capabilities, by laboratory, are listed in **Table 4-11**. GCWW analyzed drinking water samples for volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), free cyanide, and concentrated large-volume samples using ultrafiltration for biological analyses. The Ohio Department of Health performed the radiochemical analyses and analyzed the ultrafiltrate prepared by GCWW for biological agents (select agents and toxins). The Metropolitan Sewer District performed the metals analysis. Mobile Analytical Services, Inc. analyzed all the samples for carbamate pesticides. These laboratories were selected based on proximity to GCWW and the ability to use the methods recommended by EPA for the analysis of the priority contaminant classes.

Test America-Savannah performs contingency analyses for the Cincinnati pilot. Contingency analysis serves two purposes: the contingency laboratory can substitute for other laboratories when capacity is exceeded, and the contingency laboratory can process samples in the event that Cincinnati is disabled (e.g., natural disaster). Test America-Savannah was selected as a contract laboratory through a competitive bidding process to perform the analyses listed in Table 4-11. Test America-Savannah is located in Savannah, Georgia, so samples must be shipped via overnight delivery to the laboratory.

Table 4-11. Laboratories Supporting the Cincinnati Pilot, Analytical Methods, and Analytes

Laboratory	Contaminant Class	Instrumentation
GCWW Utility Laboratory and Local Partner Laboratories		
Greater Cincinnati Water Works	VOCs	Gas Chromatography with Mass Spectrometry Detection using purge and trap
	SVOCs	Gas Chromatography with Mass Spectrometry Detection using liquid-solid extraction (LSE)
Greater Cincinnati Water Works	Cyanide	Colorimeter
	Sample Concentration for the LRN BT-Agent Screening Protocol	Pumps and Filters
Metropolitan Sewer District of Greater Cincinnati	Metals	Inductively Coupled Plasma - Mass Spectrometry
Mobile Analytical Services Inc.	Carbamates	High Performance Liquid Chromatography with fluorescence detection

Cincinnati Pilot Post-Implementation System Status

Laboratory	Contaminant Class	Instrumentation
GCWW Utility Laboratory and Local Partner Laboratories		
Ohio Department of Health	BT Agents	Real-time PCR and Immunoassay (TRF) platforms
	Radiochemicals	Alpha Beta Scintillation Scaler or Gas Flow Low-Background Proportional Detector
		High Purity Germanium Gamma Spectrometry System
Test America – Savannah	Metals	Inductively Coupled Plasma - Mass Spectrometry
	Total Cyanide	Colorimetry with Reflux Distillation Extraction
	VOCs	Gas Chromatography with Mass Spectrometry Detection using purge and trap
	SVOCs	Gas Chromatography with Mass Spectrometry Detection using liquid-solid extraction (LSE)
	Carbamates	High Performance Liquid Chromatography with fluorescence detection

*Test America – Savannah will process samples using these methods when Cincinnati area laboratories' capacity is exceeded. This laboratory is also contracted to analyze total cyanide.

4.2.2 Sampling and Analysis

This section describes enhancements implemented for sampling and analysis activities at GCWW as part of the pilot. This includes baseline monitoring design, sampling and analysis plans, standard operating procedures, forms, and other supporting resource documents.

EPA designed a baseline monitoring program at GCWW to determine contaminant occurrence (contaminant, levels detected and frequency of detection) and method performance of the chemical, biological, and radiochemical methods implemented. This design is summarized in the document, *Baseline Monitoring at the Greater Cincinnati Water Works Water Security - Contamination Warning System Pilot* (USEPA, 2007o). The document identifies six phases of baseline monitoring, presents the statistical design of specific sampling efforts, and identifies sampling locations and frequencies to provide adequate spatial and temporal coverage of the GCWW distribution system. The document provides detailed sampling and analysis plans for field measurements, chemical contaminants, radiochemical contaminants, and select agents and toxins. Prior to the development of the baseline monitoring plan, laboratory specific study plans were prepared for Ohio Department of Health and Metropolitan Sewer District.

GCWW requested toxicity information for the targeted contaminants being monitored for during baseline monitoring in case any were detected in drinking water samples. Existing EPA toxicity data for these contaminants was compiled and provided to GCWW in a document titled *Supplemental Information for Water Security - Contamination Warning System Targeted Contaminants Monitored During the Pilot at the Greater Cincinnati Water Works* (USEPA, 2007p).

Several day to day sampling and analysis tools were developed to aid in the execution of sampling and analysis during Cincinnati pilot. These include chain of custody forms for baseline monitoring that contained pre-populated baseline monitoring analyses and laboratory contact information, and Method 1600 data reporting forms developed to standardize the quality control data generated by GCWW when conducting ultrafiltration quality control samples.

EPA created a data management system to store and manipulate data received from the laboratories supporting the pilot. Currently GCWW does not have a laboratory information management system, and many of the support laboratories are inflexible as to the type of electronic deliverables they are able to produce. Therefore, EPA established a separate mechanism to collect electronic data from each source. The various data streams and the database used to house them are summarized in the *WS-CWS Pilot Study Data Management Plan* (USEPA, 2007q).

4.2.3 Field Screening and Site Characterization

This section describes enhancements implemented for field screening and site characterization activities at the Cincinnati pilot. EPA, GCWW, the Cincinnati Fire Department, and the Greater Cincinnati Hazardous Materials Response Unit participated in a series of conference calls between January and April 2006 to discuss and identify field screening equipment that would be most appropriate for a water utility. The equipment and methods were selected to screen for as wide a variety of contaminant classes as possible using available technologies. Preference was given to equipment that had been tested by EPA's Environmental Technology Verification Program. Due to the sensitive nature of revealing specific detection capabilities at the GCWW pilot, **Table 4-12** instead summarizes the contaminant classes for which capabilities were identified and implemented. Ease of use in the field was also considered.

Table 4-12. Cincinnati Pilot Safety Screening and Field Testing Equipment

Safety Screening		
Contaminant Class	**Methodology**	**Comments**
Radioactivity (alpha, beta, and gamma)	Hand-held device	May be expanded to water testing with a special probe
General hazards	HazCat (explosives, oxidants, etc.)	Should be performed by trained HazMat responder
VOCs and combustible gases	Hand-held device	Detects chemicals in air
Rapid Field Testing		
Contaminant Class	**Methodology**	**Comments**
Cyanide	Portable colorimeter	Tests water for cyanide ion, but not combined forms
Chlorine residual	Portable colorimeter	Absence of residual may indicate a problem
pH/conductivity/ORP	Portable electrochemical detector	Abnormal pH or conductivity may indicate a problem
Rapid Field Testing		
Turbidity	Portable Turbidimeter	High turbidity may indicate a problem
Chemical Warfare Agents (VX, sarin, etc.)	Test Kit	May also detect some pesticides and common chemicals
Toxicity	Test Kit	Need to establish a baseline

Once the field screening equipment was purchased, standard operating procedures were developed for each instrument listed in Table 4-12; these standard operating procedures are available in the Site Characterization Plan (Appendix O of the Consequence Management Plan). Field data reporting forms were developed for the new equipment and streamline collection of field screening data and capture time-of-use quality control. GCWW also developed a training program for field equipment. In addition, each analyst is required to perform ongoing quality control. Field screening is practiced regularly during baseline monitoring sampling and would be performed during triggered sampling events. Triggered sample collection activities are identical to baseline monitoring, except that additional health and safety precautions are taken in the field and additional samples may be collected in case additional or contingency analyses are required.

Additional standard operating procedures were drafted for sampling and safety procedures required for triggered sample site characterization activities which were developed by EPA and reviewed by GCWW. These standard operating procedures encompass a wide variety of sample collection activities that might be encountered at GCWW, and include necessary procedures that support sample collection. They include: site approach including hazard awareness, pre-sampling guidelines from drinking water sources, sample container labeling and packaging, decontamination of personnel and equipment, sampling from accessible water taps, sampling from fire hydrants, sampling from water towers, and sampling from underground tanks or reservoirs. The standard operating procedures are also available in the Site Characterization Plan (Appendix O of the Consequence Management Plan).

GCWW, in conjunction with EPA, conducted a sampling and field screening training session in August of 2006 for GCWW, Cincinnati Fire Department, and Greater Cincinnati Hazardous Materials Unit personnel. The training covered all of the standard operating procedures listed above for field screening equipment and triggered field sampling and safety procedures. Follow-up training exercises occurred in April 2007 for GCWW and first responders on appropriate use of the site characterization standard operating procedures. The training also provided guidance to GCWW regarding instances when HazMat Units should be contacted for sample collection. This training is described in more detail by the consequence management component section of this report.

4.2.4 Summary of Post-Implementation Status

EPA and GCWW have worked collaboratively to expand in-house utility laboratory capabilities and developed standard operating procedures for new procedures at GCWW. These include sample concentration using the Laboratory Response Network ultrafiltration procedure, analysis of semivolatile organic compounds, and development of triggered sampling and field screening site characterization procedures. EPA and GCWW have also developed a laboratory network for a wide variety of contaminants for which GCWW does not possess capability to analyze. GCWW site characterization procedures and screening techniques have been developed with cooperation from the Cincinnati Fire Department and the Greater Cincinnati HazMat Unit.

One year of baseline monitoring for all field and laboratory methods should be completed by the end of April 2008. Initial demonstrations of capability were performed for each laboratory analysis that was not part of the state drinking water certification program. Baseline data has been collected from the treatment plants and strategic locations. Data was collected over an extended period of time to evaluate seasonal and temporal trends, and spike recovery studies were pursued to determine matrix interference. A survey study of water from over sixty (60) locations throughout the distribution system was conducted to determine whether local trends could be detected. Maintenance monitoring will continue beyond the baseline monitoring period to maintain response capabilities and to periodically update baseline contaminant occurrence and method performance data. Through implementation of a maintenance monitoring program, the utility will sustain the capability to respond to triggered events.

Table 4-13 lists all of the most significant sampling and analysis capabilities implemented for the Cincinnati pilot.

Table 4-13. Sampling and Analysis Post-Implementation Status

Attribute	Description of Installed Component
1. Laboratory capability and capacity	• Semivolatile organic compound analysis at GCWW • Ultrafiltration concentration capability at GCWW • Laboratory response network capable of analyzing drinking water samples for EPA priority contaminant classes
2. Sampling and analysis	• Baseline monitoring design • In April 2008, GCWW will have completed one year of baseline monitoring. Results from the baseline monitoring period will be used to determine a maintenance monitoring schedule. EPA is working with GCWW to address unique sampling and analysis scenarios such as sample apportionment for analyses when sample volume is limited and evidentiary chain of custody procedures.
3. Field screening and site characterization	• Purchased field screening equipment for GCWW and local HazMat teams • Developed site characterization procedures compatible with local HazMat response teams • Integrated local HazMat response teams into the GCWW triggered sampling procedures • Four triggered sampling kits were assembled by EPA, in case a triggered event occurred • Currently the consequence management component has performed two field drills for triggered sampling, one including CFD and Greater Cincinnati Hazmat Unit. The drills are described in more detail in the consequence management section.

Figure 4-1 provides a summary of the level of effort associated with design and implementation of the sampling and analysis component for the Cincinnati pilot. Sampling and analysis activities, as summarized in Table 4-13, relied on support from EPA, GCWW, and local partners. The most significant effort was associated with coordination of sampling and analysis activities during implementation of baseline monitoring at GCWW. Utility laboratory personnel at GCWW were responsible for collecting all baseline monitoring samples, and conducted some sample analyses for targeted biological and chemical analytes. Local partner laboratories expended a considerable amount of effort during implementation of the pilot study to analyze samples that could not be processed at the utility laboratory. EPA also expended effort to conduct training at the utility to increase analytical capability and familiarize personnel with field screening/site characterization activities.

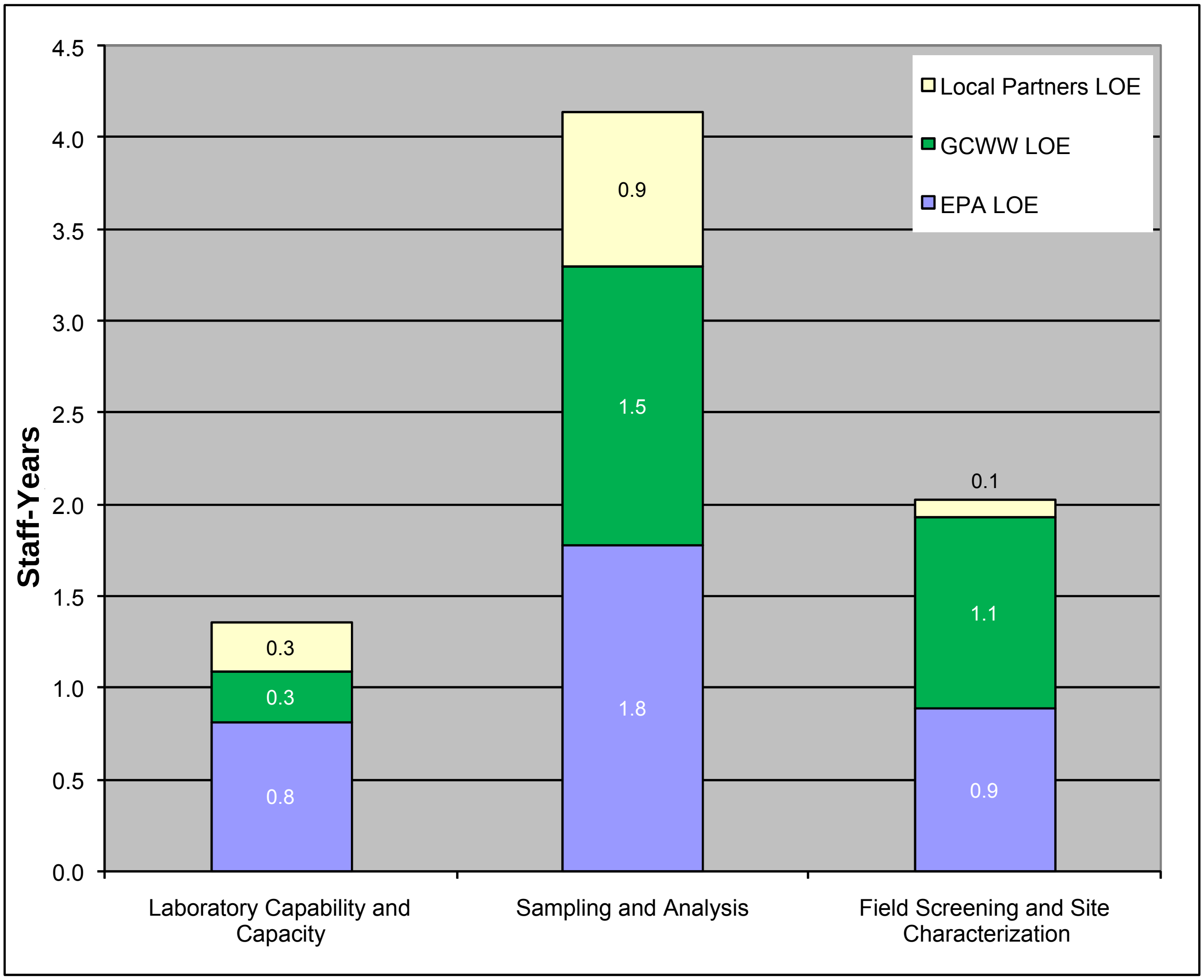

Figure 4-1. Level of Effort for Design and Implementation of the Sampling and Analysis Component (December 2005 – December 2007)

Figure 4-2 presents a summary of the extramural costs associated with design and implementation of the sampling and analysis component for the Cincinnati pilot. The most significant extramural labor costs include contractor activities associated with coordination of sampling and analysis activities during implementation of baseline monitoring at GCWW. Baseline monitoring sample data was transmitted to and analyzed by EPA contractors. The EPA contractors were also integrally involved in the establishment of a laboratory network to expand and enhance the analytical capabilities of the utility laboratory. The most significant equipment costs included procurement of analytical laboratory equipment, including a GC/MS, which was installed at GCWW. Chemistry standards, reagents, and consumable supplies (i.e., ultrafiltration equipment) were purchased for GCWW and several local partner laboratories during baseline monitoring, to allow for analysis of targeted priority contaminants. Costs associated with contractor travel were not included in this calculation.

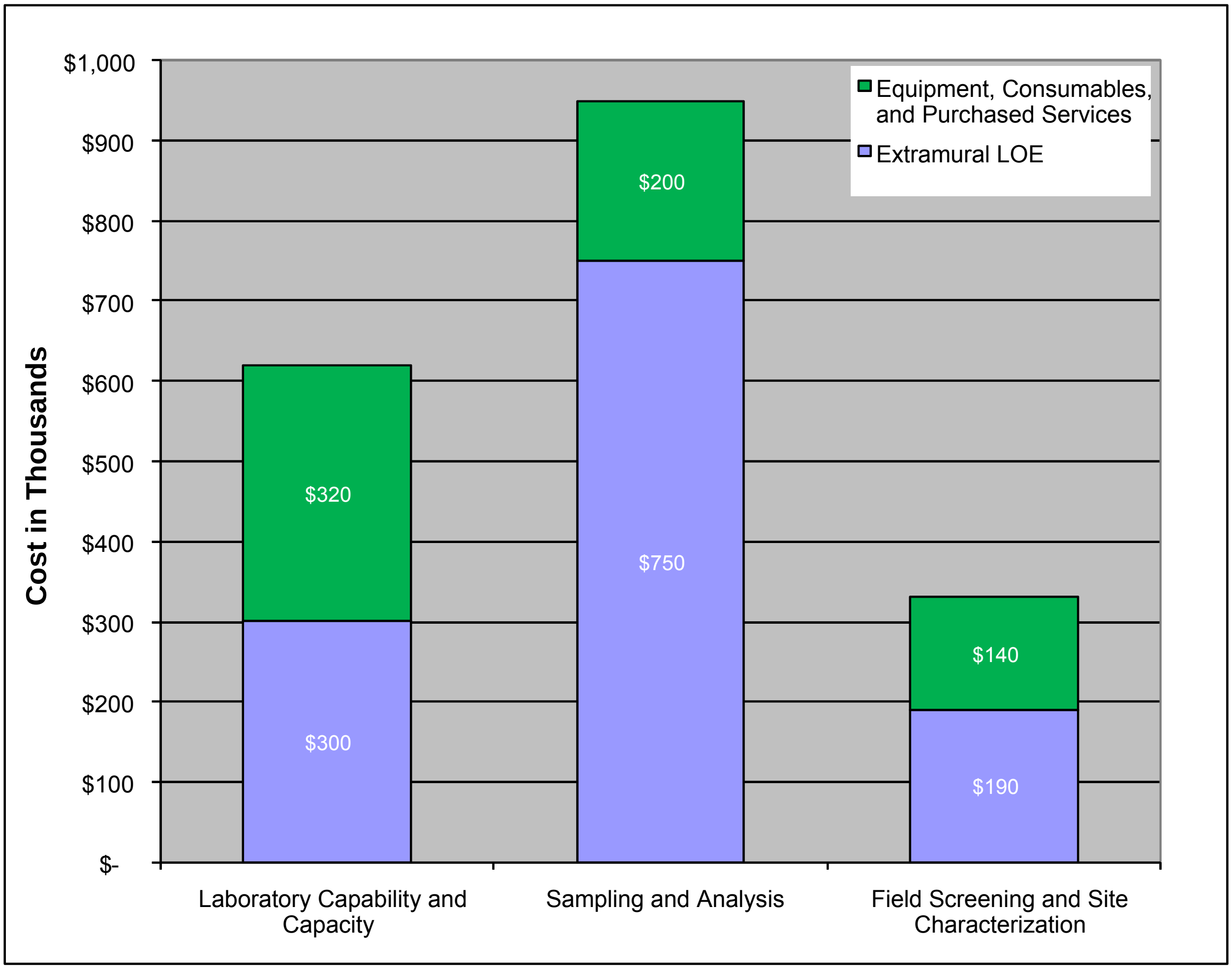

Figure 4-2. Extramural Costs Associated with Design and Implementation of the Sampling and Analysis Component (December 2005 – December 2007)

Costs associated with establishing laboratory capability and capacity and conducting baseline monitoring represent a significant portion of costs associated with sampling and analysis for the Cincinnati pilot. **Figure 4-3** shows the expenditures by laboratory to build capability and perform baseline monitoring for the Cincinnati pilot. The largest investment was made at GCWW. Costs included purchase of a GC-MS and equipment for SVOC extraction, bar code readers, pathogen concentration equipment, etc., (see Table 4-9) as well as reagents and supplies for sample collection, packaging, shipping and analysis. Contract laboratory support is the next largest expenditure. Contract laboratories provided analyses of samples for metals, carbamates, radiochemicals and provided contingency analyses. Refer to Table 4-11 for a description of partner laboratory roles. Expenses at the Cincinnati Health Department Laboratory were primarily for PCR equipment to build future capabilities to analyze for non-select agents in water. Expenditures for select agent analyses at the Ohio Department of Health Laboratory were primarily for reagents and consumables.

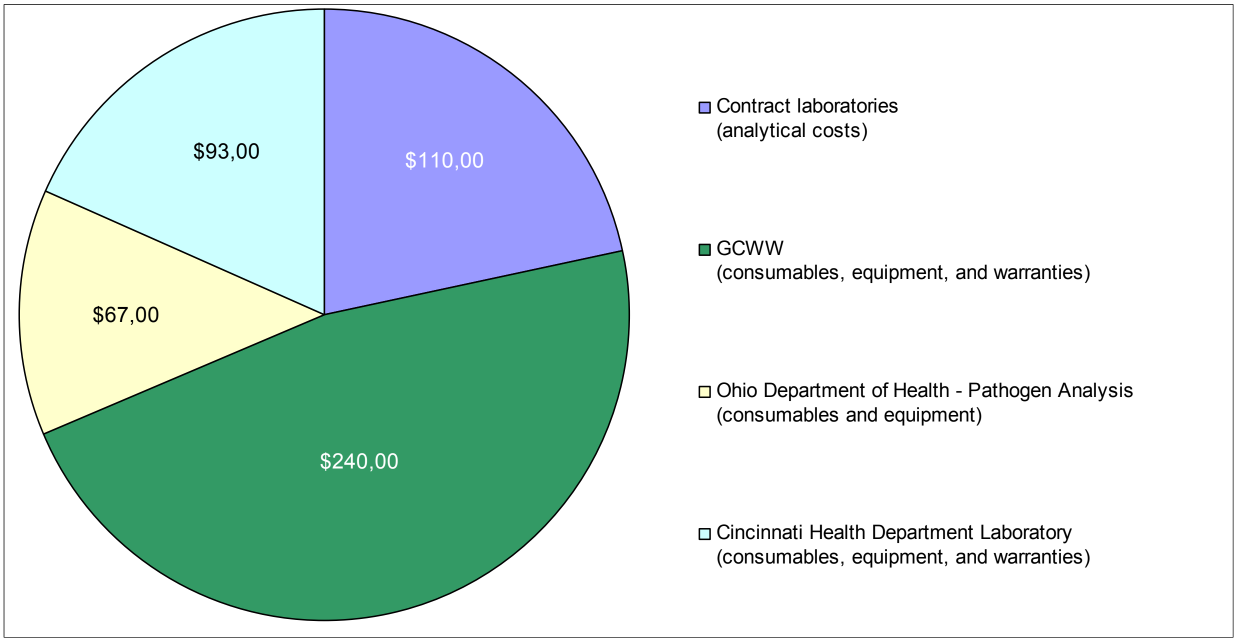

Figure 4-3. Breakdown of Expenditures per Laboratory

Expenditures were made to build capability for pathogen analysis in three (3) laboratories; the GCWW Miller Treatment Plant Laboratory, the Ohio Department of Health Laboratory and the Cincinnati Health Department Laboratory. **Figure 4-4** presents the costs associated with this effort. During baseline monitoring for select agents, GCWW utility personnel collected and concentrated by ultrafiltration large volume water samples. Special equipment had to be purchased for this purpose. Consumable expenses at the GCWW laboratory included sample collection containers, preservatives, reagents and supplies for concentration of samples as well as reagents and supplies to analyze samples for quality control purposes. The Ohio Department of Health Laboratory performed secondary filtration and analysis for five select agents. The bulk of expenditures for the Ohio Department of Health were for consumables to perform these expensive analyses as well as for method optimization experiments. Equipment purchases for the Ohio Department of Health were for small items, e.g., automatic pipets to increase processing efficiency. An investment was made in the Cincinnati Health Department Laboratory to build future capabilities for non-select agent analysis using real-time PCR. Work is still in progress to evaluate methods for the analysis of non-select agents in water at the Cincinnati Health Department Laboratory.

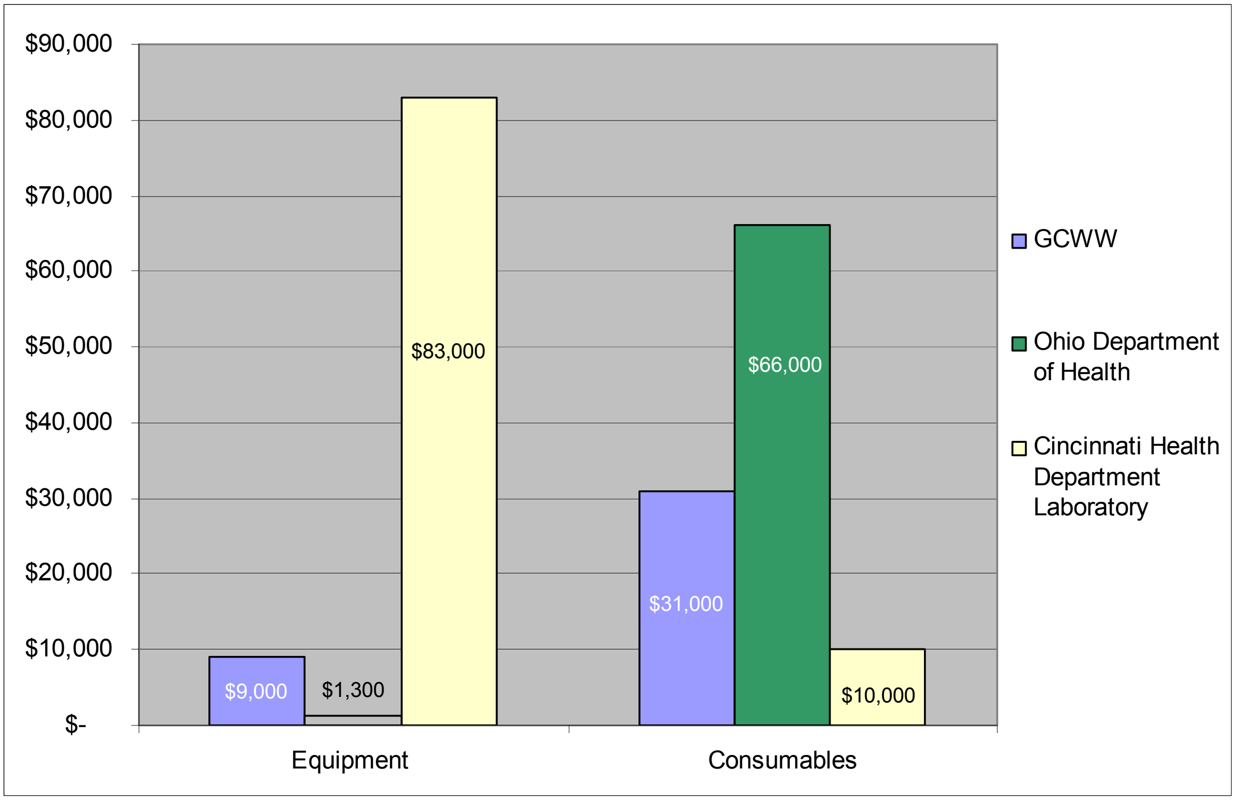

Figure 4-4. Costs Associated with Establishing Pathogen Monitoring Capabilities

Section 5.0: Enhanced Security Monitoring

The enhanced security monitoring component includes the systems, equipment, and procedures that detect, delay and respond to security breaches at distribution system facilities such as pump stations, reservoirs and storage vessels that are vulnerable to contamination. The monitoring strategy includes detection by physical security systems such as alarms and cameras, witness accounts, notifications by perpetrators, media, and law enforcement, as well as associated response methods. Alarms and video are transmitted to the central control facility at the Miller Plant (California Control Center), where they are monitored by GCWW personnel. Under the contamination warning system model, enhanced security monitoring is designed to help discriminate between notifications that may be related to a contamination incident and those resulting from other activities.

The enhanced security monitoring component design objectives are shown in **Table 5-1**, and were derived from the overarching performance objectives of the contamination warning system as described in *WaterSentinel System Architecture* (USEPA, 2005a). GCWW's pre-existing capability with respect to each attribute of the enhanced security monitoring component listed in Table 5-1 is summarized in Section 5.1 and the utility's capability after implementation of the contamination warning system is summarized in Section 5.2.

Table 5-1. Enhanced Security Monitoring Component Design Objectives

Design Element	Design Objective
1. Physical Security Equipment	Contact alarms, motion sensors and cameras designed and installed to detect intrusion and help discriminate between potential contamination threats and routine access to facilities.
2. Data Management and Communications	Communication technology which would allow video of sufficiently good quality to be transmitted in a time frame which could assist in stopping a contamination event or limiting the spread of contamination.
3.Component Response Procedures	Written standard operating procedures exist for every step in responding to a security monitoring alarm. These procedures outline effective and timely communications, including clear guidance on appropriate response actions

5.1 Pre-Implementation Status

After completing a vulnerability assessment, as required under the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (USFDA, 2002), GCWW chose to concentrate their limited funding on intruder delay and intrusion detection capabilities for distribution system facilities, rather than more advanced assessment technologies, such as video surveillance. Prioritization of the security enhancements for distribution system facilities focused on addressing the facilities with the highest consequence of attack. Intruder delay measures, which limited access to facilities with perimeter fencing and locks on points of entry, were installed at all facilities. Detection and assessment for these facilities would only occur through periodic site visits by GCWW maintenance personnel or by GCWW security staff. Intrusion detection equipment, such as contact alarms or limit switches on points of entry, was installed on all stations and tanks. Motion sensors were installed at one of the major pumping facilities.

Thus, prior to the implementation of the contamination warning system, the physical security systems and processes in place for GCWW distribution facilities were primarily intended to delay entry of unauthorized individuals and detect intrusion. GCWW did install motion sensors in one facility parking lot to deter theft from outdoor storage areas. Further details on the assessment of the existing systems, identification of gaps and proposed enhancements, and the prioritization process for final selection of improvements can be found in the *WaterSentinel Enhanced Security Assessment* (USEPA, 2006c).

5.1.1 Physical Security Equipment

During the physical security equipment assessment, GCWW's facilities were categorized into three groups that presented distinct vulnerabilities: pump stations, reservoirs/ground-level storage tanks, and elevated storage tanks. The equipment and systems in place at each type of facility prior to implementation of the contamination warning system are discussed in the following sub-sections.

5.1.1.1 Pump Stations

All pump station doors were fitted with contact switches which would trip any time the door was opened. The switches would send a door alarm signal via the utility SCADA system to California Control Center every time the door was opened. No contact or motion sensors were provided on windows or ventilation louvers to detect intrusion.

Additionally, an access control system (key card) was in place on the entrance doors at the two largest pump stations. The access control system provides for keyless entry, but is completely separate from the door alarm system. Contact switches on the station doors signal an alarm upon any entry to the facility whether or not a key card was used for entry. The access control system has a monitor in the guard post at the Richard Miller Treatment Plant that displays whether a key card was used to open a door, but this data was not communicated to the SCADA system. Therefore, entry via a key card triggers the alarm in the same manner as access at locations without the keyless entry system.

5.1.1.2 Reservoirs and Ground-Level Storage Tanks

All reservoirs and ground storage tanks were fitted with contact alarms on access hatches and doors. Metal ground-level storage tanks are cylindrical with a sizable side wall depth. Access to the top of the tank and the water surface was typically provided by an enclosed ladder. In most locations, a contact alarm or limit switch was provided on the access door to the ladder compartment. Cast-in-place concrete reservoirs are typically below grade. Personnel access to the reservoirs is provided through a stairway in an adjoining pump station or through sidewalk style access hatches. In most locations, a contact alarm or limit switch was present on the stairway access door or access hatch. Cylindrical post tensioned reservoirs have a low profile such that access to the top can be gained using a portable ladder or in some cases a portion of the tank top is at grade with the surrounding hillside. Access hatches are provided on the domed roof for access to the interior of the tank. In many locations, contact switches were present on the doors and access hatches.

All reservoirs and tanks have passive vent structures allowing air to enter and exit the storage area as the tank emptied or filled. The vent structures on reservoirs typically consisted of a box with louvers on at least one side. The vents on the cylindrical concrete tanks are manufactured aluminum or fiberglass reinforced plastic units with a mushroom shape. The openings on both type vents are covered with a screen to prevent animals from entering the storage tank, but the screens would provide little barrier to intruder access.

5.1.1.3 Elevated Storage Tanks

Access to the interior of the elevated storage tanks is provided via a ladder enclosed in the tank base or in an enclosed access shaft. The access door to the area containing the ladder was fitted with a contact alarm.

5.1.2 Data Management and Communications

Security data was managed through a custom Citect SCADA application installed during an upgrade in 2006. Door and hatch contact alarm signals were transmitted to the California Control Center and displayed on the human/machine interface to the Citect SCADA system along with operational data and alarm signals. The alarm signals on the HMI were common alarms indicating only that a door or access hatch alarm was open without identification of the specific door at that facility. The screens on the operations monitors accessed by the operators at the control center were configured to highlight operations data and system status parameters needed by the operators to maintain target water quality and pressure. The monitors and screens were judged by GCWW to display and manage nearly the maximum amount of data that operations staff could process in performing their operations duties.

A well-developed data communication system was in place at GCWW prior to implementation of the contamination warning system, primarily to support operational needs for water quality and pressure monitoring and control. T1 lines were used for communications between the California Control Center and the two largest pump stations. Private radio was used for some other remote locations; however the hilly topography of the Cincinnati area prevented direct radio communications from many locations to the California Control Center, so standard phone lines were used to transmit information in many situations. The communications system in place for the monitoring and control systems for the distribution systems facilities was developed to provide reliable yet efficient transfer of operational data and control signals between the operations center and the remote facilities. The data transfer capacity of the system was adequate for existing operational needs with some additional available capacity for future operational-related parameters. The communications system had insufficient capacity for high bandwidth additions, such as video communications.

The door access system in place at the two large pump stations is a Simplex brand system that provides for key card access to a door and identification of the status of individual key card access doors. The control system maintains a record on the time of entry of each key card controlled door. The Simplex system data record is accessible at the Richard Miller Water Treatment Plant guard house.

5.1.3 Component Response Procedures

Security alarms were indicated at the operations station in the California Control Center. Prior to the introduction of the contamination warning system enhancements, the security alarms at distribution system facilities were confined to door access or hatch access alarms. For all such alarms, the GCWW protocol was that a utility employee entering a facility was required to call the California Control Center within two minutes of entry to inform the operators that they had accessed the door. When the staff followed protocol and called in to report their visit, the alarm was dismissed. If the California Control Center did not receive a call within 2 minutes, the operator would contact local law enforcement and notify GCWW security staff of the potential unauthorized intrusion.

The security staff of GCWW is charged with securing the central utility office, treatment facilities and distribution facilities. GCWW closely partners with all law enforcement agencies/jurisdictions in their large geographic service area for investigation of intrusion incidents. These partnerships were based on a concerted effort by the utility to minimize the number of false alarms.

5.1.4 Summary of Identified Gaps

Table 5-2 presents the gaps identified during the initial assessment. Section 5.2 describes the post-implementation status for each of the attributes listed below.

Table 5-2. Enhanced Security Monitoring Component Gap Analysis

Design Element	Description of Gap
1. Physical Security Equipment	• Existing ground storage tank vent structures provided an opening near the ground surface through which a contaminant could be introduced to treated water stored at atmospheric pressure; no system was in place to minimize or detect intrusion at or around the vents. • The security system in place for the pump station facilities provided for detection of intrusion only and not assessment.
2. Data Management and Communications	• The communications system had insufficient capacity for high bandwidth additions such as video communications.
3. Component Response Procedures	• A formalized, documented process for responding to security alarms was in place. However, due to the security improvements recommended as part of the pilot project, the existing process needed to be revised.

5.2 Post-Implementation Status

In conjunction with GCWW, EPA first reviewed the results of their initial vulnerability assessment, completed as required under the "Bioterrorism Act" (USFDA, 2002). The approach described in the *WaterSentinel Enhanced Security Assessment* (USEPA, 2006c) and shown in **Table 5-3** was used to prioritize facilities which would receive security system enhancements as part of the WS program.

Table 5-3. Enhanced Security Monitoring Design and Implementation Approach

Activity	Description
1. Preliminary Facility List	Determination of which GCWW distribution system facilities (elevated storage tanks, ground storage reservoirs and pump stations) may be at the highest risk for contamination. The list was developed primarily based on simulations of contamination at 28 of the facilities represented in the GCWW water quality and hydraulic model, as well as knowledge of system hydraulics for two facilities that are not in the model. In addition, other factors were considered, such as site location, accessibility and visibility.
2. Site Assessment	A detailed site assessment was performed for the facilities, including investigation of structural attributes and physical locations of the facilities and existing security systems and practices. These included physical security, proximity to the public, terrain, adjacent land uses, site access, site lighting, alarm and detection systems, and physical barriers such as fencing and hardened structures.
3. Design Basis Threat	The threats faced were defined, including types and capabilities of adversaries and quantity and type of contaminants that could be used.
4. Risk Ranking	The contamination risk faced by each facility was evaluated by estimating the effectiveness of existing security systems, the consequence of contamination at that facility, and the probability that a facility may be attacked. This approach used a modified approach to the Risk Assessment Methodology for Water (RAM-W™), developed by Sandia National Laboratory.
5. Improvements Recommendations	For facilities ranked highest, a more detailed evaluation was done of existing security systems, and recommendations were made for potential security system improvements, including cost estimates. A cost-to-benefit analysis was done by estimating cost in terms of the amount that contamination risk would be reduced by implementing the security improvements. Improvements were made at facilities with the best cost–to-benefit ratios that could fit within the component budget of $400,000.

5.2.1 *Physical Security Equipment*

Table 5-4 provides a complete list of the major security equipment installed as part of the contamination warning system, organized by location. The sub-sections following the table discuss the equipment installed at each group of facilities.

Table 5-4. Enhanced Security Components at GCWW Distribution Facilities

Component	Manufacturer	Model	Quantity	Site(s) Installed (Quantity)
ESM PLC	Bristol	Controlwave Micro PLC	3	3 Pump Stations
Local Facility Switch	Cisco	2955	3	3 Pump Stations
Digital Cellular Modem	Digi	Connectport WAN VPN 3G 300 KBPS*	3	3 Pump Stations
Remote Video Engine	Longwatch™	RVE-100	3	3 Pump Stations
Cameras	Pelco	CC377OUH-6-Fixed	6	3 Pump Stations
		SD53CBW-PG-1-PTZ	5	2 Pump Stations

Component	Manufacturer	Model	Quantity	Site(s) Installed (Quantity)
Door Status Switch	GE Security	2507AD	35	3 Pump Stations
Hatch Status	GE Security	2507AH	13	4 Reservoirs
Level Switch	Omega	LV-40	5	4 Reservoirs
Ladder Motion Sensor (MSL)	Protech	Piramid SDI-77XL-DIR-LT	7	2 Stand pipes at pump stations 4 Elevated tanks 1 Ground level storage tank
Indoor Motion Sensor (MSC)	Honeywell	Intellisense DT-906 120' x 10' Pattern	10	3 Pump Stations
Rollup Door Status (RS)	GE Security	2317AH	2	1 Pump Station

* This is the modem capacity on a 3G network. The CBT network is currently a 2.5G network using the EDGE technology. Actual network throughput is around 50 kbps.

5.2.1.1 Pump Station Equipment

The video monitoring equipment was the most important piece of the security enhancements installed at the three (3) pump stations. The Longwatch™ video system was selected because it includes a unique feature that provides event-based video versus continuously streaming video typically found in conventional closed circuit TV systems. This allows the Longwatch™ video system to function on low bandwidth communication networks, and so may have applicability beyond the Cincinnati pilot. The intent of the event-based system is that while the Longwatch™ system continuously records the video from the cameras on a local video recorder, it only sends short duration video clips in response to a detected security incident. Thus, while streaming video continuously consumes considerable bandwidth on the communications system, the event-based video clips imposes only a brief data load on the system. The continuous video stored on the video recorders at each of the pump stations provides an additional assessment tool for intrusion after the event, without imposing a heavy communications load. Event detection at the pump stations is provided by contact switches on external doors and by area motion detectors on interior walls that have windows or ventilation louvers. The video clips are transmitted to the California Control Center for assessment by the operations staff monitoring the human/machine interface consoles. This approach provides a very communications-efficient means of using video.

Except for entrance gate monitoring (discussed below), the video systems deployed at the pump stations were entirely confined to the interior of the stations. The intent was to detect and respond to intrusion where the perpetrator has access to water-bearing equipment and piping. The video cameras are intended to capture video clips of the area where intrusion occurs in order to provide an initial assessment of the intruder. To achieve this level of functionality, two different types of video cameras were used: pan-tilt-zoom (PTZ) and fixed cameras with zoom capability. The PTZ cameras can rotate to provide coverage over a large area and zoom in on a specific location. These cameras provided video coverage of multiple intrusion points more cost effectively than individual fixed cameras for each entry point. The fixed cameras were used for pump stations with four (4) or fewer points or areas of entry. One (1) camera was enclosed in a sealed and pressurize cylinder because the access area atmosphere contained a high concentration of chlorine that would be corrosive to a camera in a standard enclosure.

Supplemental lighting systems were also installed in the pump stations and tied to the video controls. The lighting systems provided sufficient illumination for resolution of the video images, whether taken in daylight or nighttime conditions. The supplemental lights are energized any time a door contact or motion sensor alarm is tripped. Halogen or fluorescent bulbs were used for supplemental lighting because of the slower illumination time associated with metal halide or sodium vapor lights. A detailed description of the function and operation of the video systems is provided in *Water Security Initiative Enhanced Security Monitoring Video Intrusion Alarm Assessment Operations Manual* (USEPA, 2007r).

Because of the frequency of deliveries and visits by non-utility personnel to two (2) pump stations, GCWW requested that fixed cameras be installed outside these locations to provide video coverage of the vehicle gates. The vehicle gates allow access to employees with key cards. The video cameras allow the California Control Center operators to take a video clip when a call is received to verify the identity of the caller before opening the gate. The vehicle gate cameras also provide for intrusion assessment if a large vehicle was used to break through the gate.

Two (2) of the pump station facilities also have large standpipes that provide access to finished water from the treatment plant. Motion sensors were installed for the ladders that provide access to the top of the standpipes. These sensors send an intrusion alarm back to the California Control Center, but are not tied into the video control systems.

5.2.1.2 *Reservoir and Ground Level Storage Tank Equipment*

Enhanced security equipment was installed at five (5) reservoirs, including four (4) circular tanks with walls projecting above ground level and shallow domed concrete roofs, and one (1) cast-in-place reservoir that is entirely below the ground surface. For reservoirs with above ground roofs, rectangular fabricated aluminum structures were added over the existing vent structures to eliminate direct access to the vents. The structures contained screened holes in the walls of at least equal area to the openings in the vents to allow the vents to function as intended. However, the openings were covered with a screen and inverted L-shaped louvers to block the line of sight to the vent. The structures were also fitted with sidewalk style hatches to provide access to the vents for inspection and cleaning.

Two (2) types of intrusion detection devices were installed at each vent enclosure. The first was a contact switch on the hatch that sends an alarm when the hatch is opened. The second was a liquid-level switch installed at the base of the enclosure sidewall. The enclosures have drain holes at the base to allow rain water that enters through the louvers to drain out. The liquid-level switches were provided to detect a situation where a terrorist would plug the drain holes and the louvers and introduce a liquid contaminant into the enclosure. The liquid level switch inside the enclosure will send an alarm to the California Control Center if the fluid level in the structure rises to the detection level. The reservoirs have existing access hatches which were previously fitted with contact switches. The alarm signals from the vent enclosure are wired in series with the existing access hatch alarms.

The single below-grade reservoir is accessed by a stairwell in an adjacent pump station. The stairwell has only an exterior door, which is already protected by an alarm. A fixed camera was installed inside the stairwell and enclosed in a sealed container to protect against chlorine vapors that may corrosive to the camera (see Section 5.2.1.1).

5.2.1.3 *Elevated Storage Tank Equipment*

Four (4) elevated storage tanks and one (1) ground storage tank were fitted with enhanced security equipment. Each of the tanks has a ladder to provide access to the top of the storage bowl. The ladder is enclosed either in the center column or in a side column (in the case of the ground level storage tank). The entrance doors to the enclosures were protected by existing contact switches, so motion sensors were installed for the ladders to provide an added level of security. The ladder motion sensors have both microwave and infrared sensors; both sensors must be activated to trigger an alarm. The enclosures typically contain equipment in addition to the ladder, so the motion sensors were installed at least thirty feet up the ladder to reduce false alarms from floor-level personnel accessing this equipment (i.e., only an intruder climbing the ladder would be sensed). Both the door contact switch and the ladder motion sensor alarms are relayed to the operators at the California Control Center. This approach provides two (2) sources of alarms, which helps to screen-out false alarms arising from the motion sensors and from utility staff entering the tank base who neglect to call the California Control Center.

5.2.2 Data Management and Communications

The existing contacts and sensors installed at the storage tanks and reservoirs require minimal data flow capacity for communication to the California Control Center, and have low data capacity needs for storage of event records. The data management and communications needs for these systems were readily accommodated by the existing GCWW SCADA system. However, it was decided that other alarm signals, video clips and live video from the pump stations would be best transmitted to the California Control Center via a separate digital cellular network. Thus, a parallel WS SCADA system was installed for the pilot project to assist in data transmission for both the enhanced security monitoring component and the water quality monitoring component. Section 3.2.3 provides more details on the architecture of this parallel WS SCADA system. A HMI was also deployed at the California Control Center as part of this parallel WS SCADA system to allow the operators to assess and respond to intrusion alarms for the pump station sites. The SCADA HMI also provided an interface for the operators to manage the video alarm assessment.

The normal operating mode for Longwatch™ is to transmit single frame images from the cameras at each monitored facility to the California Control Center at regular intervals, while also retaining continuous video files in digital video recorders, termed remote video engines. When a security event is indicated by a tripped door contact switch or a motion sensor signal, the fixed camera remains stationary, while the PTZ camera focuses on the preset view dedicated to the particular intrusion location. The Longwatch™ video system accesses the video data from the camera covering the intrusion location and assembles a short video clip of adjustable duration (initially set at ten seconds) beginning at the time of the alarm for the PTZ cameras and three seconds before the alarm for the fixed cameras. The intrusion event clip is transmitted to the operators in the California Control Center for assessment.

The Longwatch™ system Video Control Center software at the California Control Center maintains a record of alarm events and stores attributes of the alarms and any video clips that result. This system allows the video data to be reviewed after an event for further assessment. A full video record is maintained in the video recorders located at each facility. Video data from the remote recorders must be downloaded manually and are intended for use in post-event investigations to support criminal prosecution and provide a more complete record of the actions of an intruder. More details on the operation of the Longwatch™ video systems can be found in the *Enhanced Security Monitoring Video Intrusion Alarm Assessment Operations Manual* (USEPA, 2007r).

5.2.3 Component Response Procedures

To ensure GCWW timely response to the newly installed enhanced security alarms, EPA in conjunction with GCWW reviewed the existing response procedures for investigating a security alarm and modified the procedures based on new security equipment, such as the video cameras. Distinct protocols were developed depending on the whether the security alarm was from a video or non-video site. The procedures were documented in the *Concept of Operations for the GCWW Contamination Warning System* (USEPA, 2007b). The Concept of Operations guides initial alarm validation actions, defines specific roles and responsibilities and outlines process and information flows for the enhanced security monitoring component. It also provides a formalized process that concludes with the determination if an alarm or a witness account is or is not a “possible” contamination incident. If a possible contamination incident is identified through the enhanced security monitoring component, the process outlined in the Concept of Operations would transition the utility personnel to the credibility determination process outlined in Consequence Management Plan. EPA provided training to GCWW mid-level managers in June 2006 on the use of the enhanced security monitoring Concept of Operations and the associated procedures.

The enhanced security monitoring systems that involve video provide for a considerably more rapid assessment of security breaches at critical pump stations. Without the video, the sole means of assessing a breach is to dispatch personnel to the remote facility. The Longwatch™ system begins to capture the video clip the instant a security alarm is tripped, and within two minutes a video clip is received at the

California Control Center. This allows the operator to verify whether the person entering the station is an unauthorized intruder and if so, to develop a description and begin to assess the actions of the intruder. The information will allow security personnel who are dispatched to prepare for response actions and minimize assessment time when arriving at the site. If the video clip or subsequent video monitoring clearly confirms a possible contamination event, this information will allow utility personnel to begin preparation for response actions such as isolation of the facility suspected to have been the target of tampering.

At the elevated storage tanks, the addition of the ladder motion sensors provides more definitive information that an intruder has entered the site and has moved towards the finished water supply. Although a thorough assessment must still be completed by personnel dispatched to the site, the dual alarm signals provide a more complete record of the possible intrusion, and may communicate a higher level of urgency to the security team dispatched to the site.

5.2.4 Summary of Post-Implementation Status

Enhanced security monitoring equipment was installed at three (3) pump stations, four (4) finished water reservoirs, four (4) elevated tanks and one (1) ground storage tank. A digital cellular network was installed to accommodate data communication needs for both video surveillance equipment and online water quality monitoring equipment (see Section 3.2.3). Response protocols, which document the necessary human actions to both existing and newly installed security equipment alarms, were written and mid-level manager training on these protocols was completed. **Table 5-5** provides a summary of the post-implementation status of the enhanced security monitoring component of the contamination warning system.

Table 5-5. Enhanced Security Monitoring Component Post-Implementation Status

Design Element	Description of Installed Component
1. Physical Security Equipment	• Completed an enhanced security assessment report outlining recommended security improvements. • Completed engineering designs for security improvements and coordinated project management activities. • Installed video cameras, motion sensors, door contact switches and transmission equipment at 3 pump stations to enable visual identification of a potential intruder with intent to contaminate water. • Installed vent covers on 3 ground level storage tanks with liquid level sensors and hatch contact switches to deter the introduction of contaminates. • Installed ladder motion sensors on 7 water storage tanks to provide additional detection of potential intruders climbing towards the finished water.
2. Data Management and Communications	• Video data are transmitted via a secure digital cellular network system in conjunction with water quality monitoring data. • Video data are displayed on a dedicated user interface with menu drive commands to request additional video clips and remotely control pan-tilt-zoom cameras. • Contact alarm data are shown for pump stations and elevated tanks as distinct alarms, which provides better data for security assessments.
3. Component Response Procedures	• Developed and trained enhanced security personnel on the Concept of Operations, which documented security roles and responsibilities for specific alarm types (video, ladder motion sensor, door contact).

Figure 5-1 provides a summary of the level of effort associated with design and implementation of the enhanced security monitoring component for the Cincinnati pilot. Enhanced security monitoring activities, as summarized in Table 5-5, relied on support from EPA, GCWW, and local partners. Early efforts for the enhanced security monitoring component focused on identification of recommended utility locations for security enhancements, and coordination of installation of security devices. Data management and communication activities were coordinated with related efforts to support online water quality monitoring. The level of effort displayed below reflects those activities specific to the enhanced security monitoring component.

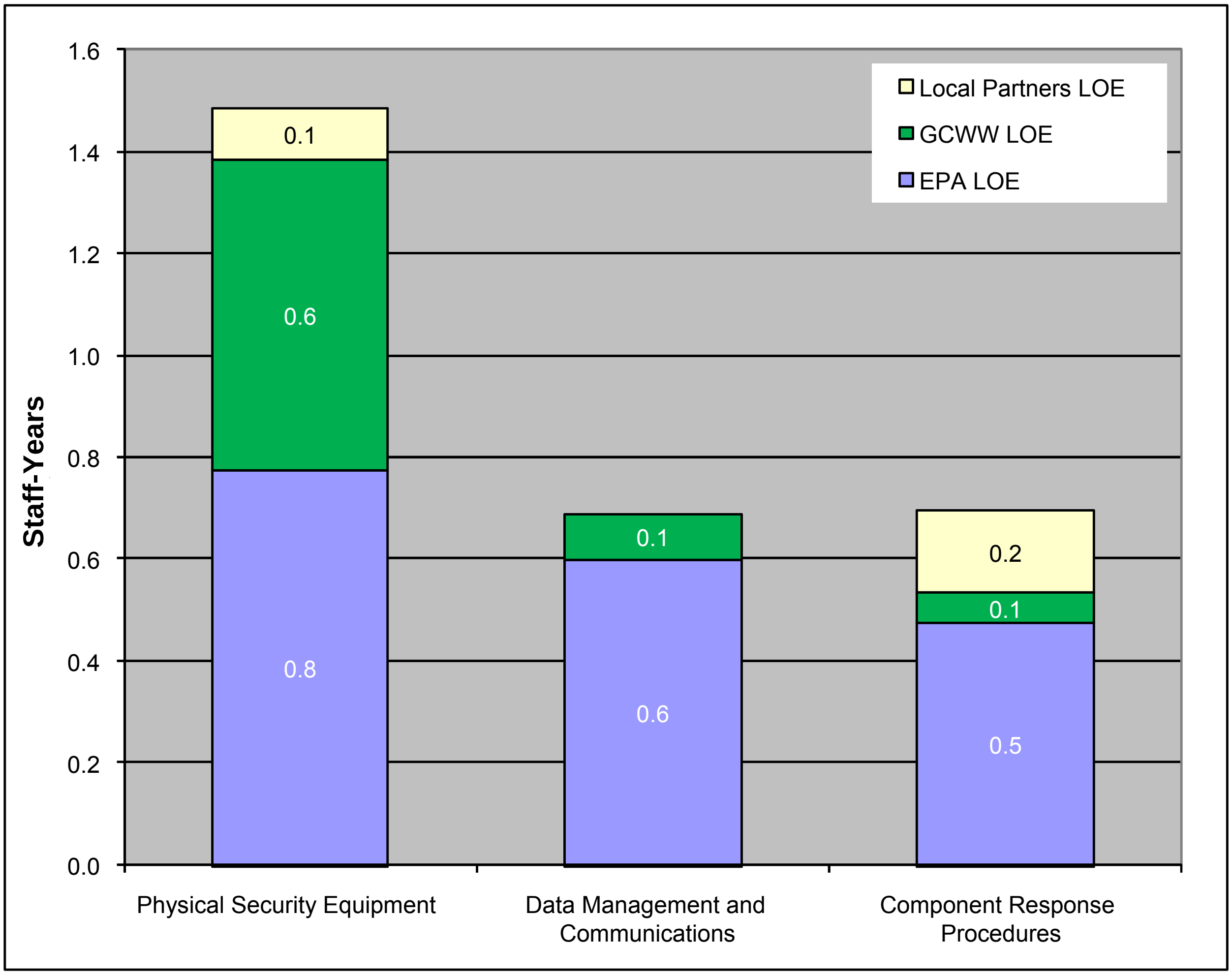

Figure 5-1. Level of Effort for Design and Implementation of the Enhanced Security Monitoring Component (December 2005 – December 2007)

Figure 5-2 presents a summary of the extramural costs associated with design and implementation of the enhanced security monitoring component for the Cincinnati pilot. As illustrated, the most significant contractor costs dealt with the procurement and installation of visible security equipment. Equipment costs included procurement of physical security equipment, such as video cameras, motion sensors, door contact switches, and transmission equipment. Costs associated with contractor travel were not included in this calculation.

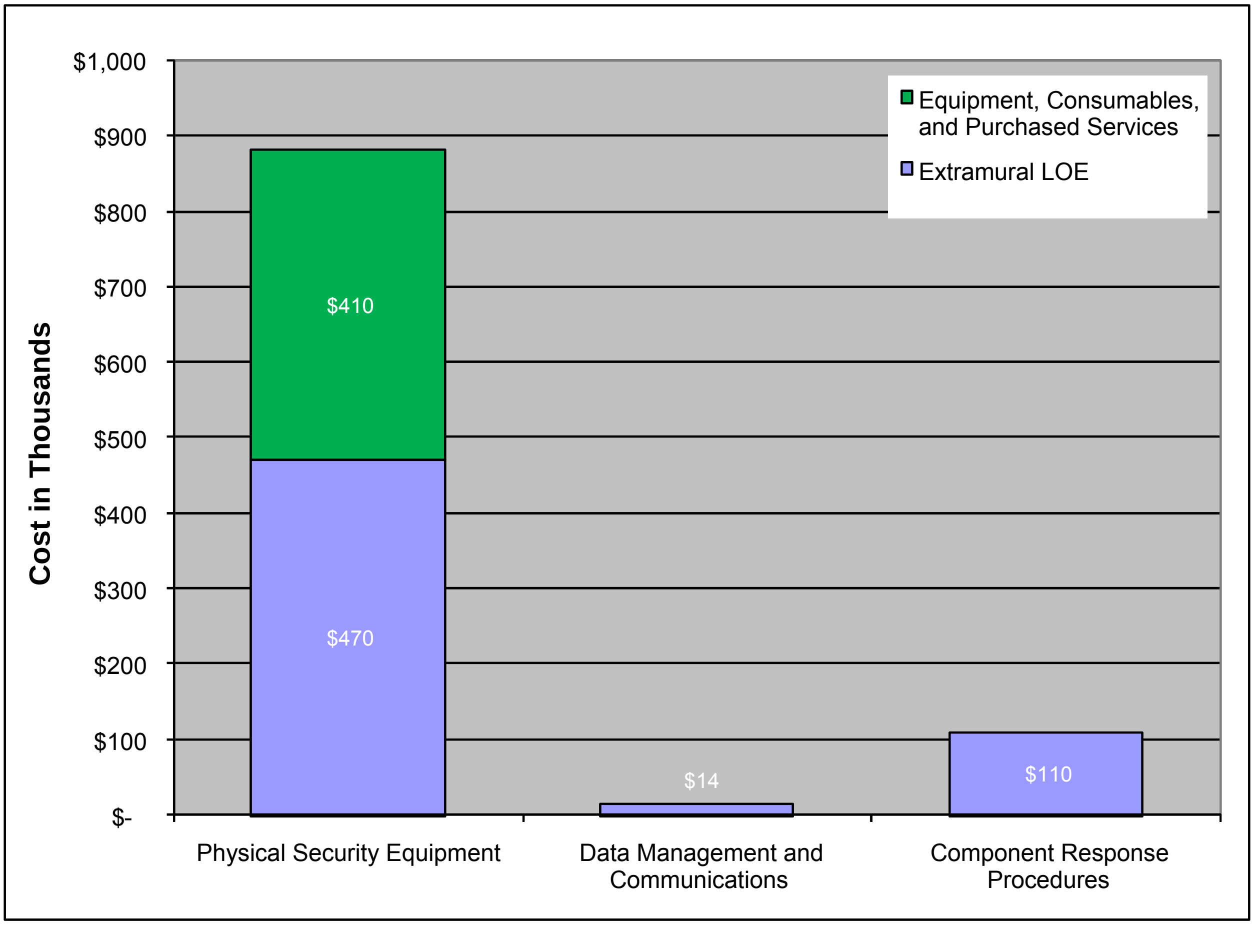

Figure 5-2. Extramural Costs Associated with Design and Implementation of the Enhanced Security Monitoring Component (December 2005 – December 2007)

Figure 5-3 shows a breakdown of the total installed equipment cost by facility type, based on October 2006 competitive bid pricing for the design improvements identified in the assessment report. The average installation cost by facility type for the Cincinnati pilot is also illustrated.

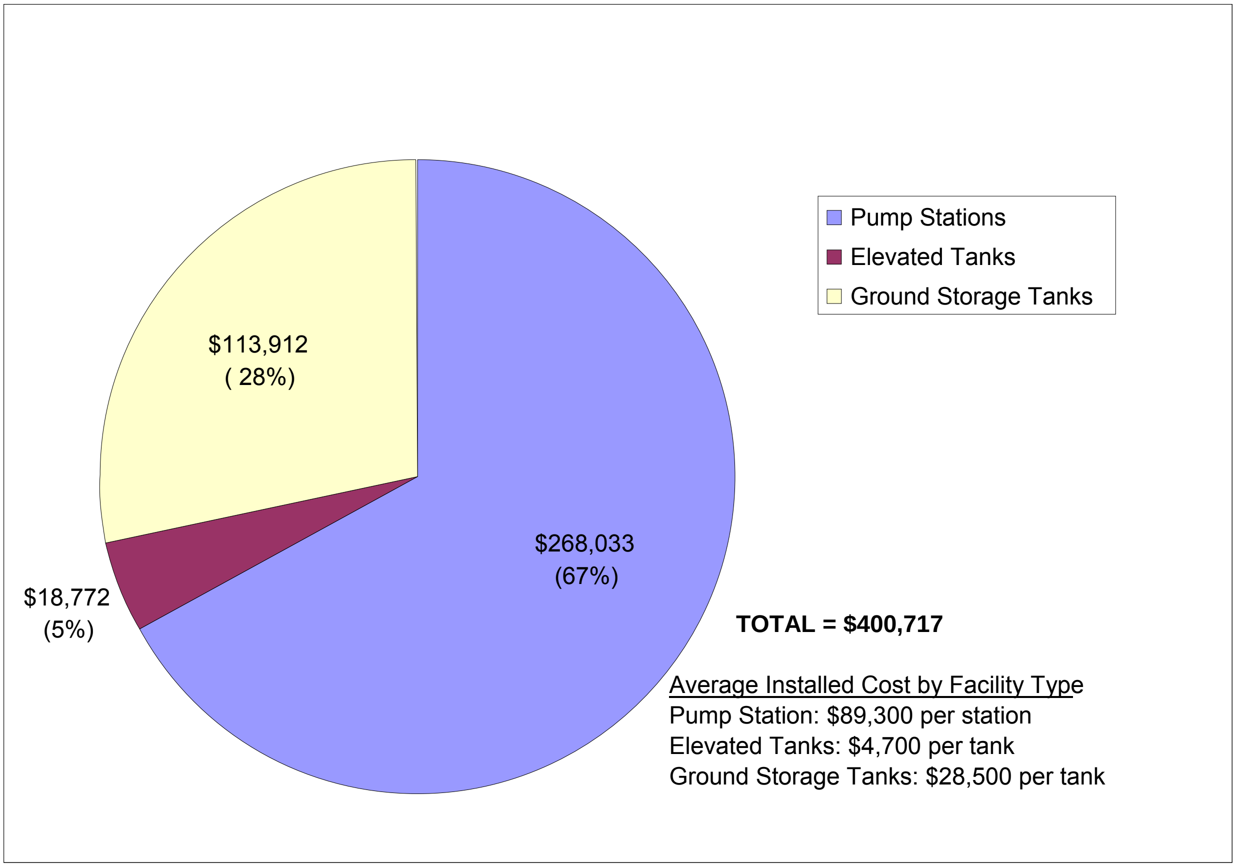

Figure 5-3. Total Costs by Facility Type Associated with Installation of the Enhanced Security Monitoring Equipment (October 2006)

Table 5-6 presents a further cost breakdown for typical equipment installed as part of the enhanced security upgrades. The 2006 figures represent equipment list pricing only, and do not include installation.

Table 5-6. Enhanced Security Monitoring Equipment Unit Cost

Equipment	Cost	Unit
Fixed Video Camera	$1,050	each
Dome Pan-Tilt-Zoom Video Camera	$4,050	each
Door Status Switch	$260	each
Indoor Motion Sensor	$450	each
Outdoor Motion Sensor (Ladder)	$1,660	each
Video Transmission Hardware and Viewing Software	$11,000	per site
Digital Cellular Modem, Antenna and Cabling	$1,200	each
Digital Cell Antenna Amplifier	$300	each
Programmable Logic Controller (PLC)	$2,600	each
PLC Programming Software	$2,400	per project

Section 6.0: Consumer Complaint Surveillance

Located throughout a utility's distribution network, consumers can provide near real-time input regarding changes in water characteristics discernable through the senses. Consumers may detect contaminants with characteristics that impart an odor, taste, or visual change to the drinking water. Complaints from residential, commercial and industrial consumers are routinely reported to water utilities on a very timely basis. As such, consumer complaints may provide one of the earliest warnings of a possible contamination incident, if an effective system is in place to detect anomalous trends in complaints and to respond quickly. The consumer complaint surveillance component extends beyond just managing complaints by providing near real-time collection and analysis of call management and work management system data, along with automated notification of utility personnel when anomalous conditions are detected.

The consumer complaint surveillance component design objectives are shown in **Table 6-1**, and were derived from the overarching performance objectives of the contamination warning system, as described in *WaterSentinel System Architecture* (USEPA, 2005a). GCWW's pre-existing capability with respect to each design element of the consumer complaint surveillance component listed in Table 6-1 is summarized in Section 6.1 and the utility's capability after implementation of the contamination warning system is summarized in Section 6.2.

Table 6-1. Consumer Complaint Surveillance Component Design Objectives

Design Element	Design Objective
1. Comprehensive Complaint Collection	A "funnel" for collecting all water quality complaints into the consumer complaint surveillance system. For example, a unified call center with a widely publicized telephone number in place to capture the largest percentage of potential complaints. Procedures must also be in place to capture complaints that are directed to other points inside the utility or that are initially received by other agencies.
2. Electronic Data Management	All water quality complaints are entered into an electronic database as they are received and categorized by type. A complaint record is carried through the process with information added to it as it is received or investigations are conducted.
3. Automated and Integrated Data Analysis	As data are captured in electronic format, automated event detection algorithms indicate when consumer complaint surveillance data reach pre-determined thresholds, signaling the need for human involvement in the assessment process. When thresholds are exceeded, notifications are sent to appropriate personnel, and complaint spatial information is displayed for easy identification of clustering events.
4. Component Response Procedures	Written standard operating procedures exist for every step in the water quality complaint handling process and for alarms. These procedures outline effective and timely communications, including clear guidance on appropriate response actions.

6.1 Pre-Implementation Status

Prior to implementation of the contamination warning system, GCWW had systems and processes in place that could be enhanced and used to create an integrated consumer complaint surveillance system. Data supporting this component resided in call management data systems, customer information data systems, asset management data systems, and water quality data systems, but were not automatically aggregated and analyzed and notifications of potential events were not sent. Although call volume reports were reviewed periodically by supervisors, event detection relied exclusively on staff experience to recognize trigger events involving customer water quality complaints. Through assessments and demonstrations of existing GCWW Customer Complaint Management System operations, along with interviews with GCWW staff, gaps were identified between current operations and a functional consumer complaint surveillance system. Consumer complaint processes, procedures and data management systems that existed prior to the Cincinnati pilot implementation are summarized below. Further details on the assessment of the existing systems can be found in the *Consumer Complaint Surveillance Assessment Report* (USEPA, 2006d).

6.1.1 Comprehensive Complaint Collection

GCWW routinely received consumer calls from residential, commercial, and industrial consumers via a single, widely published utility phone number. During business hours, customer calls are routed to the GCWW call center, where a customer service representative from the Commercial Services Division handles the call. During non-business hours, customer calls are routed to the distribution dispatcher, a Distribution Division position, who directs and coordinates the work being done on the distribution system. GCWW used informal call management protocols and operating procedures, but many of the procedures were not documented.

Some water quality related complaints were received outside of the GCWW Call Center. The City of Cincinnati's Customer Service and Communications Center received the largest portion of these calls, while the GCWW Director's office would receive occasional calls directly from City Hall, public health organizations, the media, and concerned citizens.

6.1.1.1 GCWW Call Center: Consumer Calls during Regular Business Hours

During normal business hours, all calls are directed to individual customer service representatives through an automated call management system using an interactive voice response (IVR) system. The pre-existing IVR system script prompted the customer to select a menu option as follows:

"Welcome to Greater Cincinnati Water Works
For automated bill payment using your credit or debit card, press 1;
To speak with a service representative about billing or account information, or if you are moving, press 2;
To speak with a service representative if your water has been turned off or to report a water leak, press 3;
To speak with a service representative about meter reading, press 4;
For recorded directions to the GCWW business office and hours of operation, press 5;
For all other services or information, press 0 to speak to a service representative."

The call management system then routes the call to a customer service representative who has been trained in that area. The existing IVR system script did not have a menu item specifically for water quality concerns or complaints. In general, there were three types of water distribution system-related (non-billing) calls handled by the customer service representatives:

- ***General Inquires.*** General inquiries, including questions on basic water parameters like pH and hardness, were most often answered by the customer service representative. If the customer service representative could not satisfactorily answer the question, the call was transferred to the Water Quality and Treatment Division.
- ***Infrastructure Issues.*** For distribution system infrastructure issues, such as main breaks and leaky hydrants, the customer service representative created a "work request" using the Distribution Work Center application. The work request was then forwarded electronically to the Distribution Division for review prior to generation of a work order by the dispatcher to begin field activities.
- ***Water Quality Issues.*** Water quality complaints (discoloration, taste, and odor concerns) were transferred by the customer service representative directly to the Water Quality and Treatment Division receptionist without generating a work request. During normal business hours the receptionist transferred the call to the on-duty customer water quality representative to initiate a response. Customer service representatives that received what they perceived to be an unusual water quality complaint, or began seeing several water quality issues over a short period of time, were instructed to inform the call center supervisor. However, it was unlikely that one customer service representative would receive all water quality complaints due to the large number of agents fielding calls. Therefore, the Water Quality and Treatment Division receptionist and the customer water quality representative would likely be the first to recognize a potential water contamination event. The WQT customer water quality representative would conduct an investigation in the event that a predefined threshold of water quality calls was exceeded.

6.1.1.2 Distribution Division Dispatcher: Consumer Calls during Non-Business Hours

The IVR system functioned during non-business hours, but customers are told to call back during normal business hours for all non-emergency issues. For emergencies, such as water main breaks or water quality issues, the call is transferred to distribution dispatch because this position is staffed 24 hours a day and is capable of responding to emergencies. The distribution dispatcher also received emergency calls directly from other GCWW staff and from the City of Cincinnati's Customer Service and Communications Center. Non-emergency calls would also be received by the dispatcher, since customers could select '0' on the IVR system if they desire to talk with someone at GCWW. If so, the dispatcher evaluated the type and urgency of the call.

The dispatcher is an experienced staff member capable of answering general inquiries and handling infrastructure issues. However, for water-quality issues, the dispatcher would contact Distribution Division Senior Management, who would then consult with the Water Quality and Treatment Division Senior Management to determine whether a work order is needed to investigate the incident. For calls requiring field action, the dispatcher created a work order directly using the Distribution Work Creation application, and bypassed the step of generating a work request.

6.1.2 Electronic Data Management

GCWW used call management, customer information and asset management data systems, along with water quality databases to manage and respond to consumer calls. The IVR system was part of the call management system, while the generation of work requests and work orders resided in the asset management systems. Water quality data concerning water quality related complaints, collection of field samples, and associated analytical results were captured on various paper forms and then transferred to the water quality database. These data systems are described below.

6.1.2.1 Banner

A customer service software application called Banner was used by the customer service representatives to link incoming calls to a GCWW account, and acted as the platform for the utility's customer information system. The IVR software used a table in the Banner database to write the caller's initial IVR menu choice.

6.1.2.2 Distribution Work Creation

The Distribution Work Creation (DWC) application existed to manage and track the scheduled and unscheduled work that was being performed in the distribution system. The primary users were Distribution Division personnel, particularly the distribution dispatcher, and Water Quality and Treatment personnel. The dispatcher and Water Quality and Treatment personnel would create work orders that directed crews into the field to perform the necessary work. Customer service representatives were able to enter the application to create a work request for distribution system infrastructure issues (main breaks, etc.) or water quality issues related to maintenance work (rusty or cloudy water, etc.). These requests were reviewed by the distribution dispatcher, triaged, and either converted into a work order or declined, depending on the dispatcher's assessment of the current conditions. Work requests and work orders were periodically archived. Water quality work orders were monitored to conduct investigations in the event that a predefined threshold for water quality was exceeded.

6.1.2.3 Water Quality Database

If a customer was transferred from the customer service representative to the Water Quality and Treatment Division, additional complaint information was collected over the phone by the customer water quality representative or shift chemist using a paper form. This information was then entered into the Water Quality Database (an Excel spreadsheet), which was used to track and record every water quality complaint received, and the Distribution Work Creation application was used to create a work order, as described above. To ensure that work orders were not missed, the representative printed a hardcopy and emailed the Distribution Dispatcher to indicate that a new work order was in the system.

If a sample was collected from the location of the complaint, the results were recorded in both the Sample Request Form (hard copy) and the Water Quality Database. Information on the Sample Request Form was used to complete a notes field in the utility's asset management system, Enterprise Maintenance Planning and Control, and then the paper form was filed. Finally, a form letter and survey were sent to the customer as a follow-up.

6.1.3 Automated and Integrated Data Analysis

Event detection systems were developed and deployed to analyze data from the IVR system, work requests, and work orders. Additionally, some GIS capability was developed to facilitate spatial analysis of water quality related consumer calls.

6.1.3.1 Event Detection

Detection of anomalous water quality related call volumes relied on manual, experience-based processes from call center and Water Quality and Distribution staff. As mentioned previously, customer service representatives were trained to inform the call center supervisor if they received what they perceived to be an unusual water quality complaint, or began seeing several water quality issues over a short period of time. However, it was unlikely that the same customer service representative would receive all water quality complaints due to the large number of agents fielding calls. To address this, the utility captured the water quality related complaints on paper logs, transferred the information to an Excel worksheet and manually determined whether a threshold number of calls had been exceeded. If more than four (4) calls were recorded in the Water Quality Database within a 24-hour period an investigation call type and spatial patterns was performed, and appropriate Water Quality and Treatment management was notified. Customer water quality representatives recognizing a trend developing (same complaint area or type) were, however, trained to alert a supervisor before waiting for the entire 24-hour period.

6.1.3.2 Spatial Analysis

The Distribution Work Creation application provided some GIS ability when creating work requests and work orders. Although limited in scope, the GIS application allowed the user to view a pre-defined area around the premises location and showed areas of the distribution system construction in the immediate vicinity of the work request or work order location.

6.1.4 Component Response Procedures

GCWW has established informal protocols and operating procedures that are not formally documented. While GCWW employees exhibit an ability to deal effectively and professionally with consumer complaints, identification of water quality related call volumes may be hindered by the numerous individuals within the same division or call center that may be involved in processing requests concurrently. Informal procedures can also break down during emergencies, shift changes, and as institutional knowledge is lost through personnel retirements, promotions, or job changes.

6.1.5 Summary of Identified Gaps

GCWW's existing call management system and procedures were robust and functioned efficiently for the addressing routine customer service issues. The existing systems provided a solid foundation to address the design objectives summarized in Table 6-1. The specific gaps identified for each design element are summarized in **Table 6-2**. These gaps provided the design basis for enhancements to the GCWW consumer complaint system, and the post-implementation status of the resulting system is described in Section 6.2.

Table 6-2. Consumer Complaint Surveillance System Gap Analysis

Design Element	Gap Description
1. Comprehensive Complaint Collection	• A defined procedure for transferring water quality related calls from City Call Center to the GCWW Call Center is needed.
2. Electronic Data Management	• Multiple data streams from call management and asset management systems should be developed to serve as indicators of possible contamination incidents. • Mechanisms to capture electronic data from the interactive voice response (IVR) system are needed to provide the earliest indication of possible water quality problems.
3. Automated and Integrated Data Analysis	• Automated event detection algorithms are needed to analyze data in near real-time. • Automated notifications to key utility personnel are needed to alert them when water quality related consumer complaint thresholds are surpassed. • A GIS user interface is needed to spatially display alarm data.
4. Component Response Procedures	• Standard operating procedures for operating the CCS component are needed for Customer Service Representatives and Distribution Dispatch personnel. • A specific definition concerning calls that should be categorized as potential indicators of a significant water quality concern. • Some procedures need altering to produce discrete data streams for the CCS component. • Training materials are needed for consumer complaint surveillance standard operating procedures.

6.2 Post-Implementation Status

Modifications to the GCWW consumer complaint surveillance component were based on the "Funnel, Filter and Focus" model (**Figure 6-1**). This model provided an efficient process flow and filtering mechanism for consumer complaint calls, where non-water quality related calls were quickly removed from consideration.

- **Funnel**. All customer calls directed to the GCWW call center.
- **Filter**. GCWW customer service representatives respond to billing, meter reading and general water quality concerns. Calls with water quality issues based on a specified definition are forwarded to customer water quality representatives.
- **Focus.** Customer water quality representatives gather in-depth information from the consumer and determine whether the situation requires field sampling.

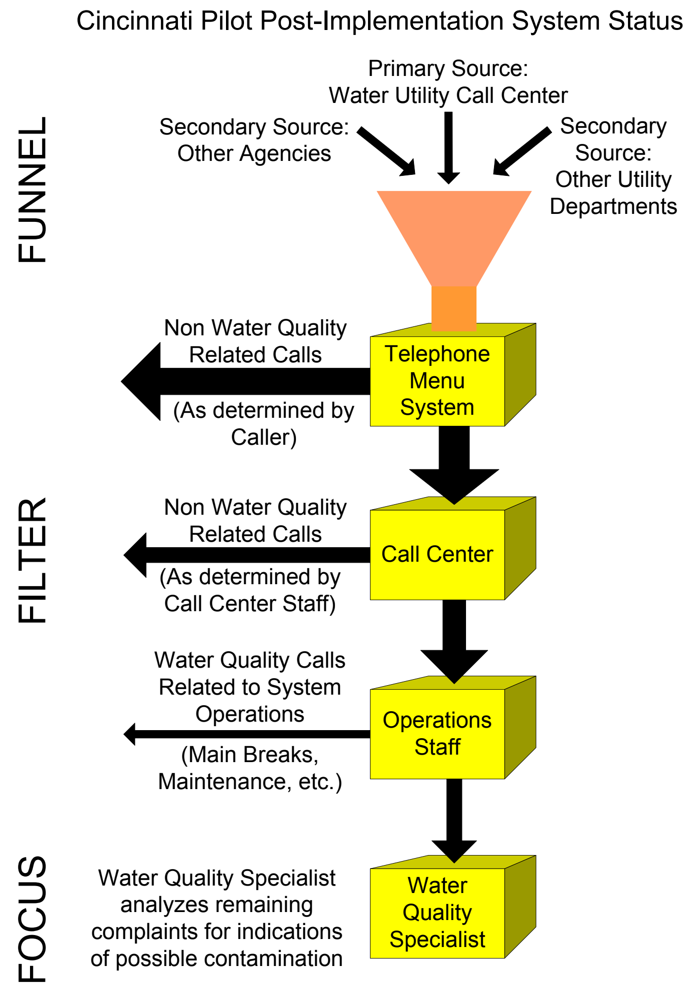

Figure 6-1. The Filter, Funnel, and Focus Model

6.2.1 Comprehensive Complaint Collection

A "backdoor number" was implemented, with the assistance of the City of Cincinnati Call Center, to transfer all water quality related calls to the GCWW Call Center. The backdoor number not only transfers the call from the City Call Center, but also places the caller to the head of the queue for immediate attention by GCWW customer service representatives. A standardized definition of a water quality issue was also developed for the City call center personnel to aid in the proper identification of the calls that should be forwarded to the GCWW Call Center.

6.2.2 Electronic Data Management

In general, data management activity for the consumer complaint surveillance component involves the automated, near real-time (every 1-minute) collection of customer complaint data from utility call management and asset management data systems, and transferring and transforming (where necessary) that data to the event detection software. A summary of the data management systems involved in this component is provided in **Table 6-3**.

Table 6-3. Consumer Complaints Surveillance Data Management System Inventory

Data System	Pre-Existing System?	Description
Call Management System (CMS)	Yes	Includes interface used by customer service representatives and the interactive voice response (IVR) system
Banner	Yes	Customer information system with account and address information

Data System	Pre-Existing System?	Description
Enterprise Maintenance Planning and Control (EMPAC) System	Yes	Primary GCWW asset/work order system
Distribution Work Creation (DWC) System	Yes	Interface to EMPAC that creates work requests and work orders, with limited GIS mapping feature
Hydra	Yes	Web-based interface to EMPAC that creates work requests and work orders, with more advanced GIS mapping capability. GCWW is in the process of replacing DWC with Hydra.
Microsoft Exchange Server (Email)	Yes	GCWW email system used to send alarm notifications to groups of pre-defined utility personnel
WS Simple Mail Transfer Protocol (SMTP) Server	No	System used to send alarm notifications from the event detection system to the utility's Microsoft Exchange Server
Hydra Map Display	No	GIS-based map to spatially display work request and work order information in near real-time (2-minute updates)
WS Database Server	No	Server responsible for storage of WS-CWS data
WS Application Server	No	Server containing code to process data, including the event detection algorithms

The consumer complaint surveillance component includes an automated, real-time data collection process to obtain data from GCWW systems using a web services application, a mechanism for machine-to-machine interaction over the network application. Once retrieved, the data are stored locally and analyzed using a variety of statistical event detection algorithms on the Water Security Application Server. Data management elements of the consumer complaint surveillance component have been gradually deployed at GCWW, beginning in December 2006. As of April 2007, the major data management aspects of this component were functional at GCWW, including data collection, data analysis, and the distribution of notifications. **Figure 6-2** illustrates data management systems used by the component and how they are accessed by utility staff throughout the process.

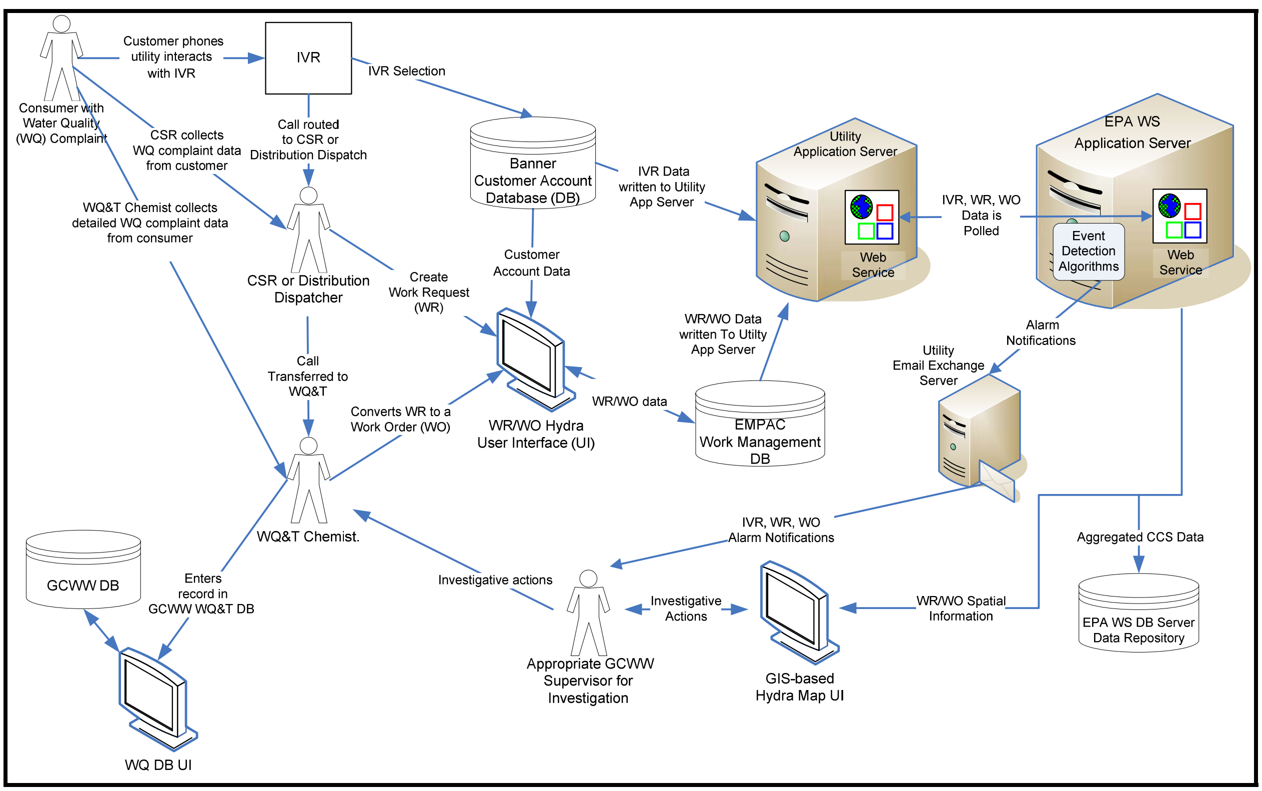

Figure 6-2. Information Flow for the Consumer Complaints Surveillance Component

The consumer complaint surveillance component has implemented three "tiers" of alarms, based on the following discrete data streams:

1. **Interactive Voice Response.** GCWW customers, when placing a call to the utility, have the opportunity to indicate that their call relates to "water quality information, questions or concerns." By selecting this newly added option in the IVR system, calls are flagged as relating to water quality and are moved to the head of the call center queue.

2. **Water Quality Work Requests.** All calls that are not general inquiries or do not relate to rusty or cloudy water are termed "water quality requests." For these calls, the customer service representative, or the distribution dispatcher after hours, generates a work request in the Hydra work management interface. All such work requests are tracked through the process and can trigger an alarm when a threshold value is reached.

3. **Water Quality Work Orders.** Water quality work requests can be converted into work orders, which direct field personnel to collect water samples as part of a response to a suspected water quality problem. Work orders, like work requests, are tracked through the process and can trigger an alarm when a threshold value is reached.

6.2.2.1 Interactive Voice Response

The interactive voice response (IVR) menu was modified to add the following option for water quality related concerns (note that the former option #5 was moved to #6):

"For water quality information, questions, or concerns, press 5 to speak with a service representative"

Addition of this option created the data stream necessary for analysis by the event detection algorithms. Callers who push #5 are also forwarded to the top of the call queue for immediate attention by the next available customer service representative.

Because a selection in the IVR system represents the first contact between the customer and the water utility, it is the timeliest indication of a possible contamination incident. However, the IVR system does not provide any complaint description or location information. The IVR web services client collects a count of water quality (#5) selections, aggregates the selections, applies a date/time stamp to each, and exposes the data for retrieval by the Water Security initiative web service client. This data are retrieved from the call management system. The Water Security initiative web services client queries the latest IVR selection data from the web service every minute. Additionally, the web services client collects all IVR selection data once per day. This complete data set is collected for the purpose of EPA evaluation and is not analyzed by an event detection algorithm.

6.2.2.2 Water Quality Work Requests

In 2007, GCWW upgraded its distribution system work management software (Distribution Work Creation) and renamed it "Hydra." One function included in the upgrade was the ability to classify work requests according to "problem type." Now a work request can be generated in Hydra by a customer service representative or the distribution dispatcher and classified as one of three new problem types that relate to potential water quality problems ("rusty water", "cloudy water" and "water quality request"). The creation of such a work request electronically captures additional information regarding the customer's complaint, including its location, and indicates the likely need for a sample to be collected in the field to investigate a possible water quality problem. Work requests classified as such have been made available via web services to the consumer complaint surveillance event detection algorithms since March 2007. Currently, only work requests classified as a "water quality request" are analyzed by the consumer complaint surveillance event detection algorithms.

A work request web services client collects counts of work requests generated in the Distribution Work Creation/Hydra application, aggregates them, applies a date/time stamp to each, and exposes the data for retrieval by the Water Security initiative web service client. The work request data are retrieved from the EMPAC system via the Hydra interface. The work request web services client queries the latest work request data from the work request web service every minute.

6.2.2.3 Water Quality Work Orders

Each water quality work request is reviewed by staff in the Water Quality and Treatment Division, and is converted to a work order if a water quality specialist confirms the need for sampling or other field investigation. Using the work request already generated by the customer service representative, the Water Quality and Treatment representative or distribution dispatcher creates a work order in EMPAC, using Hydra, to initiate the field sample process. The conversion of the work request to a work order signals an even greater likelihood that the complaint is related to a water quality issue because the call has been reviewed by a water quality specialist. This data stream is therefore the most reliable, but the time required to gain this confidence and to perform this review makes it the least timely indication of a possible contamination event.

As with work requests, a work order web services client collects counts of work orders generated in Hydra, aggregates them, applies a date/time stamp to each, and exposes the data for retrieval by the Water Security initiative web service client. The work order data are retrieved from the EMPAC system via the Hydra interface. The work order web services client queries the latest work order data from the work order web service every minute. Before March 2007, GCWW categorized work orders related to water quality as "taste and odor complaint." Since then, GCWW has been categorizing work orders related to water quality as "water quality request" and analyzing them with the consumer complaint surveillance event detection algorithms.

6.2.3 Automated and Integrated Data Analysis

All consumer complaint surveillance data are captured in a consistent electronic database format to facilitate access to the data and the use of automated analysis tools. Automated anomaly detection algorithms detect when critical indicators of a potential contamination event reach pre-determined thresholds. Human involvement in the assessment process is then initiated. Quantitative triggers are based on analysis of historic data and statistical analysis. The use of pre-determined threshold levels is advantageous in that they can be adjusted as more data becomes available. Additionally, the triggers can be changed depending on the threat level intelligence. If the threat level is higher, fewer calls might be needed to trigger an alarm and begin an investigation. Further details regarding the functional and technical specifications for the data implementation elements of CCS improvements can be found in the *Water Security Contamination Warning System, Consumer Complaint Surveillance, Detailed Design Specification, Version 2.0* (USEPA, 2007s).

6.2.3.1 Event Detection

The event detection system is more appropriately thought of as a collection of algorithms which analyze data collected from the utility's source databases. The event detection system automates the data analysis and alarm process based on pre-established frequencies of water quality related calls, work requests and work orders. The automated event detection system provides a dependable, robust surveillance system that is not affected by human errors that may occur in maintaining continuity of observations across the large number of staff involved in the process and transferring information across shift changes. Once an alarm is triggered, a notification is generated and sent to appropriate personnel, bringing in the human element for the subsequent investigation actions.

There are five (5) algorithms applied to three (3) data streams (the numbers of IVR #5 selections, water quality related work requests, and water quality related work orders), for a total of fifteen (15) potential triggers. Because some algorithms are designed to operate only on weekends or only on weekdays, not all triggers are active at the same time. The algorithms are described in **Table 6-4**.

Table 6-4. Event Detection Systems Deployed for Consumer Complaint Surveillance

Algorithm	Description
Scan Statistics, 1 day weekday Scan Statistics, 2 day Scan Statistics, 7 day	A prospective scan statistic monitors current data and evaluates it against past data in a time window. Separate trigger, or threshold, levels were established for 1, 2 and 7 days.
Scan Statistics, 1 day weekend	A separate scan statistic is applied to weekend and holiday consumer complaint data, where call volumes drop significantly. Separate threshold, levels were developed for these days.
CUSUM	A cumulated sum (CUSUM) accumulates the difference between an observed number of complaints per day and a reference value. If the accumulation exceeds the trigger, and alarm is given. Because the observations can accumulate over time, the CUSUM method can detect slowly worsening situations earlier than a single day trigger.

Initial trigger threshold values were developed based on statistical analyses using existing historical data. The final selection of the trigger values also took into account the risk position and the level of effort required to investigate alarms. During baseline assessment, the trigger thresholds are set artificially low to facilitate fine tuning of the email and text notification systems (discussed below) by EPA personnel. Once GCWW enters the full deployment phase, revised trigger thresholds will be adopted based on the data collected during the baseline assessment phase, and notifications will be sent to GCWW users.

Trigger parameters, such as algorithm thresholds, are implemented within text files separate from the core code of the algorithms themselves. This programming structure allows the utility to fine-tune trigger parameters without accessing and re-writing complicated computer code or disrupting the central functioning of the automated algorithms.

6.2.3.2 Notifications

If a trigger level is not reached, an alarm will not be generated. The event detection algorithms will continue to monitor the data streams. Once the trigger level has been reached, however, an electronic alarm will be generated and notification of the appropriate GCWW staff will follow through email and cell phone text message. The consumer complaint surveillance component harnessed the existing GCWW Microsoft Exchange server to deliver email notifications of alarms generated by the new event detection system. Using defined email groups, targeted notification emails for each type of consumer complaint surveillance alarm are sent to the utility personnel responsible for further investigation of that data stream. Since GCWW's mobile workforce will not always have access to email, text messaging was also incorporated as part of a redundant notification strategy. Email notifications are divided into four general groups: business hours, business hours (cell format), after hours, and after hours (cell format). An example email alarm notification is included in **Figure 6-3**.

Interactive Voice Response Alarm (Water Quality Selection by Consumer High) - Business Hours

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Subject: CCS ALARM NOTICE: Water Quality Selection by Consumer High

Body:
Over the past <*duration*> the threshold number (<*threshold number*>) of water quality consumer self-identified calls in the Interactive Voice Response (IVR) system has been surpassed.

ALARM DETAILS
Alarm ID: <*Alarm ID*>
The algorithm <Algorithm ID> is responsible for triggering this notification.

The customer service representative supervisor should:

1) Check on the call waiting queue time
2) Discuss the nature of the calls with customer service representatives or the distribution dispatcher
3) Assess the need for additional personnel to handle the increased call volume
4) Inform the Utility Director's office and City's call center supervisor of increased water quality call volume (if appropriate)
5) Inform the customer water quality representative supervisor (Water Quality and Treatment Division) of increasing water quality call volume and nature (if appropriate)

Figure 6-3. Example Email Alarm Notification

6.2.3.3 Spatial Analysis

To quickly determine whether there is a geographic correlation within a consumer complaint surveillance alarm, an internet map service display, referred to as the Hydra map, was built using a custom GIS web application. A separate web services application, similar to the one developed to collect interactive voice response, work request, and work order data, is used to transfer location information from the work orders and work requests. The Hydra map then displays these in near real-time (2-minutes) so that spatial clustering of complaints can more easily be identified. Note that the IVR data cannot be analyzed spatially, since there is no location information associated with the calls. An example Hydra map screen shot is shown in **Figure 6-4**.

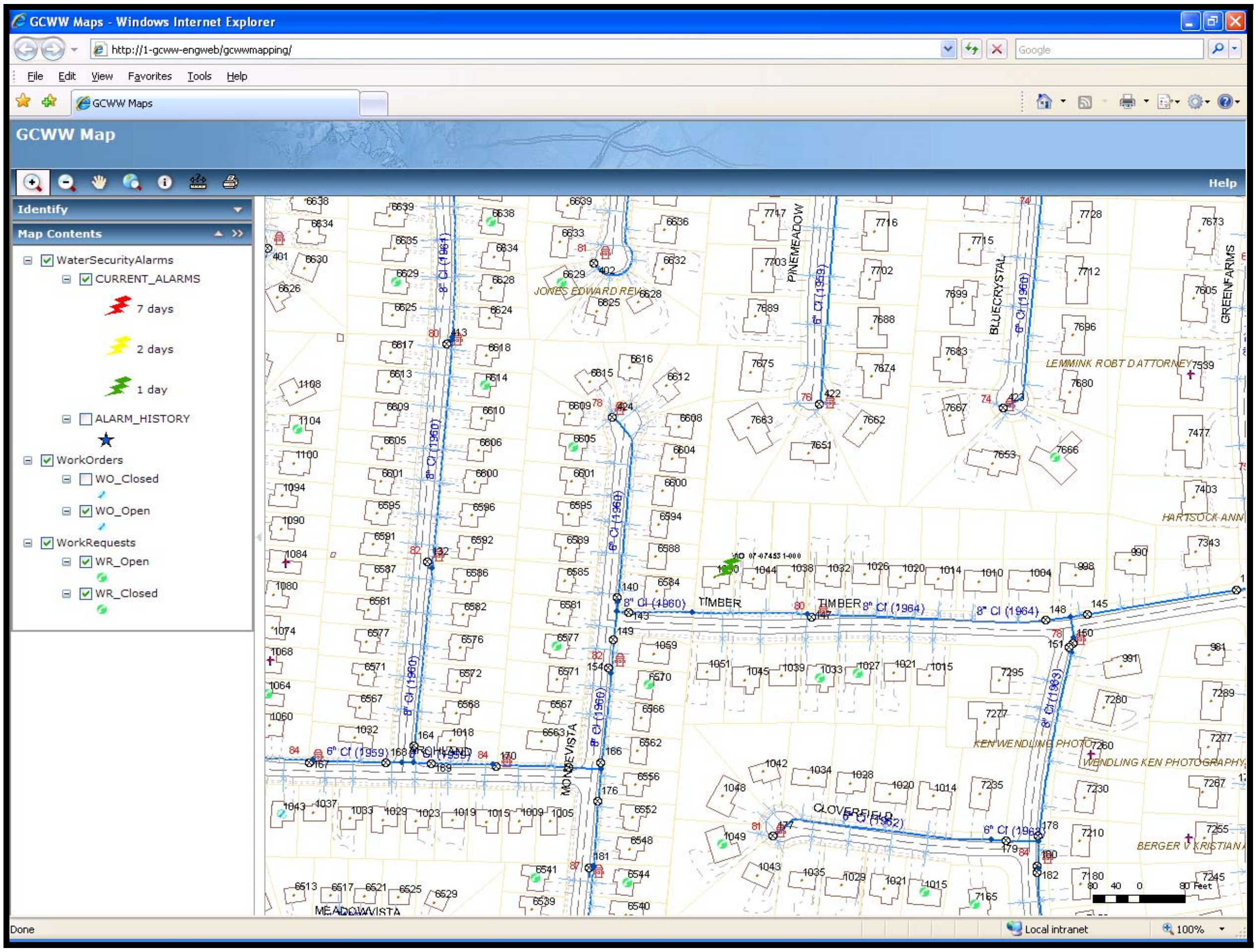


Figure 6-4. GCWW Hydra Map - Detailed Map with Alarm Data and Work Orders and Work Requests

6.2.4 Component Response Procedures

The integration of the consumer complaint surveillance component with GCWW's call management system required additional procedures and protocols to direct human response to a notification from the consumer complaint surveillance component. A detailed Concept of Operations was developed to cover the routine operations of the component leading up to and after issuance of an alarm notification. It describes the process and procedures involved in the operation of the consumer complaint surveillance component, including the initial investigation and validation of an alarm. The Concept of Operations also establishes specific roles and responsibilities, and detailed procedural and information flow descriptions (see Figure 6-2). In addition, a series of trigger validation checklists are included in the Concept of Operations to support the investigation of consumer complaint alarms. This process concludes with the determination of whether or not an alarm generated from several water quality consumer complaints is indicative of a possible contamination incident.

Further details on the Concept of Operations protocols can be found in the *Concept of Operations for the GCWW Contamination Warning System* (USEPA, 2007b).

Initial training of utility staff, in particular with respect to their roles and responsibilities during the investigation of a possible contamination event, was needed to prepare for response to such an event. Training was conducted by EPA for front line and supervisory GCWW personnel involved in the routine operation of the consumer complaint surveillance component. These trainings were based on the consumer complaint surveillance section of the *Concept of Operations for the GCWW Contamination Warning System* (USEPA, 2007b).

Future training to maintain the capabilities of the consumer complaint surveillance component will be integrated with the existing GCWW training program for new personnel in the call center. If new protocols and procedures are developed for the consumer complaint surveillance component, the customer service representatives and supervisors, distribution dispatchers and customer water quality representatives from the Water Quality and Treatment Division would be involved in their review and development.

6.2.5 Summary of Post-Implementation Status

EPA, with the assistance of GCWW, completed a comprehensive assessment of the consumer complaint call management, customer information, asset management and water quality data systems in place at GCWW. During this assessment, the existing practices and systems were compared to an ideal consumer complaint surveillance concept (Table 6-1) which could assist a utility in the early detection of a contaminant event. Following the completion of the assessment, gaps were identified where EPA and GCWW believed changes or additions to the practices and systems in place at the utility to process consumer complaint calls could be improved (Table 6-2). EPA and GCWW worked collaboratively to develop and implement solutions which would address the identified gaps. A summary of the installed consumer complaint surveillance is presented in **Table 6-5**.

Table 6-5. Consumer Complaint Surveillance System Post-Implementation Status

Design Element	Description of Installed Component
1. Comprehensive Complaint Collection	• Completed the CCS assessment report to identify and prioritize needed improvements. • Established a "back door" number for the transfer and prioritization of consumer water quality complaint calls from the City wide call number to GCWW.
2. Electronic Data Management	• Modified the interactive voice response (IVR) system to include water quality concern as a selection option. • Established a water quality complaint categorization in the utility's work request and work order form that can be tracked. • Included a problem type characterization field in the work order form to establish a uniform description of a water quality complaint to assist in the determination of a possible contamination event.
3. Automated and Integrated Data Analysis	• Completed historic assessment of water quality related calls to set initial alarm trigger levels. • Development, testing and deployment of automated event detection algorithms to count the number of water quality related interactive voice response (IVR) selections, work request and work orders. • Establish a method for automatic notification of key utility personnel when water quality consumer complaint thresholds were surpassed. • Worked jointly with GCWW to ensure consumer complaint alarm data are displayed on the utility wide geographic information system to allow a faster determination of geographically related water quality problems.
4. Component Response Procedures	• Developed and trained GCWW on the Concept of Operations for the CCS component which included: - The standardization of a water quality complaint definition. - Modified procedures for customer service representatives and distribution dispatchers to generate work requests for water quality related complaints. - Checklist to assist the utility in determining whether an alarm is a possible contamination event.

Figure 6-5 provides a summary of the level of effort associated with design and implementation of the consumer complaint surveillance component for the Cincinnati pilot. Consumer complaint surveillance activities, as summarized in Table 6-5, relied on support from EPA, GCWW, and local partners. The most significant effort was associated with incident response procedures for this component, which entailed standardization of a water quality complaint definition and modification of response procedures for utility customer service representatives and distribution dispatchers. A considerable effort as also associated with establishment of a "back-door" number for the transfer and prioritization of consumer

water quality complaint calls from the City wide call number to GCWW – part of the comprehensive complaint collection design element.

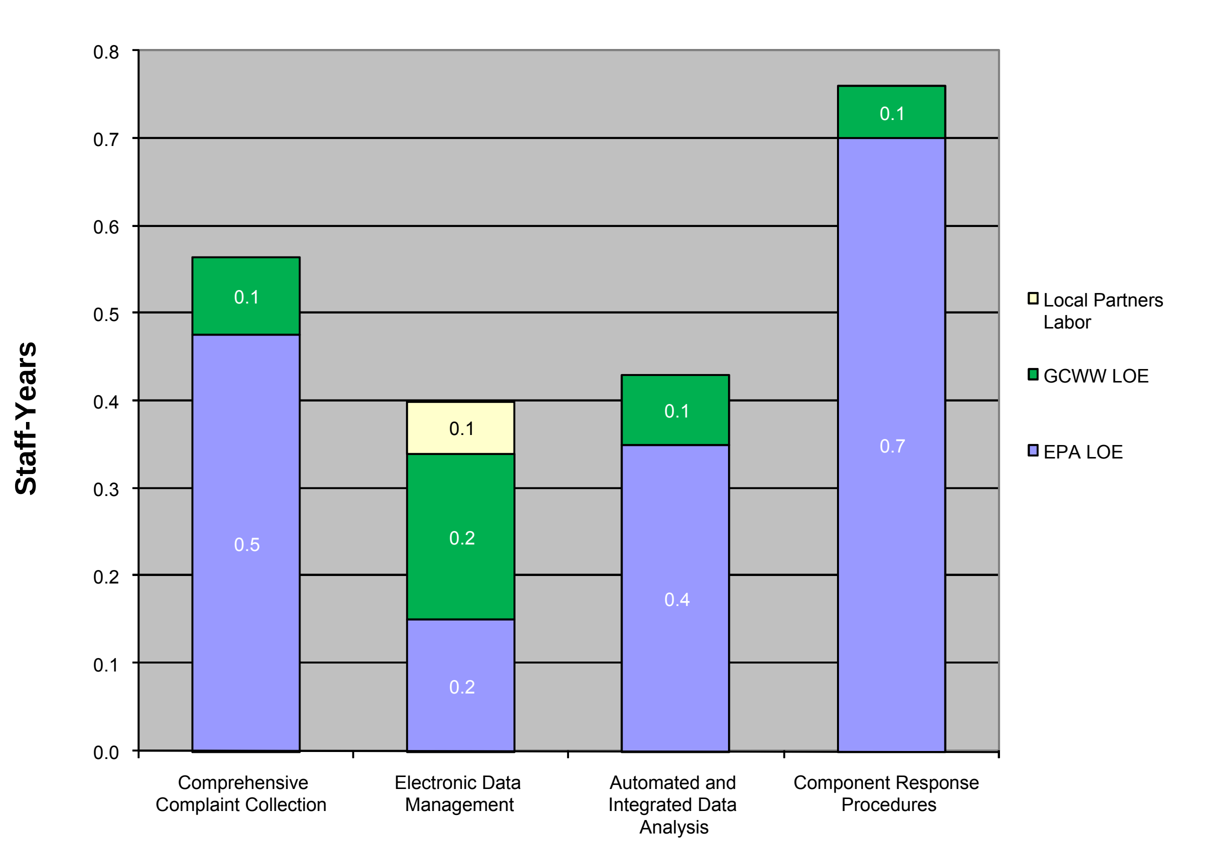


Figure 6-5. Level of Effort for Design and Implementation of the Consumer Complaint Surveillance Component (December 2005 – December 2007)

Figure 6-6 presents a summary of the extramural costs associated with design and implementation of the consumer complaint surveillance component for the Cincinnati pilot. It is important to note that there were not significant equipment or consumable costs associated with this component due to the fact that existing software and hardware systems employed by GCWW and the City of Cincinnati were leveraged for data collection, processing, and analysis. Costs associated with contractor travel were not included in this calculation.

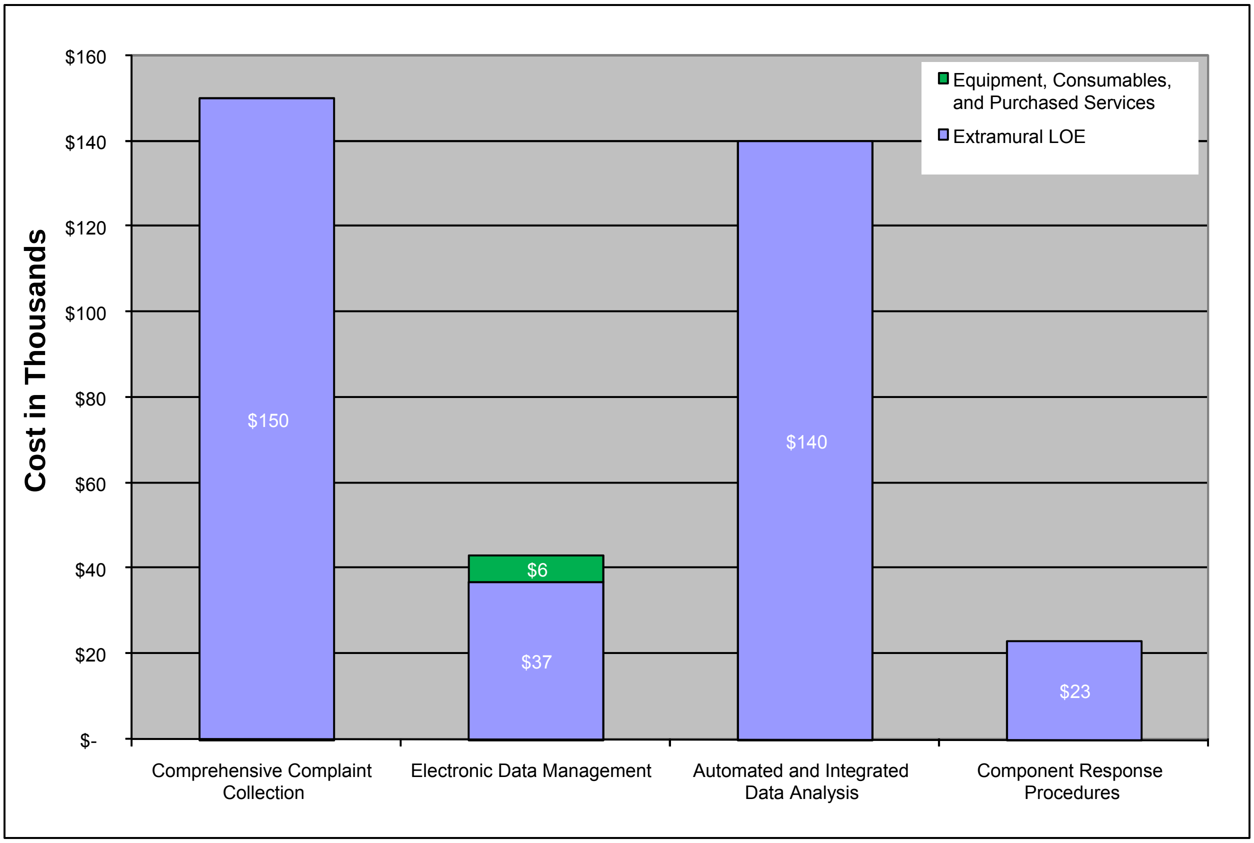


Figure 6-6. Extramural Costs Associated with Design and Implementation of the Consumer Complaint Surveillance Component (December 2005 – December 2007)

Section 7.0: Public Health Surveillance

Public health surveillance is included as a contamination warning system component due to the tools, procedures, and lessons learned from the public health sector that can be leveraged to enhance detection capabilities for a broad range of contaminants. 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 public health issues than clinical signs and symptoms alone (Foldy, 2004; Hrudey, 2002).

As defined by the Centers for Disease Control and Prevention (CDC), public health surveillance is the ongoing and 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). Syndromic surveillance is a specific type of public health surveillance that relies on electronic data such as 911 calls, emergency room visits, emergency medical service logs, over-the-counter 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 a potential public health issue (Henning, 2004).

In the Cincinnati pilot, the following public health surveillance data streams are leveraged as part of the contamination warning system: 911 calls, emergency medical service logs, over-the-counter drug sales, Poison Control Center calls, emergency room chief complaints, and infectious disease reporting systems. If an alarm is generated through one of these systems and it appears that the alarm indicates possible water contamination, the local health departments work collaboratively with GCWW utility staff to conduct an investigation to determine whether or not the public health issue is related to an actual drinking water contamination.

The public health surveillance component design objectives are shown in **Table 7-1** and were derived from the overarching performance objectives of the contamination warning system as described in *WaterSentinel System Architecture* (USEPA, 2005a). Cincinnati's pre-existing capability with respect to each attribute of the public health surveillance component listed in Table 7-1 is summarized in Section 7.1, and the post-implementation capability of the contamination warning system is summarized in Section 7.2.

Table 7-1. Public Health Surveillance Component Design Objectives

Attribute	Design Objective
1. Public Health Data Streams	Assess existing public health surveillance data streams and modify or enhance them to meet the objectives of the contamination warning system. This may include expanding notification of alerts to the local drinking water utility or modification of algorithms to include symptoms related to exposure to contaminated drinking water. Also, identify approaches for detection of fast-acting contaminants such as review or tracking of 911 calls, emergency medical service logs, or Poison Control Center calls. The spatial coverage of the public health surveillance data streams relative to the service area of the water utility should also be considered.
2. Communication and Coordination	Develop a mechanism and protocol for communication and coordination between the appropriate local public health organizations and the drinking water utility. This may include establishing a dedicated workgroup for the contamination warning system or integrating the utility into existing public health groups and forums. The local public health departments and drinking water utility should also establish procedures, roles, and responsibilities for investigation of alarms generated through the public health surveillance data streams.

7.1 Pre-Implementation Status

Through pre-existing programs and initiatives, the City of Cincinnati had several public health surveillance data streams in place that were leveraged as part of the contamination warning system pilot. However, these data streams were not optimized or comprehensively integrated in a manner to support the contamination warning system objectives. Furthermore, communication and coordination between the local health departments and GCWW was inconsistent and not well defined beyond a few specific issues, such as the utility's *Cryptosporidium Action Plan*.

7.1.1 Public Health Data Streams

As indicated previously, a number of public health surveillance data streams existed in the Cincinnati metropolitan area prior to implementation of the WS pilot. A description of the existing public health surveillance systems along with their pre-implementation status is summarized below.

- **911 calls**. The City of Cincinnati captures 911 calls electronically through a Computer Aided Dispatch system. The 911 call center receives over one million calls a year that are routed initially to the police department; those calls identified as medical emergencies are subsequently routed to the Cincinnati Fire Department for triage and response. To assist with the triage of medical emergency calls, dispatchers used paper guidecards based on procedures described in the Association of Public Safety Communications Officials Fire Service Dispatch Guidecards.
- **Emergency medical service logs**. The Cincinnati Fire Department collects information using a computerized tablet system and software that is compliant with Ohio state reporting standards for emergency medical billing. The tablets were procured under an Urban Area Security Initiative grant – a homeland security grant designed to improve activities during a weapon of mass destruction incident. Patient information captured includes patient age, gender, vital signs, chief medical complaint, medical observations made by the emergency medical technician or paramedic, medication, and incident zip code. Data was manually uploaded to the centralized Cincinnati Fire Department server on a daily basis and were used for training, patient tracking, billing, reporting requirements, and quality assurance.
- **Poison Control Center calls**. The Drug and Poison Information Center of the Cincinnati Children's Medical Center is a 24-hour emergency and technical information telephone service resource for use by the public regarding concerns involving drugs or poisons. A specially trained staff of pharmacists, pharmacologists, nurses, paramedics, and students within related medical professions answer questions about poisonings, environmental contaminants and drugs, including, drug abuse, product contents, substance identification, and adverse reactions. Toxicall®, a specialized medical database, is used to capture information received on the 24-hour hotline. In addition, an existing contract between Drug and Poison Information Center and the Southwest Ohio Public Health Departments, provided a mechanism for evening, weekend and holiday infectious disease reporting. Under this contract, protocols existed for reporting potential food or waterborne outbreaks, notification of public health officials to a potential biological terrorist incident, reporting of unusual disease reporting, and physician consultation.
- **Over-the-counter drug sales.** Local public health officials receive over-the-counter drug sale data through the National Retail Drug Monitor. Through this tool, retail pharmacy, grocery, and mass merchandise operations provide certain over-the-counter sales data which are aggregated into eighteen (18) product categories, analyzed, and displayed via a secure website. Users are able to view timeline sales by product category or geographically by zip code on a map. Regions with unusually high sales are 'flagged' using wavelet time series prediction models. Automated alerts are not generated and the number of participating retailers is proprietary, thus the exact population coverage is unknown.
- **Emergency room chief complaints.** Greater Cincinnati area hospitals provide healthcare registration data in real-time through the Real-Time Outbreak and Disease Surveillance system. Specific data provided include age, gender, home zip code, date/time of admission, and a free-text chief complaint of the patient. A natural language processing program is used to classify the chief complaint into one of eight (8) categories: gastrointestinal, constitutional, respiratory, rash, hemorrhagic, botulinic, or neurological. Four (4) algorithms (moving average, recursive least

square, wavelet, cumulative sum calculation (CUSUM) with weighted moving average) are used to determine deviations from an established baseline level of emergency department visits. Alerts to Ohio Department of Health are automatically generated when the threshold is four standard deviations above the mean. Once received by the Ohio Department of Health, alerts are forwarded to the appropriate health jurisdiction for investigation. This system, along with the National Retail Data Monitor, is financially supported by the Ohio Department of Health through use of public health infrastructure funds.

- **Infectious Disease Reporting.** Mechanisms for standard infectious disease reporting to the Ohio Department of Health and/or the CDC are in place for notifiable diseases such as acquired immune deficiency syndrome, anthrax, botulism, cholera, and others (CDC, 2007). Reporting of these diseases typically occurs after receipt of diagnostic test results and while more reliable, is not as timely of an indicator as the syndromic surveillance tools.

7.1.2 Communication and Coordination

Thirteen (13) health jurisdictions are included in the GCWW service area with the primary jurisdictions serviced by GCWW being the City of Cincinnati and the Hamilton County Public Health. In collaboration with Cincinnati Health Department and Hamilton County Public Health, GCWW developed a *Cryptosporidium Action Plan* that described roles and responsibilities and general protocols in the event of a *Cryptosporidium* outbreak that could be associated with contaminated drinking water. However, there was no mechanism in place for *routine* communication and coordination between GCWW and the health departments for the jurisdictions within GCWW's service area.

Several public health committees with responsibilities related to surveillance activities, outbreaks, and terrorism preparedness existed prior to implementation of the pilot. The most relevant committees are those established in response to a Public Health Infrastructure grant awarded to the State of Ohio from the CDC. A Health Commissioners Executive Steering Committee was created to manage and discuss requirements for deliverables related to the grant and established the following sub-committees:

- **Regional Epidemiologists and Disease Investigators**. Responsible for epidemiological and disease investigation grant requirements. This group developed a protocol, implemented by local health jurisdictions, for responding to infectious disease outbreaks.
- **Environmental Surety**. Formed to focus on the response to West Nile Virus and other environmentally-related outbreaks.
- **Bioterrorism Coordinators**. Consists of both regional and local bioterrorism coordinators. Their primary focus is to coordinate regional and local response to a bioterrorism event and to ensure that response plans were in place.
- **Public Health Information Officers**. Responsible for creating talking points and message maps related to specific outbreaks or public health crises and collaborating with the Joint Information Center during an event.

GCWW was not a member or active participant in any of these committees.

7.1.3 Summary of Identified Gaps

The existing public health surveillance data streams and infrastructure provided a solid foundation for this component of the contamination warning system pilot. However, a number of enhancements and modifications were needed to fully develop and/or optimize the data streams and communication and coordination protocols to meet the design objectives described in Table 7-1. Specifically, the public health surveillance data streams that could provide early indication of drinking water contamination with a fast-acting contaminant (911 calls, emergency medical service logs, and Poison Control Center calls) were not fully optimized for timely detection of contamination incidents or the degree of automation necessary for near real-time detection. In addition, the lack of a consistent and reliable mechanism for communication and coordination with local health departments presented a challenge in terms of defining roles and responsibilities and developing a protocol to investigate alarms generated through the public health surveillance data streams. The specific gaps identified for each attribute are summarized in **Table**

7-2. These gaps provided the design basis for enhancements to public health surveillance, and the post-implementation status of the resulting system is described in Section 7-2.

Table 7-2. Public Health Surveillance Gap Analysis

Attribute	Description of Gap
1. Public Health Data Streams	• **911 calls**: Although calls were captured electronically, information was gathered using a manual triage process resulting in a data set that was not standardized and difficult to analyze for trends. There was no mechanism for automated or real-time analysis of the data. • **Emergency medical service logs**: Patient information was recorded using standardized software; however, manual uploads were required to transfer data to a centralized location thereby reducing the timeliness of any analyses. There was no mechanism for automated or real-time analysis of the data. • **Poison Control Center calls**: The Drug and Poison Information Center captured standardized data electronically on a 24/7/365 basis. There was no defined approach for filtering and analyzing data that could be indicative of drinking water contamination. • **Emergency room chief complaints**: An automated mechanism for simultaneous notification of local public health departments and GCWW utility staff did not exist.
2. Communication and Coordination	• No reliable link or consistent mechanism for data sharing had been established between GCWW and local public health partners.

7.2 Post-Implementation Status

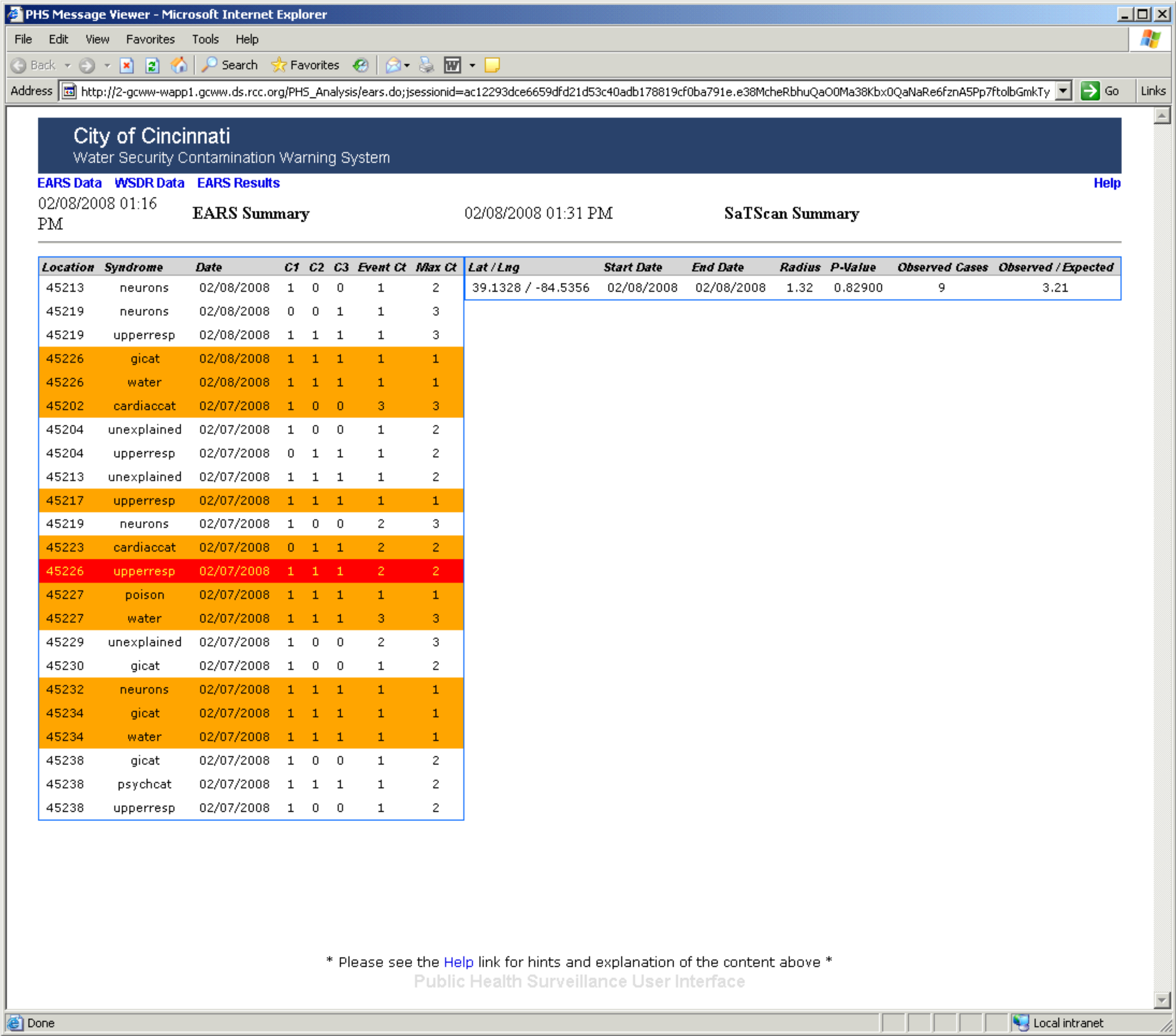
The design and implementation of the public health surveillance component for the contamination warning system in Cincinnati focused on two primary objectives 1) enhancing data streams for the detection of fast-acting contaminants and 2) improving communication and coordination between GCWW and the local public health community. In order to enhance the 911 calls and emergency medical service logs to meet the contamination warning system objectives, a significant development effort that required support from multiple City partners was necessary. Modifications to mechanisms for analyzing Poison Control Center calls and enhancing the notifications for emergency room chief complaints were more modest in scope and effort. The following subsections describe the post-implementation status of the public health data streams and communication and coordination between GCWW and the local public health community.

7.2.1 Public Health Data Streams

Design and implementation activities related to the public health surveillance data streams focused on enhancements and development of 911 calls and emergency medical service logs into data streams that could support the contamination warning system objectives for detection of fast-acting contaminants. Collaboration with the local Poison Control Center provided the opportunity to implement modifications to protocols for processing and analyzing these calls to support the contamination warning system objectives as well. Based on the assessment of the emergency room chief complaints data stream, the only modifications made through the Cincinnati pilot were related to notifications as discussed in Section 7.2.2.

Public Health Surveillance User Interface

The use of 911 calls and emergency medical service logs as a surveillance tool was a new application for these data streams. In order to support the analysis of data by local public health partners and the utility, it was necessary to develop a Public Health User Interface to display data and results. The Public Health Surveillance User Interface, deployed on Cincinnati's wide area network, contains three sources of data for event investigation: Early Aberration Reporting System (EARS) Results Summary, SaTScan™ Results Summary, EARS Data, and WSDR Data. As illustrated in **Figure 7-1**, the initial page of the Public Health Surveillance User Interface includes a combined EARS Results and SaTScan™ Results Summary page.



City of Cincinnati
Water Security Contamination Warning System

EARS Data WSDR Data EARS Results Help

02/08/2008 01:16 PM **EARS Summary**

Location	Syndrome	Date	C1	C2	C3	Event Ct	Max Ct
45213	neurons	02/08/2008	1	0	0	1	2
45219	neurons	02/08/2008	0	0	1	1	3
45219	upperresp	02/08/2008	1	1	1	1	3
45226	gicat	02/08/2008	1	1	1	1	1
45226	water	02/08/2008	1	1	1	1	1
45202	cardiaccat	02/07/2008	1	0	0	3	3
45204	unexplained	02/07/2008	1	0	0	1	2
45204	upperresp	02/07/2008	0	1	1	1	2
45213	unexplained	02/07/2008	1	1	1	1	2
45217	upperresp	02/07/2008	1	1	1	1	1
45219	neurons	02/07/2008	1	0	0	2	3
45223	cardiaccat	02/07/2008	0	1	1	2	2
45226	upperresp	02/07/2008	1	1	1	2	2
45227	poison	02/07/2008	1	1	1	1	1
45227	water	02/07/2008	1	1	1	3	3
45229	unexplained	02/07/2008	1	0	0	2	3
45230	gicat	02/07/2008	1	0	0	1	2
45232	neurons	02/07/2008	1	1	1	1	1
45234	gicat	02/07/2008	1	1	1	1	1
45234	water	02/07/2008	1	1	1	1	1
45238	gicat	02/07/2008	1	0	0	1	2
45238	psychcat	02/07/2008	1	1	1	1	2
45238	upperresp	02/07/2008	1	0	0	1	2

02/08/2008 01:31 PM **SaTScan Summary**

Lat / Lng	Start Date	End Date	Radius	P-Value	Observed Cases	Observed / Expected
39.1328 / -84.5356	02/08/2008	02/08/2008	1.32	0.82900	9	3.21

* Please see the Help link for hints and explanation of the content above *

Public Health Surveillance User Interface

Figure 7-1. Public Health Surveillance User Interface Summary Screen

This summary page provides a table of the latest analysis results, color-coded according to severity for each data source; the color code corresponds to that established by the Department of Homeland Security Advisory System (Department of Homeland Security, 2006). According to the current business rules, only conditions that merit a "red threat level" for each data source that also applies to the entire City of Cincinnati would initiate an email alert notification to the appropriate local public health partners and utility staff. The EARS Data page provides access to multiple Excel® worksheets that collectively contain a detailed alert table by syndrome category and zip code as well as time-series graphs of the syndromes. The WSDR Data page provides a user link to the de-identified patient information as obtained from the EMS run. The *Water Security Initiative Cincinnati Pilot Public Health Surveillance User Interface Guide* provides a detailed explanation for navigation of the user interface (USEPA, 2007t).

911 Calls

To improve standardization and electronic call tracking for 911 calls a commercial software package, Priority Dispatch ProQA software was deployed. This software package assists 911 dispatchers in effective triage of calls by gathering a variety of health data in a systematic manner. Data elements include chief complaint and geographic location (latitude / longitude) of the call. The caller initiates the complaint (i.e., breathing problems) and more specific information is attained through the questions asked using prompts provided by the software program. In addition, instructions are provided to the caller until medical assistance arrives.

Cincinnati Fire Department began using the ProQA 'card' set in December 2006 to triage all medical 911 calls and implemented the software package to support this analysis upon installation of the City's new Computer Assisted Dispatch software. This Priority Dispatch ProQA software directs the call-taker through a series of questions for the purpose of triage and incident coding.

In order to meet the objectives of the contamination warning system, the 'Incident Type' field was identified as the most appropriate filter for the 911 call data analysis. Priority Dispatch ProQA contains 366 unique incident type codes, i.e., caller's chief complaint. A review of all potential incident types by the User Group (see Section 7.2.2) identified 107 that are relevant for WS 911 data analysis. Incident types include symptoms such as abdominal pain, breathing problems, cardiac or respiratory alert, and seizures as well as certain events such as chemical spill and carbon monoxide alert that can be used to quickly rule out drinking water contamination as a potential cause.

Figure 7-2 illustrates the information flow for the 911 calls data stream. The 911 dispatcher uses the Priority Dispatch ProQA software to document information, including the incident type. Select data are then exported from the Computer Aided Dispatch server to a database table developed by the Cincinnati Fire Department. Java 2 Platform, Enterprise Edition (J2EE)-compliant software components were developed to acquire and reformat the table row contents uniquely and evaluate the data against the 107 selected incident types. Only those records that contain one of the 107 incident types are transferred to the WSDR, hosted at GCWW, for analysis. Additional Data Access components retrieve the last 21 days of 911 call data from the WSDR in reverse chronological order on an hourly basis to populate input files for SaTScan™ analysis. Once the latest data set is retrieved, SaTScan™ is queried to provide the latest analysis results. Upon analysis completion, data display and alerting tools publish a new analysis summary to the Public Health User Interface (discussed below) for user review. Through an automated process, analysis results are compared against business rules to determine if there is a deviation from the baseline and users should be notified. If such conditions exist, an email notification is sent to public health partners including the Cincinnati Health Department and Hamilton County Public Health and GCWW as a prompt for further investigation in accordance with the procedures defined in the *Concept of Operations for the GCWW Contamination Warning System* (USEPA, 2007b).

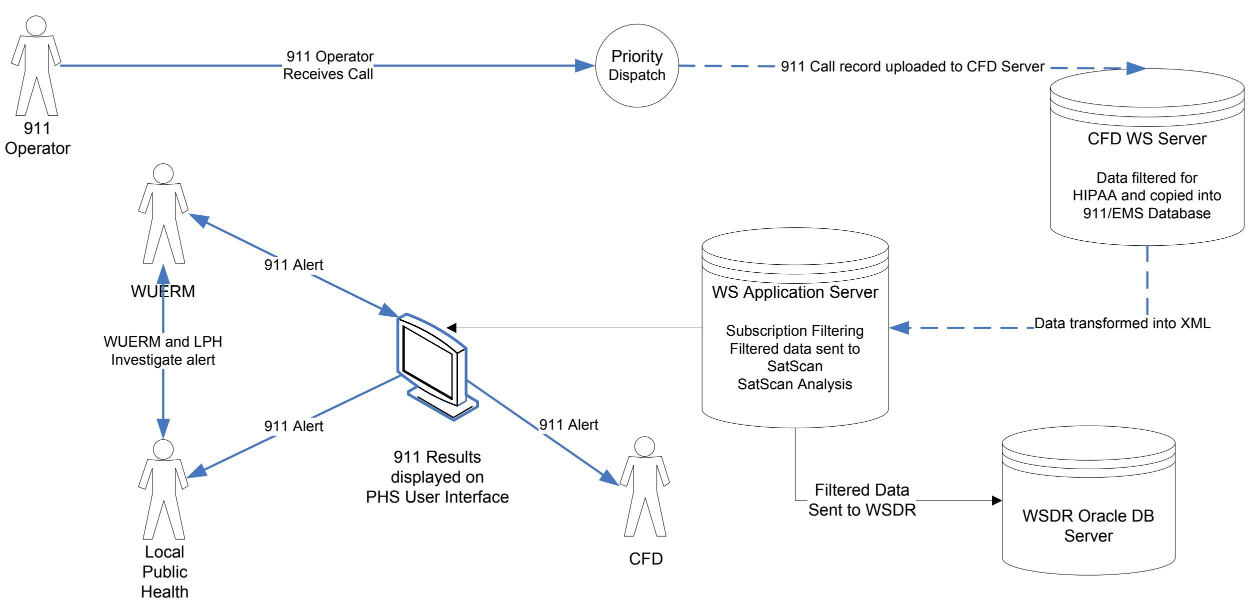


Figure 7-2. Information Flow for 911 Calls

The SaTScan™ prospective space-permutation method is used as the event detection tool for this public health data stream. More information is available at http://www.satscan.org. This method detects a cluster in a time space setting using the latitude and longitude coordinates of the call location. A cluster is defined as a high proportion of cases over a twenty-four hour period in one geographic location (zip code) compared to another; the Cincinnati pilot has established notification rules for clusters at a significance level of $p \leq 0.025$ and display requirements of clusters at a significance level of $p \leq 0.10$.

Emergency Medical Service Logs

To improve the timeliness of data collection from the Cincinnati Fire Department's emergency medical service tablets, wireless CISCO WISM devices and Aironet routers were installed in all twenty-six (26) Cincinnati Fire Department stations. Installation of these wireless routers allowed for automatic upload of patient information to the Cincinnati Fire Department server upon return of the vehicle to the firehouse.

Figure 7-3 presents an illustration of the information flow for emergency medical service logs, beginning with entry of data into the tablets in the field. The provider's impressions are categorized into syndromes using the Early Aberration Reporting System software developed and maintained by the CDC (CDC, 2006). The syndromes are analyzed temporally based on zip code of the location of the run. Data are collected and results are generated on an hourly basis. Upon analysis completion, data display and alerting tools publish a new analysis summary to the Public Health User Interface (discussed below) for user review. Through an automated process, analysis results are compared against business rules to determine if there is a deviation from the baseline and users should be notified. If such conditions exist, an email notification is sent to public health partners including the Cincinnati Health Department and Hamilton County Public Health and GCWW as a prompt for further investigation in accordance with the procedures defined in the *Concept of Operations for the GCWW Contamination Warning System* (USEPA, 2007b).

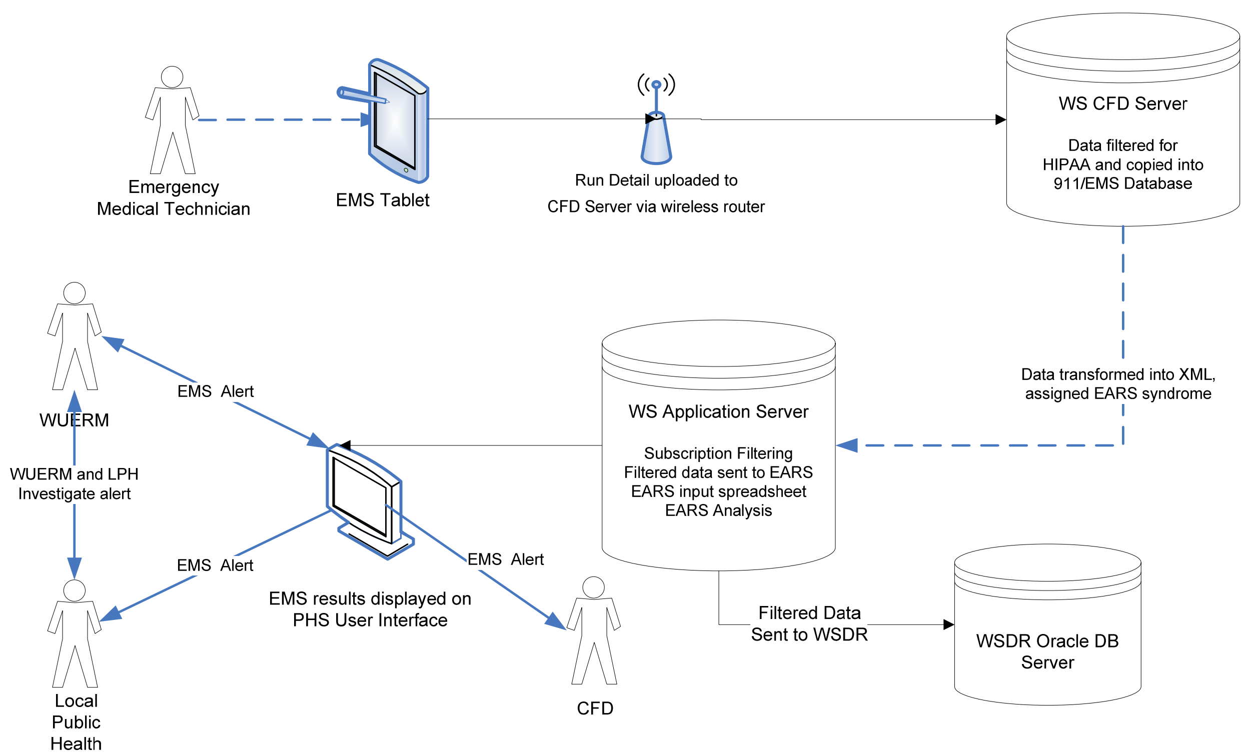


Figure 7-3. Information Flow for Emergency Medical Service Logs

The EARS software allows for customization of syndrome categories. A list of provider impressions that might indicate a drinking water contamination incident was developed through discussions with local health partners. The provider impressions are categorized into the following eight syndromes:

- **Cardiac category**: angina pectoris, cardiac arrest, chest pain/discomfort, congestive heart failure, dysrhythmia, hypertension, hypotension, myocardial infarction, unconscious (unknown etiology)
- **Gastrointestinal category**: abdominal pain minor, abdominal pain severe, appendicitis, dehydration, diarrhea, food poisoning, lower gastrointestinal bleeding, nausea/vomiting, upper gastrointestinal bleeding
- **Neurological category:** altered level of consciousness, cerebrovascular accident or stroke, dizziness/vertigo, headache, numbness/tingling, paralysis/loss of motion, seizures/convulsions unknown, syncope/fainting, transient ischemic attack
- **Poison category**: abuse/dependency, alcohol related, drug induced emotional, drug overdose, food poisoning, hematuria, ingestion, inhalation, renal failure
- **Psychological category**: abuse/dependency, alcohol related, anxiety, behavioral disorder, depression, drug induced emotional, drug overdose, psychiatric disorder, suicide attempt (not dead on arrival)
- **Unexplained category**: blank (provider impression not provided), dead on arrival, other, respiratory arrest, unconscious (unknown etiology)
- **Upper respiratory category**: airway obstruction/choking, cold/flu, croup, epiglottitis, respiratory distress, respiratory distress (acute), respiratory involvement, smoke inhalation
- **Water category**: altered level of consciousness, abdominal pain minor, abdominal pain severe, diarrhea, dizziness/vertigo, ingestion, nausea/vomiting, seizure/convulsions febrile, seizures/convulsions (unknown)

The mechanism for event detection employed by the EARS software relies on a cumulative sum or CUSUM method. A CUSUM is best defined as a measure of how much higher a current observation is than a reference baseline. The EARS software utilizes three CUSUM algorithms to analyze the data: C1, C2, and C3. Each of these algorithms is explained below:

- **C1 algorithm**. Includes data from the current day only [that is, hits from one (1) day of data], but uses the prior seven (7) days worth of data to calculate the (baseline) reference mean. C1 is the least sensitive of the three (3) algorithms. A flag or alert generated by the C1 algorithm is most useful when evaluating acute events.
- **C2 algorithm**. Analyzes data from the current day but shifts the data start back two (2) days from the current day; the baseline mean is calculated using the seven (7) prior days of data from that initial point. C2 is also based on one day of information. C2 can help define the length of an outbreak's acceleration and when the outbreak has peaked. C2, however, does not include the initial start of the upward swing of an outbreak. A flag or alert generated by a C2 algorithm is slightly more sensitive than a flag or alert generated by a C1 algorithm.
- **C3 algorithm**. Uses the same timeframe as C2 (it shifts the starting point of the data to start from two (2) days prior to the current day and then the baseline mean is calculated using the seven (7) prior days of data from that initial point). However, C3 includes an average of three (3) days of events which it compares against the seven (7) day baseline mean. C3 is useful when there is not a sharp increase above the baseline. For example, in cases where data from the past three (3) days have been above the mean but not far enough above the mean to produce a flag from a C1 or C2 algorithm. A flag or alarm generated by a C3 algorithm is considered to be the most sensitive of the three.

Based upon historical analyses of emergency medical service logs, descriptions of the CUSUM algorithms, and the protocol for regional surveillance in the Cincinnati area, alerts generated by the C1 algorithm were considered to be the most useful for the Cincinnati pilot.

Poison Control Center Calls

As part of the Cincinnati pilot effort, a contract for testing the feasibility and benefits of integrating local poison control center calls into the contamination warning system framework was funded by EPA's Office of Research and Development (ORD) NHRSC. The purpose of the project was to determine how local poison control centers can contribute to early detection, notification, and rapid response for a more robust drinking water contamination warning system.

The Drug and Poison Information Center implemented a multi-tiered approach to event detection that included statistical, non-statistical, and human surveillance as illustrated in **Figure 7-4**.

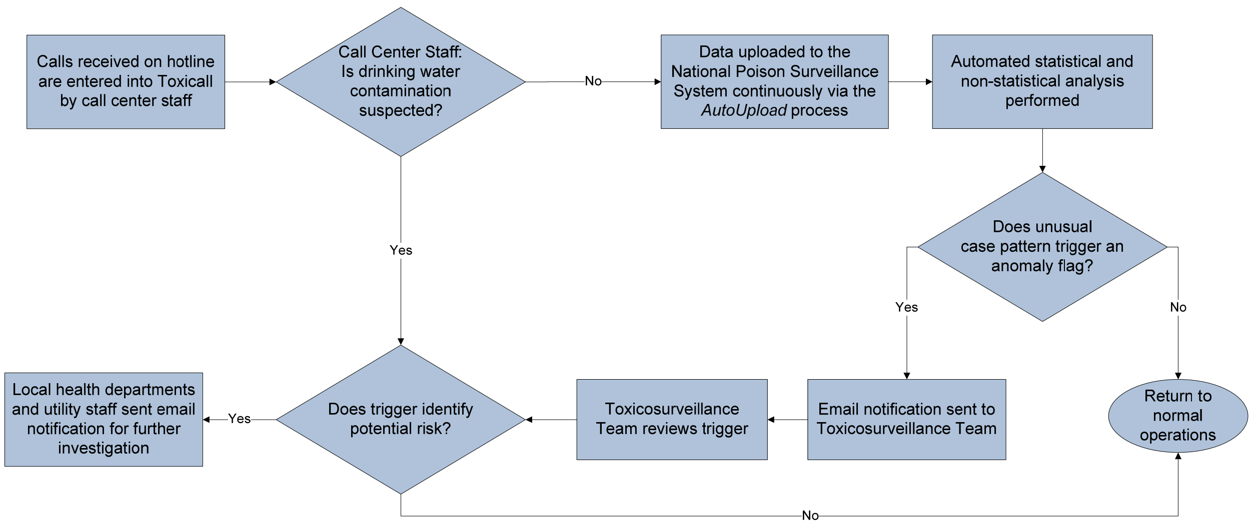


Figure 7-4. Drug and Poison Information Center Drinking Water Surveillance Process Flow

The American Association of Poison Control Centers National Poison Data System aggregates data collected from poison control centers across the nation, with data uploaded on a near real-time basis and hourly statistical analysis, alert processing, and communication of findings. The system allows poison control centers to develop customized statistical analysis parameters for three individual types of toxicosurveillance definitions including: total call volume, human exposure call volume, and clinical effect count. Zip codes or telephone numbers can be fixed for each definition to provide a more targeted regional approach for surveillance. For the Cincinnati pilot, this included all Ohio zip codes in the GCWW service area.

The statistical surveillance approach for the Cincinnati pilot relies on the human exposure call volume and clinical effect count definitions. For human exposure call volume, statistical analysis is performed only on the total number of human exposure calls uploaded to the National Poison Data System. Analysis on the clinical effect count definitions are performed on each individual symptom that is coded in the Toxicall medical database used by the Drug and Poison Information Center. Aberrations greater than three times the standard deviation from the baseline that involve at least two (2) cases trigger an email to be sent to the toxicosurveillance team (on call 24/7/365) for further investigation.

Non-statistical analysis methods leverage the National Poison Data System's Syndromic Definition Module. The toxicosurveillance team developed a customized search through this module that incorporates specific substances thought to be most likely related to a water contamination event (e.g., arsenic, cyanide, dioxin, ricin, botulinum toxin, etc.) and eliminates records where the reason for exposure to the substance is understood and unrelated to water (e.g., intentional suicidal exposures, occupational injuries).

The third surveillance method deployed by the Drug and Poison Information Center relies on human surveillance. The Drug and Poison Information Center is staffed by trained physicians, pharmacists, nurses, paramedics, and students within nursing and pharmacy programs. In addition, a Certified Specialist in Poison Information staff member is consulted on every exposure call received to ensure consistency in recommendations from the call center and physician toxicologists are on call 24/7/365 for more complicated or critical human poisonings. The human surveillance method for the pilot relies on this expertise along with the open call center environment that facilitates ongoing discussion and consultation among staff members.

In addition to the surveillance methods described above, as part of the project the Drug and Poison Information Center established a “Water Safety Hotline” that is dedicated for water contamination queries. Physicians, nurses, pharmacists, public health providers, and utility staff seeking toxicology consultation or related services can access this number in the event of unusual water testing results, water-related health effects or other threats.

7.2.2 Communication and Coordination

As discussed in Section 7.1.2, while a number of public health committees and organizations existed in the Cincinnati area, communication and coordination with the utility was inconsistent and limited. To improve this area a Public Health User’s Group was established. The User’s Group is comprised of members from EPA, GCWW, Cincinnati Fire Department, law enforcement, the Drug and Poison Information Center, the Environmental Health and Safety Officer from Northern Kentucky Health Department, and a representative from the Executive Steering Committee, Bioterrorism Coordinators, Environmental Surety, and Regional Epidemiologists and Disease Investigators of the Southwest Ohio public health committees described in Section 7.1.2. These representatives report the progress of the Cincinnati pilot to the members of their respective committees and organizations to ensure awareness of the program.

During the early stages of design and deployment, the Public Health User’s Group met on a monthly basis to inform the design, use, and evaluation of tools proposed for the public health surveillance component of the Cincinnati pilot drinking water contamination warning system. With the completion of implementation activities the group has transitioned to a quarterly meeting schedule. The User’s Group provided a forum to discuss not only issues related to the pilot, but other issues that impacted both the public health community and the drinking water utility. Through participation in these meetings, an ongoing dialogue has been established that improves communication and coordination between GCWW and its local public health partners.

In addition to the Public Health User’s Group, development of the GCWW Concept of Operations (USEPA, 2007b) provided an opportunity to better define the protocols and procedures for how GCWW would work with local public health partners to investigate alarms generated through the contamination warning system. As part of this development effort the User’s Group identified improvements and/or defined protocols for issuing notifications of alarms. For the 911 calls and emergency medical service logs this involved developing an automatic notification tool to send emails to GCWW, Cincinnati Health Department, Hamilton County Public Health, and Drug and Poison Information Center representatives simultaneously so each organization could begin the process of trigger investigation as described in the Concept of Operations. Similarly, the Drug and Poison Information Center includes the same health and utility contacts on email notifications related to anomalies detected through the analysis of poison control center call data. Although the Real-Time Outbreak and Disease Surveillance system for analyzing emergency room chief complaint data was not customized for the objectives of the contamination warning system pilot, the notification protocol was modified to include staff from GCWW for email alerts generated in response to elevated gastrointestinal illness in Hamilton County, OH (including the City of Cincinnati).

7.2.3 Summary of Post-Implementation Status

The public health surveillance component of the contamination warning system has been installed, is fully operational, and is currently generating data needed to establish baseline performance. The public health surveillance component includes the following data streams: 911 calls, emergency medical service logs, Poison Control Center calls, over-the-counter medication sales, emergency room chief complaints, and infectious disease reporting. A user interface was developed and deployed on the City's WAN to view and analyze data generated by 911 calls and emergency medical service logs. Customized syndrome categories were developed to support analysis of 911 calls and emergency medical service logs by spatial and statistical algorithms, respectively. A user's group was created to better integrate GCWW into the public health community and joint notification protocols were implemented to improve coordination and communication relative to potential drinking water contamination incidents. **Table 7-3** provides a summary of the post-implementation status of the public health surveillance component of the contamination warning system.

Table 7-3. Public Health Surveillance Post-Implementation Status

Attribute	Description of Installed Component
1. Public Health Data Streams	• 911 call information collection is standardized through the use of Priority Dispatch software and transferred to a centralized server where it is processed for analysis • Wireless routers have been installed at the City's 26 fire stations to support automatic upload of emergency medical service data • Customized syndrome categories defined for spatial and statistical analysis of 911 calls and emergency medical service logs • Public Health User Interface developed and deployed on the City's Metropolitan Area Network to view and analyze 911 calls and emergency medical service data • Enhanced algorithms and protocols implemented for handling of Poison Control Center calls
2. Communication and Coordination	• Public Health User's Group with representatives from key public health partners and GCWW meets on a quarterly basis to discuss issues related to the public health surveillance component of the contamination warning system • An automated email notification mechanism is in place to notify local public health and GCWW of alarms generated through the analysis of 911 calls and emergency medical service logs • Local public health departments and GCWW receive simultaneous automated email notifications of alarms generated through the analysis of emergency room chief complaints for gastrointestinal illness • 24-hour Water Safety Hotline established by the Poison Control Center to provide toxicological support to GCWW and local public health on issues related to drinking water contamination • A concept of operations has been developed that guides the day-to-day operation of the component

Figure 7-5 provides a summary of the level of effort associated with design and implementation of the public health surveillance component of the Cincinnati pilot. Public health surveillance activities, as summarized in Table 7-3, relied on support from EPA, GCWW, and local partners. The level of effort for both design elements – available data streams and communication and coordination – was comparable. Local public health partners participated in regular Public Health User Group meetings, and received and reviewed automated email notification of alarms generated through analysis of 911 calls and emergency medical service logs.

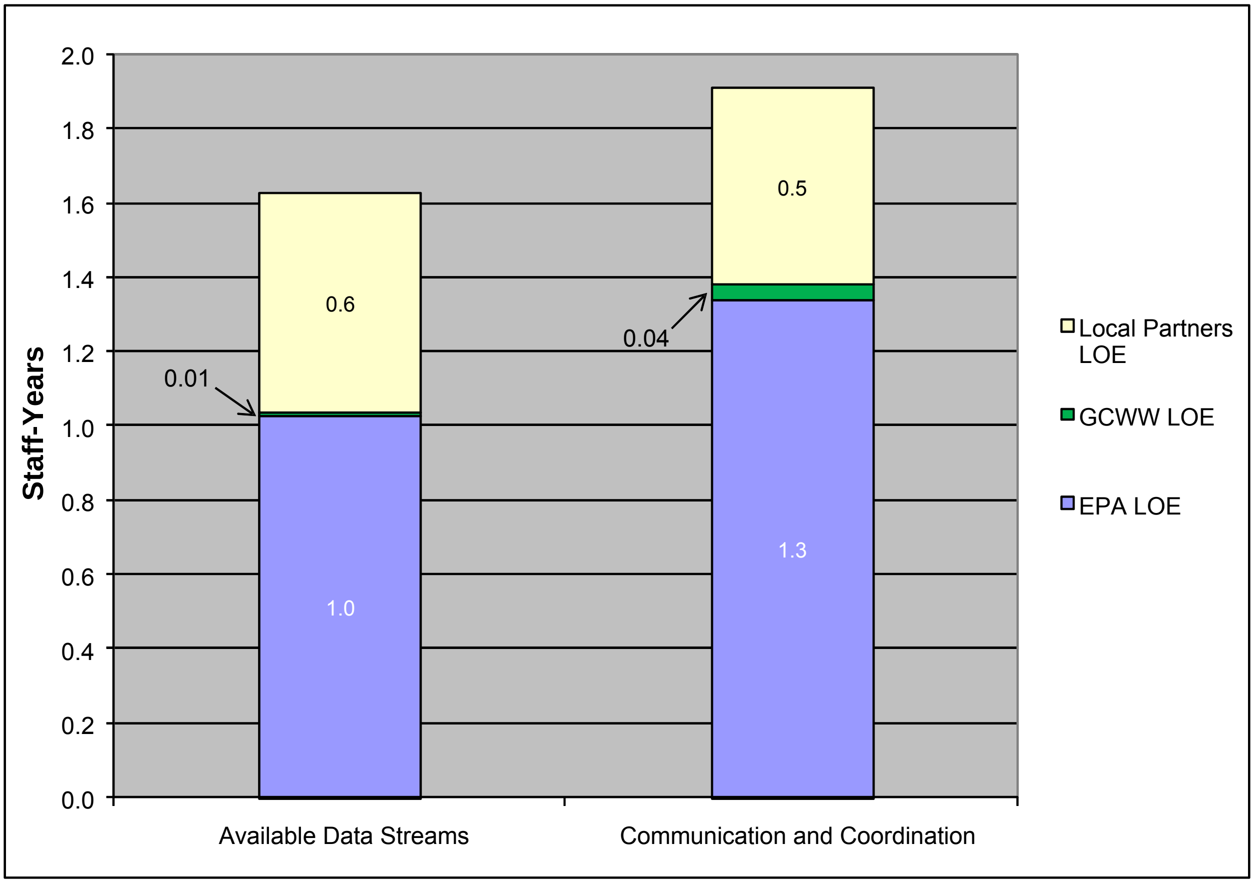


Figure 7-5. Level of Effort for Design and Implementation of the Public Health Surveillance Component (December 2005 – December 2007)

Figure 7-6 presents a summary of the extramural costs associated with design and implementation of the public health surveillance component for the Cincinnati pilot. Significant EPA contractor labor was associated with design and deployment of the 911 call and emergency medical service data flows. EPA contractor support to communication and coordination activities included design and deployment of notification procedures, development of the concept of operations, and support to the Public Health User's Group. Costs associated with contractor travel were not included in this calculation.

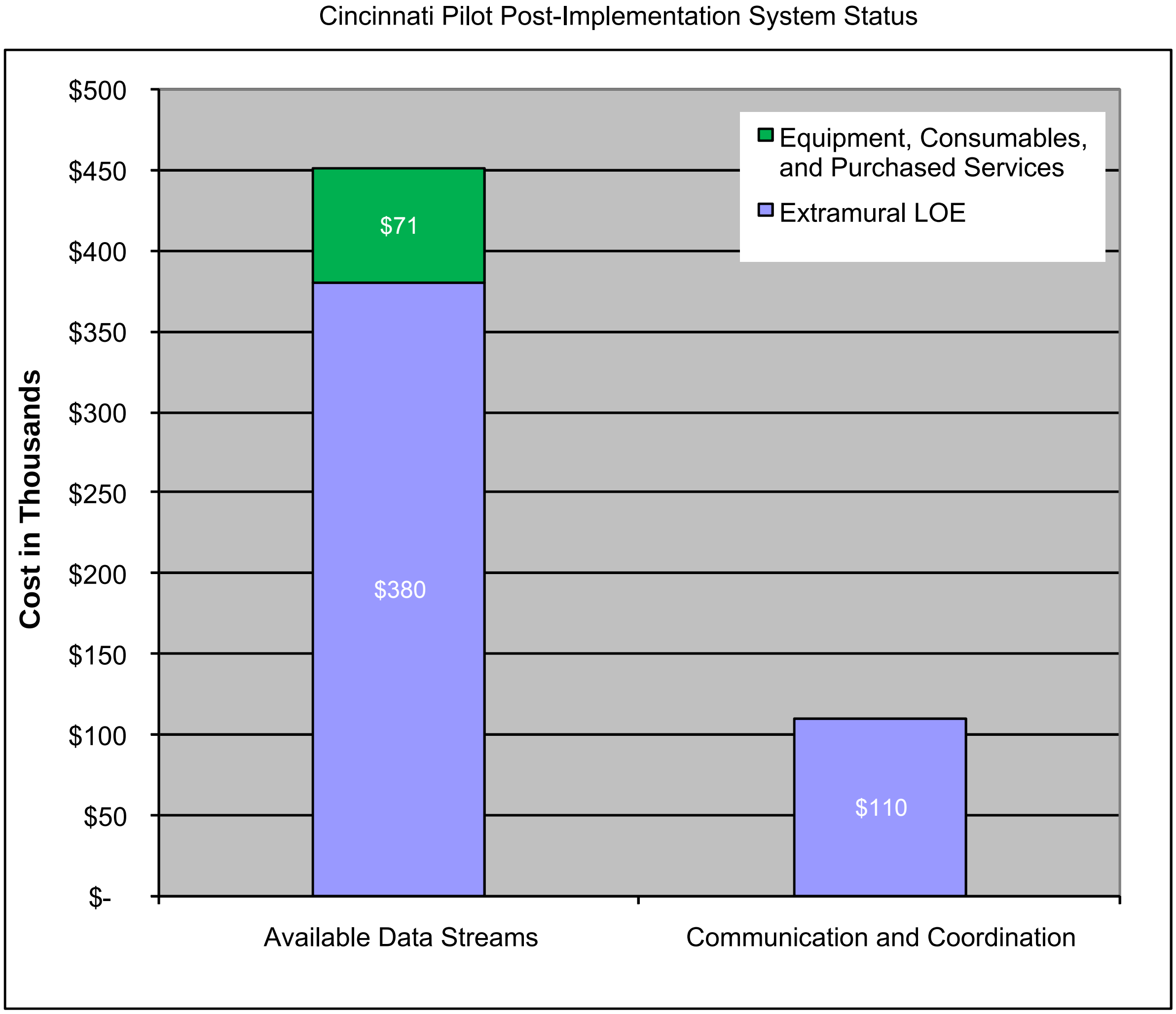


Figure 7-6. Extramural Costs Associated with Design and Implementation of the Public Health Surveillance Component (December 2005 – December 2007)

As illustrated in **Figure 7-7**, the primary costs for design and implementation of the public health surveillance component were associated with the 911 call logs and emergency medical service records data streams. These two data streams required significant enhancements in order to meet the objectives of the Cincinnati pilot contamination warning system. Procurement and installation of wireless routers at the twenty-six (26) Cincinnati Fire Department stations accounted for the primary difference in costs for these two (2) data streams.

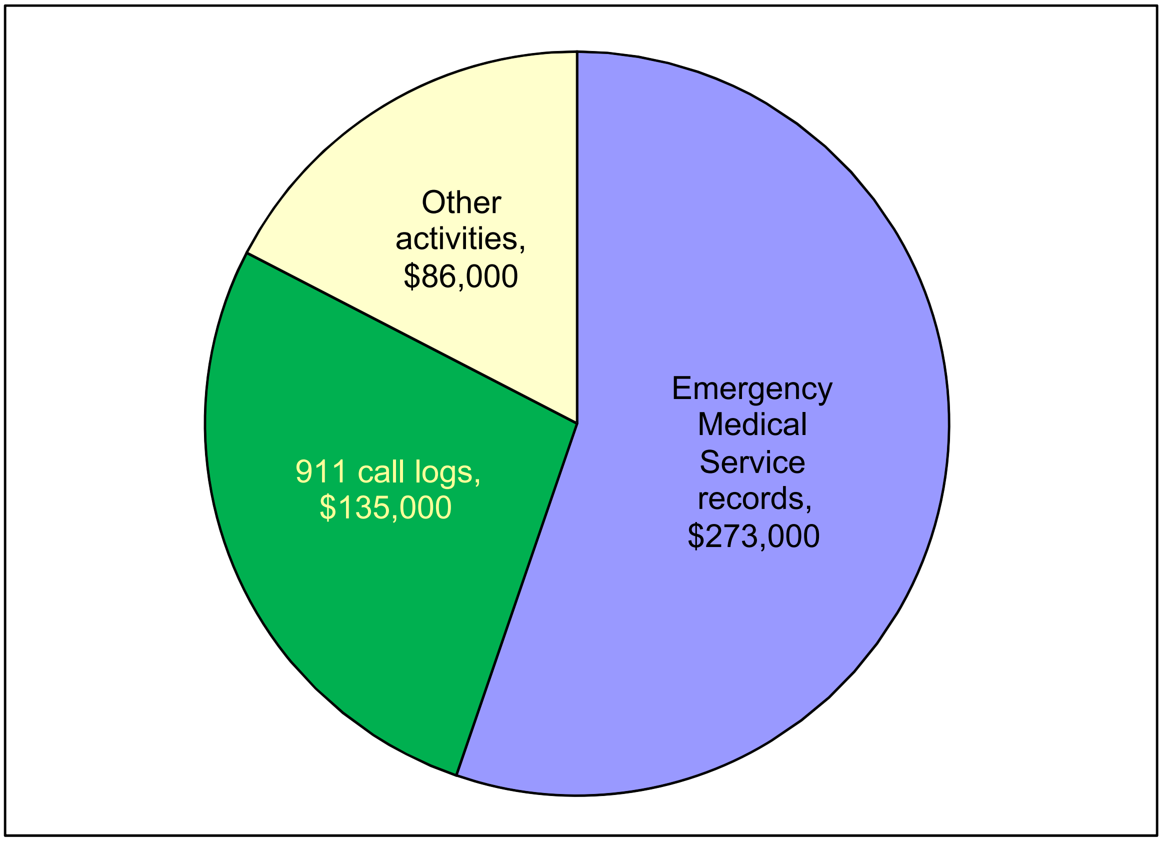


Figure 7-7. Breakout of Costs Associated with Deployment of 911 Call Logs and Emergency Medical Service Records

The costs associated with significant enhancements for a public health surveillance data stream relative to leveraging data streams already in place for the purpose of syndromic surveillance may be an important consideration for contamination warning system design and deployment in other jurisdictions. Through evaluation of the Cincinnati pilot, the return on investment will be considered and may further influence the decision-making process for contamination warning system design.

Section 8.0: Consequence Management

Consequence management is a key aspect of the GCWW contamination warning system and consists of actions taken to plan for and respond to potential drinking water contamination incidents in the distribution system. These actions are meant to minimize response and recovery timelines through a pre-planned, coordinated effort between the utility and a network of local response partners. Investigative and response actions initiated upon determination of a “possible” contamination threat are used to establish credibility, minimize public health and economic impacts, and ultimately return the utility to normal operations.

The Consequence Management Plan (USEPA, 2006e) serves as a guide for GCWW that describes the actions that should be taken upon determination of a “possible” contamination threat, as detected by one of the contamination warning system monitoring and surveillance components. In the event of a confirmed contamination incident, the plan can be used by utility staff and/or local response partners to guide remediation and recovery steps to return the utility to normal operation. The Consequence Management Plan relies on extensive pre-planning efforts to establish clear roles and responsibilities with local, state, and federal response organizations, and to define strategies for communicating with the public.

The GCWW Consequence Management Plan was developed to be a component of the utility’s existing emergency response plan and focuses specifically on a contamination threat to the distribution system. The Consequence Management Plan includes sections and response guidelines (e.g., decision trees) to address all phases of consequence management including Credible Determination, Confirmed Determination, and Remediation and Recovery. In addition, information is included that describes how to address utility and risk communication issues.

The pre-implementation assessment process used to initiate the development of the Consequence Management Plan consisted of the following activities:

- **Evaluation of Plans, Processes and Equipment** – Existing materials and response plans/procedures were reviewed to determine their applicability to contamination warning system consequence management.
- **Interviews with Stakeholders** – Interviews were conducted to identify the existing status of utility incident management operations for a contamination incident. Interviews were used to assess strengths and weaknesses of the utility’s emergency response plan, as well as to identify current needs, including GCWW response partner support. Three groups were identified and interviewed to assess existing procedures: utility group consisting of representatives from GCWW’s operations, distribution, laboratory, engineering, business services and commercial services divisions; local group consisting of city, county, state and regional federal agency representatives (police/fire departments, city/state public health, etc.); and technical consultant group consisting of individuals with water utility or public health expertise and experience in contamination warning system processes similar to the Cincinnati pilot.
- **Workshops with Stakeholders** – Workshops with GCWW, response partner agencies and representatives from other utilities were used to determine the appropriate level of stakeholder involvement during Consequence Management Plan development. This included identifying roles and responsibilities in the pilot and the status of external response partner coordination including their response plans and procedures (e.g., Hazardous Materials responders’ protocols, law enforcement response protocols).

Coupled with the assessment process, a gap analysis was conducted to compare existing response capabilities against the objectives of the GCWW Consequence Management Plan to determine missing components. Potential solutions to close these gaps were then evaluated for impact and cost, taking into account possible leveraging of existing system plans and procedures already integrated into daily procedures.

The Consequence Management Plan design objectives are shown in **Table 8-1**, and were derived from the overarching performance objectives of the contamination warning system as described in *WaterSentinel System Architecture* (USEPA, 2005a). GCWW's pre-existing capability with respect to each attribute of the Consequence Management Plan listed in Table 8-1 is summarized in Section 8.1 and the utility's capability after implementation of the contamination warning system is summarized in Section 8.2.

Table 8-1. Consequence Management Plan Design Objectives

Attribute	Design Objective
1. Contaminant Incident Response Plans	• Review existing utility emergency preparedness plans and operations to determine potential elements of a CMP.
2. Response Partner Network	• Identify and engage response partner agencies and stakeholders that may be involved in the development of the GCWW CMP and corresponding response activities.
3. Training and Exercises	• Assess the existing utility training program to determine potential elements that address a system-wide contamination incident.
4. Equipment	• Assess existing incident response equipment to identify additional equipment needed to carry out response activities outlined in the GCWW CMP; acquire equipment, as necessary.

8.1 Pre-Implementation Status

The following section provides the pre-implementation status of the GCWW consequence management program. As stated above, the pre-implementation assessment process used to initiate the development of the Consequence Management Plan consisted of evaluating existing response plans/procedures/equipment and conducting interviews and workshops with key stakeholders. The results of the pre-implementation assessment are described below including a summary of gaps identified relative to the objectives of a functional Consequence Management Plan.

8.1.1 Contamination Incident Response Plans

Prior to the development of the GCWW Consequence Management Plan, existing utility preparedness plans and written procedures, including standard operating procedures, policies, and checklists, were collected and evaluated according to their applicability and contribution to the development of a Consequence Management Plan. During the review, a matrix was created that identified the type of plan, response resources available, areas where gaps occurred, and possible interaction points with the Consequence Management Plan and external response partner plans. A summary of the matrix is shown in **Table 8-2**.

Table 8-2. Pre-Implementation Evaluation of Utility Plans, Procedures, Equipment, and Training

GCWW Plan	Contains protocols for drinking water contamination response?	Contains a list of external partners?	Plan up to date?	Contains steps that can be included in the CMP?	Notes
Emergency Response Plan	✓	✓	✓	✓	This plan covers water contamination and has a good list of potential response partners, including a contact list.

GCWW Plan	Contains protocols for drinking water contamination response?	Contains a list of external partners?	Plan up to date?	Contains steps that can be included in the CMP?	Notes
Security Standard Operating Procedure (SOP)		✓		✓	This plan contains detailed information on working with local law enforcement that could be included in the CMP, although contact numbers need to be updated.
Cryptosporidium Action Plan	✓		✓		This plan contains specific protocols for responding to water contaminated by *Cryptosporidium*. The process portion will link to CMP and has excellent response information.
Alternate Water Supply Plan	✓	✓		✓	This plan is currently being developed by Hamilton County and City of Cincinnati with agreements with Ohio and Kentucky National Guard. When completed, it should be linked to the CMP.
CWWFlowsheet1_042503.pp			✓		These SOPs vaguely identify water flow rates. Not useful for planning, response or recovery.
MassContamPlan.doc	✓				This plan provides little information and does not address the issues of response and recovery to a mass contamination incident.
REACT.doc (may be called illness1.doc by GCWW)	✓		✓	✓	This plan provides the steps and activities involved in responding to a single contamination point, such as crossed sewer/water lines in a residence. This process is important since it reflects day to day operations and should serve as the basis for larger contamination incident response.
SecIIF4 Distribution Water Contamination	✓				This plan is incomplete and does not address full response, recovery or integration with other response partners.
BacT Route Locations.doc	✓				This plan covers BacT processes and probable locations for its growth.
Depressurization_042503.doc			✓		This plan contains SOPs with instructions concerning how to depressurize a water line.

GCWW Plan	Contains protocols for drinking water contamination response?	Contains a list of external partners?	Plan up to date?	Contains steps that can be included in the CMP?	Notes
Directions for routes.doc			✓		This plan includes general descriptions of the larger routes.
Emergencycontacts .doc	✓	✓		✓	This list provides a starting point of contacts for GCWW and integration. Contacts have not been updated in a long time; some names/numbers no longer apply.
Public Notice.doc	✓		✓	✓	This is critical for the public notification portion of planning but consists only of three flyers: Do Not Use, Do Not Drink and Boil. Meets Ohio and water guidelines. Consider whether to formalize and document the public notification procedures into a plan or SOP.

[1] The documents in this matrix were relevant at the time the matrix was created but may now be outdated.

As indicated in Table 8-2, most of the existing plans and procedures served as independent plans that focused on normal or routine operational conditions at the utility and were not fully applicable to the intent of the Consequence Management Plan. Therefore, the analysis indicated the need for GCWW and stakeholders to develop a comprehensive Consequence Management Plan that addressed the deficiencies identified during review of existing response plans. Specifically, the deficiencies included guidance for contamination threat level determination (e.g., credible, confirmed), a formal risk or crisis communication plan, and a site characterization plan or similar process.

8.1.2 Response Partner Network

The degree of GCWW integration with response partner agencies was evaluated and compared to the goals of a Consequence Management Plan. Integration addressed the level and degree to which GCWW plans, procedures and operations were coordinated with those of the external response partners. Integration was evaluated and addressed through surveys, interviews, and workshops with GCWW and response partner agencies.

Preliminary surveys and interviews with GCWW revealed a lack of participation directly with local emergency planning committees. To some degree, key officials at GCWW had active relationships with response partners, in particular with the Fire and Police departments, through the functional organization of the city government itself. In addition, the GCWW Public Information Officer had established relationships and lines of communication with other public information officers at the city, county and public health levels. However, with the exception of the *Cryptosporidium Action Plan* and REACT procedures, a formal plan or agreement had not been established to define the roles, responsibilities, processes, coordination and lines of communication between the utility and local partners in the event of a contamination incident.

Integration was further evaluated and addressed through a series of four workshops involving external response partner agencies. The workshops provided a forum to identify roles and responsibilities, procedural gaps and to pursue integration of plans and procedures. Response partner agencies from the two largest jurisdictions in the GCWW service area - the City of Cincinnati and Hamilton County - were included in the workshops. A description of the four (4) workshops is included in **Table 8-3**.

During the initial workshops, it was clear that most external agencies did not view the utility as a "first responder", even when presented with a scenario of a water contamination incident. External partners did view the water utility as a critical part of the city's infrastructure, but were unaware of its susceptibility to contamination and the potential consequences of such an incident. Most of the primary response agencies (e.g., local law enforcement and fire/HazMat) considered first response to a water contamination incident as belonging to their jurisdiction, although these agencies did not have water contamination experience or training. Since the utility was not viewed as a first response agency, the integration of plans and procedures had never been considered by local agencies and the interoperability of procedures and equipment had not previously been identified as an important issue.

Table 8-3. Response Partner Workshops

Workshop	Date	Participants	Description
Consequence Management Workshop #1	12/13/05	GCWW Key Officials, Cincinnati Fire and Police Departments	Discussed initial stages of CMP development including decision tree and response partner involvement. Cincinnati Fire Department provided introductory NIMS briefing for GCWW staff.
Consequence Management Workshop #2	01/19/06	GCWW Key Officials, City and County Public Health Agencies, Cincinnati Fire and Police Departments	Collected data from response partners and reviewed draft CMP decision trees for field operation information that would occur with possible, credible, and confirmed determination decision trees.
Consequence Management Workshop #3	02/14/06-02/15/06	GCWW Key Officials, Public Information Officers from various City and County response agencies, City and County Public Health Agencies, Cincinnati Fire and Police Departments	Provided information on risk communication and message mapping for communicating with the public during a possible contamination threat. Developed GCWW message maps.
Consequence Management Workshop #4	03/22/06	GCWW Key Officials and Department Heads, City and County Public Health Agencies, Cincinnati Fire and Police Departments, and Government Representatives from the City, State, and Federal levels.	Collected and reviewed notification and communication data focusing on credible and confirmed stages of an emergency where multiple response agencies will be involved This involved identifying key connections, linkages, and dependencies between the draft CMP and external response partner plans and procedures. Collected the same data for sub-flow decision trees (e.g., site characterization).

8.1.3 Training and Exercises

Pre-implementation assessment of training activities revealed that GCWW did not have a formal training program in place to address a distribution system-wide contamination incident. Rather, their existing training program only focused on specific standard operating procedures used in daily operations. GCWW also did not participate with outside organizations in training, cross training or general preparedness; however, on several occasions, a limited number of utility engineers and managers participated in city-wide emergency response exercises that focused on public health issues rather than utility procedures.

In addition, the utility was aware of the State and Federal preparedness training requirements, but had not yet addressed them. This included federal compliance and training under Homeland Security Presidential Directive 5, the National Incident Management System, and the State of Ohio requirements that utilities meet the National Incident Management System requirements for Incident Command System training including IS 100, IS 200, ICS 300, ICS 400, IS 700 and IS 800.

8.1.4 Equipment

As part of the preliminary assessment, GCWW staff were interviewed to assess existing incident response equipment. Throughout the development of the GCWW Consequence Management Plan, equipment needs were reviewed to ensure that any changing roles and responsibilities that required additional equipment were considered. Aside from equipment used on a daily basis for water system maintenance and field sampling, the utility lacked field response equipment for Consequence Management Plan procedures including site characterization and field screening, sample concentration, and sample analysis.

In addition, GCWW did not have communication equipment (e.g., 800 MHz radios) that was interoperable with the City and County response partner agencies. Without this equipment, key GCWW officials and engineers did not have the capability to be immediately alerted by outside agencies to incidents or potential threats of water contamination. Furthermore, GCWW field response teams did not have an established way to communicate with the Incident Commander and that the Incident Command System did not have a way to communicate with response partners in the field.

8.1.5 Summary of Identified Gaps

Table 8-4 presents the gaps identified during the initial assessment. Section 8.2 describes the post-implementation status for each of the attributes listed below.

Table 8-4. Consequence Management Component Gap Analysis

Attribute	Gap Description
1. Contaminant Incident Response Plans	• Assessment of existing plans, procedures, and policies revealed that GCWW did not have a comprehensive response plan to address system wide contamination. Additional guidance was needed for contamination threat level determination, site characterization and risk communication.
2. Response Partner Network	• There was minimal participation/communication between GCWW and response partners. The integration of response plans and procedures had never been considered by local agencies and the interoperability of procedures and equipment had not previously been identified as an important issue.
3. Training and Exercises	• Assessment of training activities at GCWW revealed that they did not have a formal training program in place to address a system-wide contamination incident. Existing training also did not meet the NIMS/ICS and State of Ohio training requirements.
4. Equipment	• GCWW did not have necessary field response equipment for site characterization and field screening, sample concentration, and sample analysis. • GCWW did not have communication equipment (e.g., 800 MHz radios) that was interoperable with the City and County response partner agencies and other GCWW response groups in the field.

8.2 Post-Implementation Status

The following section provides the post-implementation status concerning development of the GCWW consequence management program. The gaps and issues identified during the pre-implementation assessment were tracked and addressed during the development of the GCWW Consequence Management Plan and corresponding documents. The major products that resulted from the consequence management implementation efforts included the Consequence Management Plan, the Crisis Communication Plan, the Site Characterization Plan, a comprehensive training and exercise program, and the purchase of necessary response equipment.

8.2.1 Contamination Incident Response Plans

Response planning documents developed during implementation of the Cincinnati pilot are described below.

8.2.1.1 Consequence Management Plan

The GCWW contamination warning system pilot Consequence Management Plan was developed to serve as a preparedness and response guide in the event of a water contamination incident. The Consequence

Management Plan is intended to guide GCWW through the process of determining whether a “possible” contamination threat, as indicated by one of the contamination warning system monitoring and surveillance components, is “credible” and can be “confirmed.” The Consequence Management Plan also assists the utility in working with local partners, communicating with the public, and determining appropriate response actions. In the event of actual contamination, the plan provides information on remediation and recovery steps to return the utility to normal operation.

The Consequence Management Plan was developed as a stand-alone document incorporating elements of the GCWW Emergency Response Plan and the U.S. EPA Response Protocol Toolbox to address gaps identified in assessment of existing utility response plans. The Consequence Management Plan also incorporated elements of the National Incident Management System-based Incident Command System protocols to provide incident command and control guidance.

The Consequence Management Plan consists of nine (9) separate decision trees which provide response guidance to track the evolution of a contamination incident from a “possible’ contamination threat, as detected by one of the contamination warning systems monitoring and surveillance components, through system remediation and recovery. The decision trees address response topics which include threat level (“credible” and “confirmed”) determination, site hazard characterization, operational responses, response partner and public notification protocols, and remediation and recovery.

In addition, the Consequence Management Plan contains five (5) appendices of supporting material, including the Site Characterization Plan, various forms for collecting and documenting the contamination incident, and operational procedure sheets for major response activities.

8.2.1.2 Crisis Communication Plan

A Crisis Communication Plan (USEPA, 2007u) was developed to formalize public notification procedures and guide the actions of the GCWW Public Information Officer during all phases of a potential contamination incident. It was designed from best practices in risk communication and public notification to provide communication control internally during an incident and to coordinate external public notification. The Crisis Communication Plan is designed to complement the overall Consequence Management Plan and corresponding response procedures outlined in Decision Tree 400.0: Public Notification.

The Crisis Communication Plan covers communication both within GCWW and with external response partner agencies, the press, and the public. The plan includes an overview of basic crisis communication principles, detailed Consequence Management Plan decision trees adapted for use by the Public Information Officer, and a tools and resources section that includes sample public notification templates, media resources, and contact information.

8.2.1.3 Site Characterization Plan

The Site Characterization Plan (USEPA, 2006f) was developed as part of the Consequence Management Plan to provide guidance to GCWW field personnel for the preliminary investigation phase of a contamination incident. The objective of the Site Characterization Plan is to describe the steps needed to collect sufficient information from an investigation site(s) to help characterize an incident site(s) once a threat, accidental or intentional, has been suspected. It is based on principles contained in Module 3 of the U.S. EPA Response Protocol Toolbox: Site Characterization and Sampling Guide (USEPA, 2003).

The Site Characterization Plan is outlined in Decision Tree 30.0 and Appendix B of the Consequence Management Plan and describes the roles and responsibilities of GCWW management and field response personnel, and local response support (law enforcement, HazMat, health and emergency management), for site characterization activities. This includes site evaluation, field safety screening, sample collection, and rapid field testing. In addition, the Site Characterization Plan consists of seventeen (17) SOPs for approaching and characterizing an investigation site. The standard operating procedures cover site safety screening, rapid field tests of drinking water, drinking water sampling techniques for laboratory analysis and operation of the field equipment used for conducting the field investigation. Also included in the Site Characterization Plan are forms for reporting investigation observations and data, sample documentation, chain-of-custody, and a template for preparing incident-specific Site Characterization Plans.

8.2.2 Response Partner Network

Through face-to-face workshops (as described in Table 8-3 of Section 8.1.2), GCWW and response partner agencies were better able to understand, confirm, and integrate their roles and responsibilities in the event of a drinking water contamination incident. This allowed GCWW to document these roles, responsibilities, and communication requirements into the Consequence Management Plan and, in turn, allowed outside agencies to recognize the "first response" capabilities and duties of the utility.

Through each of the four (4) workshops, gaps were identified and information was gathered for use in development of Consequence Management Plan and corresponding procedures. The workshop process required each participant to describe their perception of the roles and responsibilities in a given incident. Responses from participants were compared and gaps in responsibilities were identified and addressed. Existing response plans, contact lists, and draft plans were revised according to the findings subsequent to the workshops.

A summary of the response partner network that evolved from the workshops is shown in **Table 8-5**.

Table 8-5. Summary of Pilot Response Partner Network and CMP Role

Response Partner Organization	CMP Role
Method Laboratories	Analyzes triggered samples and interacts directly with the GCWW Incident Commander for field results, event status and reporting
Cincinnati Fire Department (CFD)	Supports GCWW consequence management activities by providing field response and HazMat support
Local public health agencies (LPH) in GCWW service area	Provides local public health data; epidemiologists and disease investigators
Hamilton County Emergency Management Agency	Supports CMP by coordinating alternate water supplies and implementing Unified Command System for expanded contamination incidents
Ohio Department of Health	Provides regulatory and sampling support, investigations and threat assessments of potential or confirmed contamination events
Local, State and Federal law enforcement	Provides support by coordinating investigation and isolation issues with GCWW Incident Commander and GCWW Security
State Drinking Water Primacy Agency (Ohio EPA)	Provides support for risk communication and remediation/ recovery issues

In addition to the workshops for response partner agencies in the City of Cincinnati and Hamilton County, roll-out presentations on the Water Security initiative were provided to other jurisdictions served by GCWW to ensure that all local partners have working knowledge of the program, benefits of the program to their community, and their roles and responsibilities under the program. The roll out strategy was designed to achieve an efficient and comprehensive approach for reaching all jurisdictions through each of the disciplines (e.g., all county, city, and community public health agencies). This goal was accomplished as representatives from each agency (within one, or both, of the two primary jurisdictions) acted as primary facilitators and used the roll-out presentations to provide training within their respective agencies.

Overall, the workshop and roll-out process resulted in expanded preparedness and response capability amongst local partners and stakeholders and, as a result, a stronger local network was established. The process was also important to the development and strengthening of the utility Consequence Management

Plan and response process. Ultimately, planning, communication and coordination procedures developed with input from local response partners were tested and refined through a series of training and exercise activities.

8.2.3 Training and Exercises

Training and exercises were conducted to test the Consequence Management Plan and to train participants on processes and procedures. Training consisted of workshops, table-top exercises, functional exercises, drills, and full scale exercises. Training was also important in identifying opportunities for improving the plans, evaluating participants' ability to implement the guidance of the Consequence Management Plan, and increasing response time and accuracy. After completion of the exercise, "After Action Reports" were developed that captured comments from participants and evaluators about suggested modifications to the Consequence Management Plan and contained a critique regarding areas for improvement to future exercises.

Table 8-6 presents the training that was delivered to address gaps and enhance preparedness and response capabilities by the utility and response partners.

Table 8-6. Consequence Management Training and Exercises

Training Title	Date Received	Participants	Description
DHS FEMA/NIMS IS100 & IS700	5/16/06 - 05/18/06	GCWW	Provided participants with a basic understanding of ICS procedures and an introduction to NIMS. The material was formatted for delivery to GCWW for use in future instruction.
CMP Orientation Training Implementation	08/22/06 - 08/24/06	GCWW	Senior level staff training ensured participant understanding of their roles in the CMP. The material was formatted for delivery to GCWW for use in future instruction and updates.
Roll Out Documentation and Presentation	06/27/06 and 09/28/06	Potential partners outside the GCWW response area	Discussed the consequence management preparedness and response process with external agencies and organizations that might not otherwise be readily engaged in the GCWW response network.
Table-Top Exercise: Supervisor Training- (4 separate sessions)	08/29/06 - 08/31/06	GCWW	Provided GCWW supervisors with scenarios to improve their knowledge of the CMP and incident management processes.
Site Characterization Training (4 separate sessions)	05/11/07	GCWW	Familiarized staff with field operations associated with site investigations and corresponding equipment.
Contamination Warning System Management Training	06/15/07	GCWW	Provided an overview of the contamination warning system and CMP including contamination scenario exercises.
Consequence Management Functional Table-Top Exercise	07/31/07	GCWW and Response Partners	Provided GCWW and response partners the opportunity to practice their roles and responsibilities during a response to a possible drinking water contamination incident, identify potential revisions and corrections to the CMP, and practice plans and procedures of various agencies. This was practice for the Full Scale Field Exercise.
Site Characterization Drills	09/05/07 - 09/06/07	GCWW	Provided GCWW field repose personnel the opportunity to practice implementation of Site Characterization procedures and equipment.
Consequence Management Full Scale Field Exercise	09/25/07 - 09/28/07	GCWW and Response Partners	Provided GCWW and response partners the opportunity to exercise their roles within a field environment, test plans and procedures and identify opportunities for improvement and potential revisions to the CMP. Participants also practiced communication and coordination techniques.

8.2.4 Equipment

During the pre-implementation assessment, it was also noted that field response teams did not have an established way to communicate with the Incident Commander and that the Incident Command System did not have a way to communicate with response partners in the field. This greatly hindered the organization's ability to respond to an incident and to communicate and coordinate appropriately. To address this deficiency, eight (8) 800 MHz hand-held radios (Motorola XTS 5000) were acquired.

The 800 MHz radios are long-range multi-channel programmable units that are interoperable with response agencies in the City of Cincinnati and Hamilton County. They can also be programmed to operate on other agency frequencies in the event of a Unified Command System incident response. The radios are located and deployed with, as well as maintained by, the GCWW Site Characterization Team Leader.

8.2.5 Summary of Post-Implementation Status

EPA, with the assistance of GCWW, completed a comprehensive assessment of the existing response plans, procedures, and equipment in place at GCWW. During this assessment, the existing practices and systems were evaluated according to their applicability and contribution to the development of a Consequence Management Plan. Following the completion of the assessment, gaps were identified where EPA and GCWW felt changes or additions to the practices and systems in place at the utility to handle a contamination threat to the distribution system could be improved (Table 8-4). EPA and GCWW worked collaboratively to develop and implement solutions which would address the identified gaps. **Table 8-7** presents a summary of the post-implementation status of utility's capability with respect to consequence management activities.

Table 8-7. Consequence Management Component Post-Implementation Status

Attribute	Description of Consequence Management Program Component
1. Contaminant Incident Response Plans	• Response planning documents developed during implementation of the Cincinnati pilot were the Consequence Management Plan and the Crisis Communication Plan. • The Consequence Management Plan was developed to serve as a preparedness and response guide in the event of a water contamination incident. • The Crisis Communication Plan was developed to formalize public notification procedures and guide the actions of the GCWW Public Information Officer during all phases of a potential contamination incident.
2. Response Partner Network	• GCWW and response partners established a network to better understand, confirm, and integrate their roles and responsibilities in the event of a drinking water contamination incident. • Specific GCWW and response partner roles, responsibilities, and communication requirements were documented in the CMP.
3. Training and Exercises	• Training and exercises were conducted to test the CMP and to train participants on processes and procedures. • Training consisted of workshops, table-top exercises, functional exercises, drills, and full scale exercises.
4. Equipment	• GCWW acquired eight (8) 800 MHz hand-held radios (Motorola XTS 5000) to address the organization's ability to respond to an incident and to communicate and coordinate appropriately with response partners in the field.

Figure 8-1 provides a summary of the level of effort associated with design and implementation of the consequence management component for the Cincinnati pilot. Consequence management activities, as summarized in Table 8-7, relied on support from EPA, GCWW, and local partners. The LOE for local partners in all aspects of consequence management represents the combined efforts of more than a dozen organizations from the local and state levels. The most significant effort was expended to develop the GCWW Consequence Management Plan which outlines response plans for each component of the contamination warning system. Considerable effort was also associated with training and exercises to test the Consequence Management Plan, involving utility staff and all relevant local partners.

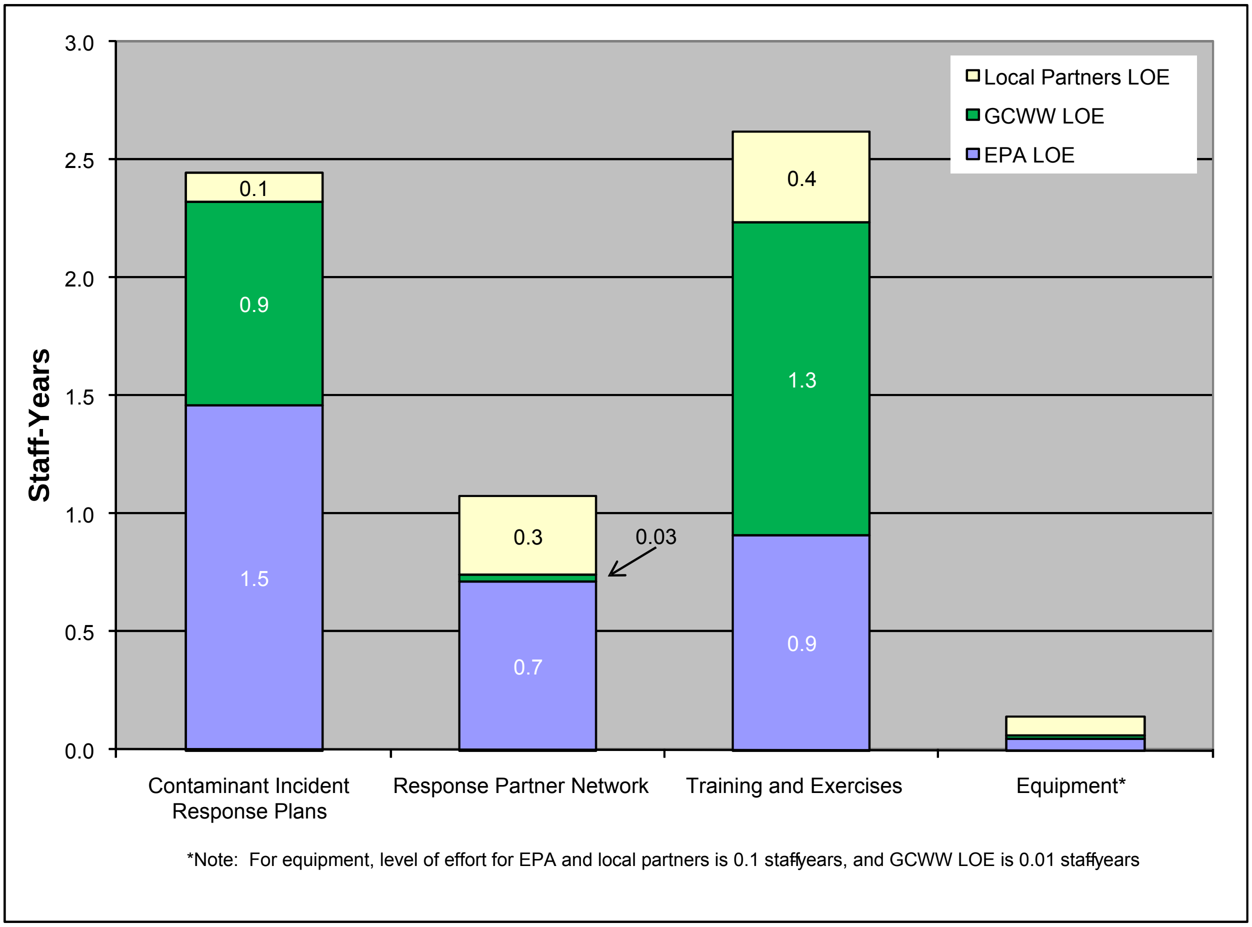
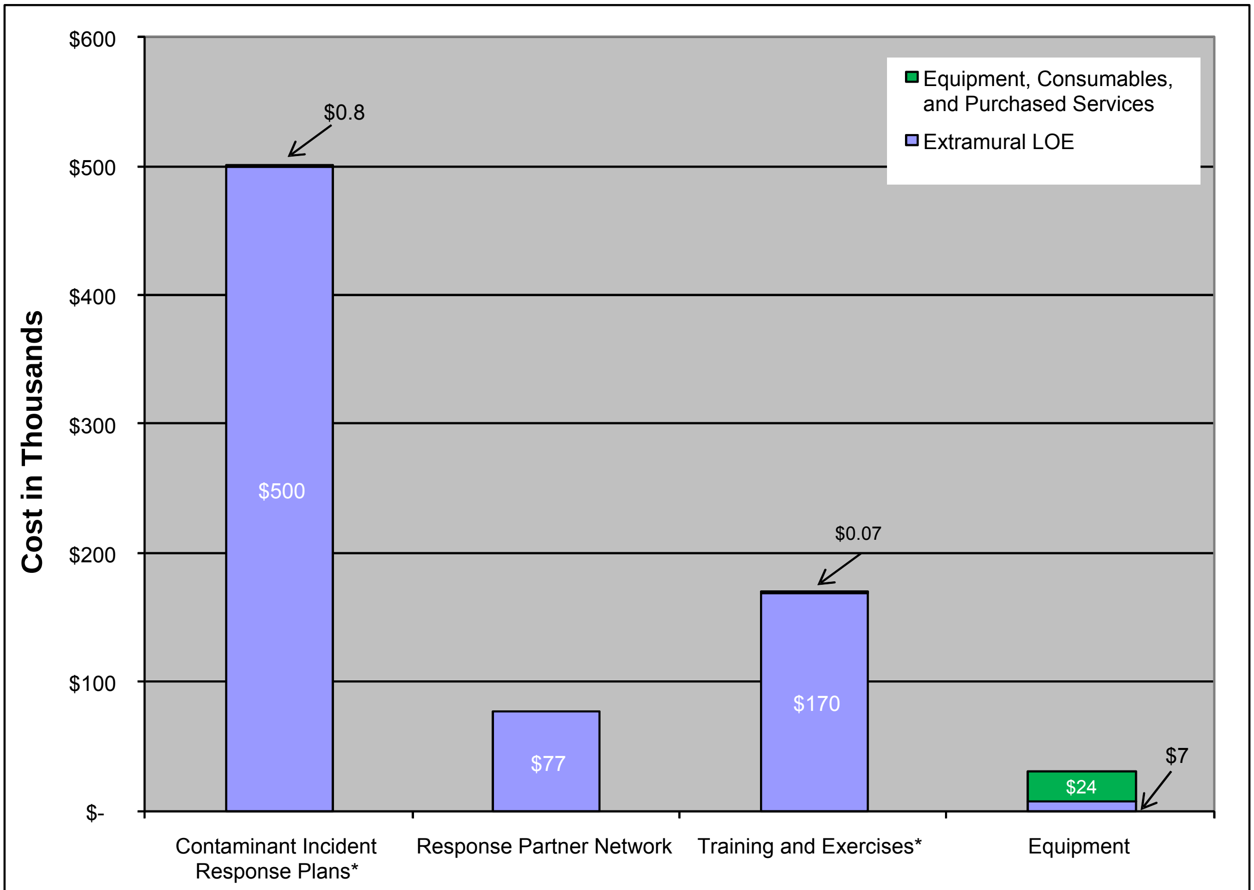


Figure 8-1. Level of Effort for Design and Implementation of the Consequence Management Component (December 2005 – December 2007)

Figure 8-2 presents a summary of the extramural costs associated with design and implementation of the consequence management component for the Cincinnati pilot. As illustrated, extramural labor costs were significant for development of the Consequence Management Plan and coordination efforts associated with drills and exercises to test the Consequence Management Plan. Equipment costs included purchase of hand-held radios for communication and coordination during emergency response. Costs associated with contractor travel were not included in this calculation.



*Note: The equipment, consumables, and purchased service cost was $800 for Contaminant Incident Response Plans and $70 for Training and Exercises

Figure 8-2. Extramural Costs Associated with Design and Implementation of the Consequence Management Component (December 2005 – December 2007)

Section 9.0: Path Forward

Implementation of the first contamination warning system pilot deployed under EPA's Water Security Initiative in Cincinnati, Ohio was completed at the end of 2007. This deployment resulted in an operational system consisting of multiple monitoring and surveillance strategies, including online water quality monitoring, sampling and analysis, enhanced security monitoring, consumer complaint surveillance, and public health surveillance.

The strength of this design lies in the integration of information from these multiple monitoring and surveillance strategies through a comprehensive concept of operations and consequence management plan. During the first phase of the Water Security initiative, simulations of the conceptual design indicated that this approach is capable of achieving timely and reliable detection of a broad array of contamination incidents. The Cincinnati pilot provides an opportunity to test and validate the conceptual design developed during that initial phase of the program.

With the completion of design and installation activities, the Cincinnati pilot entered a period of preliminary testing. During this phase, data is being collected from all system components to assess and optimize performance. This data collection is one aspect of a robust evaluation process, which will continue through the duration of the pilot. The results will be used to assess the overall performance and sustainability of the system, as well as potential revisions or alternate approaches to contamination warning system design. Preliminary findings from the Cincinnati pilot have already been incorporated into three interim guidance documents:

- *Water Security Initiative: Interim Guidance on Planning for Contamination Warning System Deployment* (EPA-817-R-07-002; 2007). Experience from implementation of the Cincinnati pilot formed the basis for guidance on developing a comprehensive plan for a drinking water contamination warning system, considering both the individual components and integrated system. Common concepts emphasized in the document include an integrated project management team; engaging IT staff early in the planning process; and component-specific considerations that influence design and implementation activities.

- *Water Security Initiative: Interim Guidance on Developing and Operational Strategy for Contamination Warning Systems* (EPA-817-R-08-002; 2008). The operational strategy developed for the Cincinnati pilot provided a model for guidance on developing an integrated operational strategy and component-specific standard operating procedures to guide routine operation of the contamination warning system and the initial investigation of triggers generated from monitoring and surveillance components. A case study based on a generalized example for the Cincinnati pilot is included as an appendix.

- *Water Security Initiative: Interim Guidance on Developing a Consequence Management Plan for Contamination Warning Systems* (EPA-817-R-08-001; 2008). The consequence management plan developed for the Cincinnati pilot provided a model for guidance on developing a consequence management plan for a contamination warning system. It includes concepts related to site characterization, determination of credible and confirmed contamination, local response partner roles and responsibilities, crisis communications, and public notification. The approach recommended in the guidance is based on lessons learned from the Cincinnati pilot and relies on a series of decision trees to guide response actions.

These guidance documents will play a key role in the deployment of up to four additional drinking water contamination warning system pilots scheduled to begin in mid and late 2008. Collectively, the data from all pilots implemented under the Water Security initiative will allow for a thorough evaluation of contamination warning system performance and sustainability under a variety of conditions. Not only do the pilot utilities represent a range of distribution system designs and water quality baselines, but also a variety of organizational structures, both within the utility and across partner organizations that play a key role in system operation. Such a robust set of pilots will provide a basis for the development of products and guidance that have broad applicability across the drinking water treatment and supply industry.

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