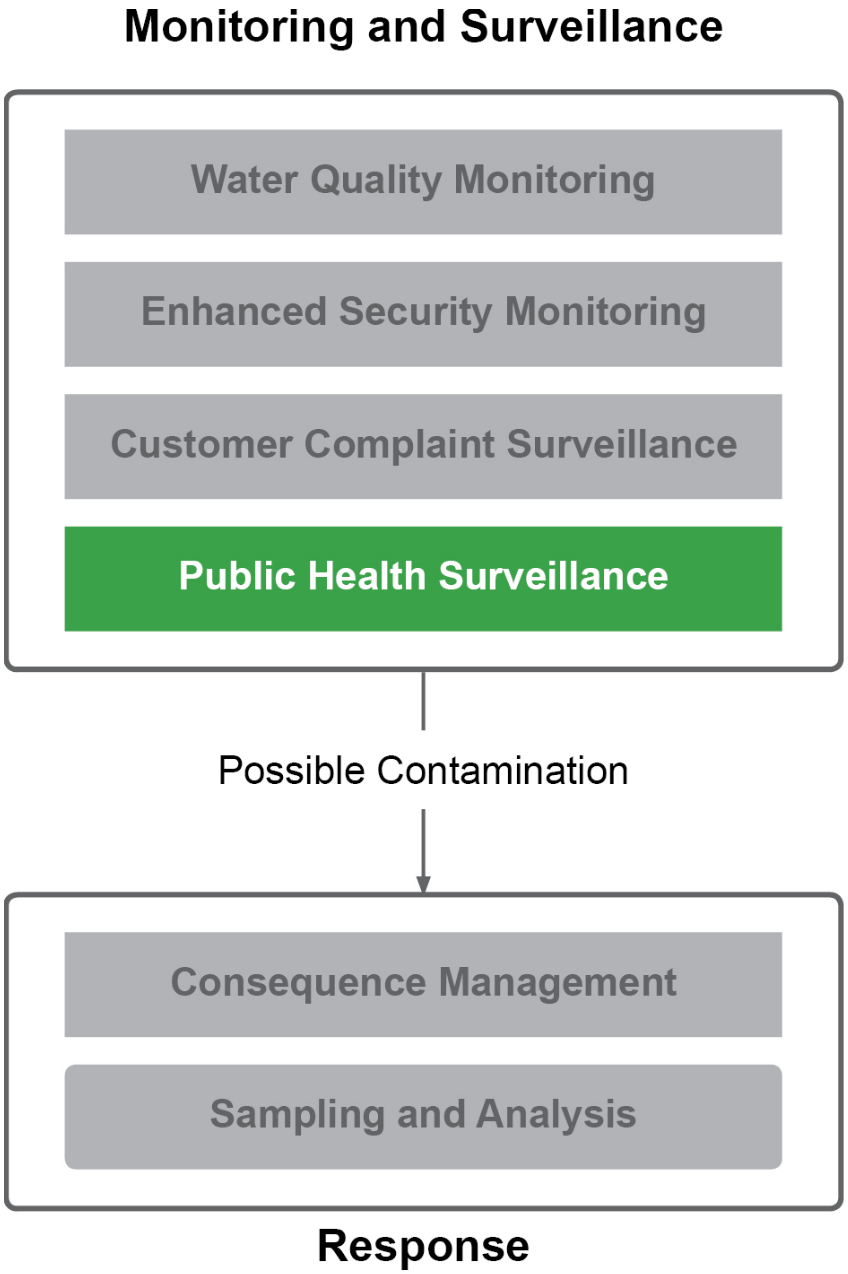
United States
Environmental Protection
Agency

Water Security Initiative: Evaluation of the Public Health Surveillance Component of the Cincinnati Contamination Warning System Pilot



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Executive Summary

The goal of the Water Security Initiative (WSI) is to design and demonstrate an effective multi-component warning system for timely detection and response to drinking water contamination threats and incidents. A contamination warning system (CWS) integrates information from multiple monitoring and surveillance components to alert the water utility to possible contamination, and uses a consequence management plan (CMP) to guide response actions.

System design objectives for an effective CWS are: spatial coverage, contaminant coverage, alert occurrence, timeliness of detection and response, operational reliability and sustainability. Metrics for the public health surveillance (PHS) component were defined relative to the system metrics common to all components in the CWS, but the component metric definitions provide an additional level of detail relevant to the PHS component. Evaluation techniques used to quantitatively or qualitatively evaluate each of the metrics include analysis of empirical data from routine operations, drills and exercises, modeling and simulations, forums and an analysis of lifecycle costs. This report describes the evaluation of data collected from the PHS component from the period of January 2008 – June 2010.

The major outputs from the evaluation of the Cincinnati pilot include:

1. *Cincinnati Pilot System Status*, which describes the post-implementation status of the Cincinnati pilot following the installation of all monitoring and surveillance components.
2. *Component Evaluations*, which include analysis of performance metrics for each component of the Cincinnati pilot.
3. *System Evaluation*, which integrates the results of the component evaluations, the simulation study, and the benefit-cost analysis.

The reports that present the results from the evaluation of the system and each of its six components are available in an Adobe portfolio, *Water Security Initiative: Comprehensive Evaluation of the Cincinnati Contamination Warning System Pilot* (USEPA 2014).

Public Health Surveillance Component Design

The PHS component consists of the following design elements: public health surveillance tools, communication and coordination and component response procedures. As part of the initial pilot of the WSI, the PHS component was developed for the Greater Cincinnati Water Works (GCWW) based on many of the city's existing public health monitoring systems. Four data streams were utilized for the PHS component: 911 surveillance tool, Emergency Medical Services (EMS) surveillance tool, EpiCenter surveillance tool, and the Cincinnati Drug and Poison Information Center (DPIC) surveillance tool. As part of the PHS component, several new systems were implemented to inform GCWW of a potential contamination incident related to anomalous data provided by the surveillance tools. Once anomalies are identified, automated email alerts are sent to public health partners and GCWW personnel, who conduct an investigation according to the Cincinnati Pilot Operational Strategy. For more information on this topic, see Section 2.0. A summary of the results used to evaluate whether the PHS component met each of the design objectives is provided below.

Methodology

Several methods were used to evaluate PHS performance. Data was tracked over time to illustrate the change in performance as the component evolved during the evaluation period. Statistical methods were also used to summarize large volumes of data collected over either the entire or various segments of the evaluation period. Data was also evaluated and summarized for each reporting period over the evaluation period. In this evaluation, the term reporting period is used to refer to one month of data that spans from the 16th of the indicated month to the 15th of the following month. Thus, the January 2008 reporting period refers to the data collected between January 16th 2008 and February 15th 2008. Additionally, three drills and two full-scale exercises designed around mock contamination incidents were used to practice and evaluate the full range of procedures, from initial detection through response.

Because there were no contamination incidents during the evaluation period, there is no empirical data to fully evaluate the detection capabilities of the component. To fill this gap, a computer model of the Cincinnati CWS was developed and challenged with a large ensemble of simulated contamination incidents in a simulation study. An ensemble of 2,015 contamination scenarios representing a broad range of contaminants and injection locations throughout the distribution system was used to evaluate the effectiveness of the CWS in minimizing public health and utility infrastructure consequences. The simulations were also used for a benefit-cost analysis, which compares the monetized value of costs and benefits and calculates the net present value of the CWS. Costs include implementation costs and routine operation and maintenance labor and expenses, which were assumed over a 20 year lifecycle of the CWS. Benefits included reduction in consequences (illness, fatalities and infrastructure damage) and dual-use benefits from routine operations.

Design Objective: Spatial Coverage

Spatial coverage is the cumulative area of the distribution system where a detectable increase in symptomatic individuals could be reported via any of the PHS tools. Spatial coverage is measured by the metrics of area and population coverage, and the spatial extent of alerts. Collectively, the surveillance tools used by the PHS component cover GCWW's entire service area (100% area coverage). **Figure ES-1** depicts the overlapping coverage of the various surveillance tools. The 911 and EMS surveillance tools monitor 911 calls and EMS runs that occur within the city of Cincinnati. The cross-hatch shows the GCWW retail service area, which is also the geographic area covered by DPIC surveillance. The black border depicts the boundary of Hamilton County, which is the area covered by the EpiCenter surveillance tool. For more information on this topic, see the relevant subsections regarding spatial coverage for each PHS surveillance tool in Sections 4.0 through 7.0 and Section 8.2 for the integrated component.

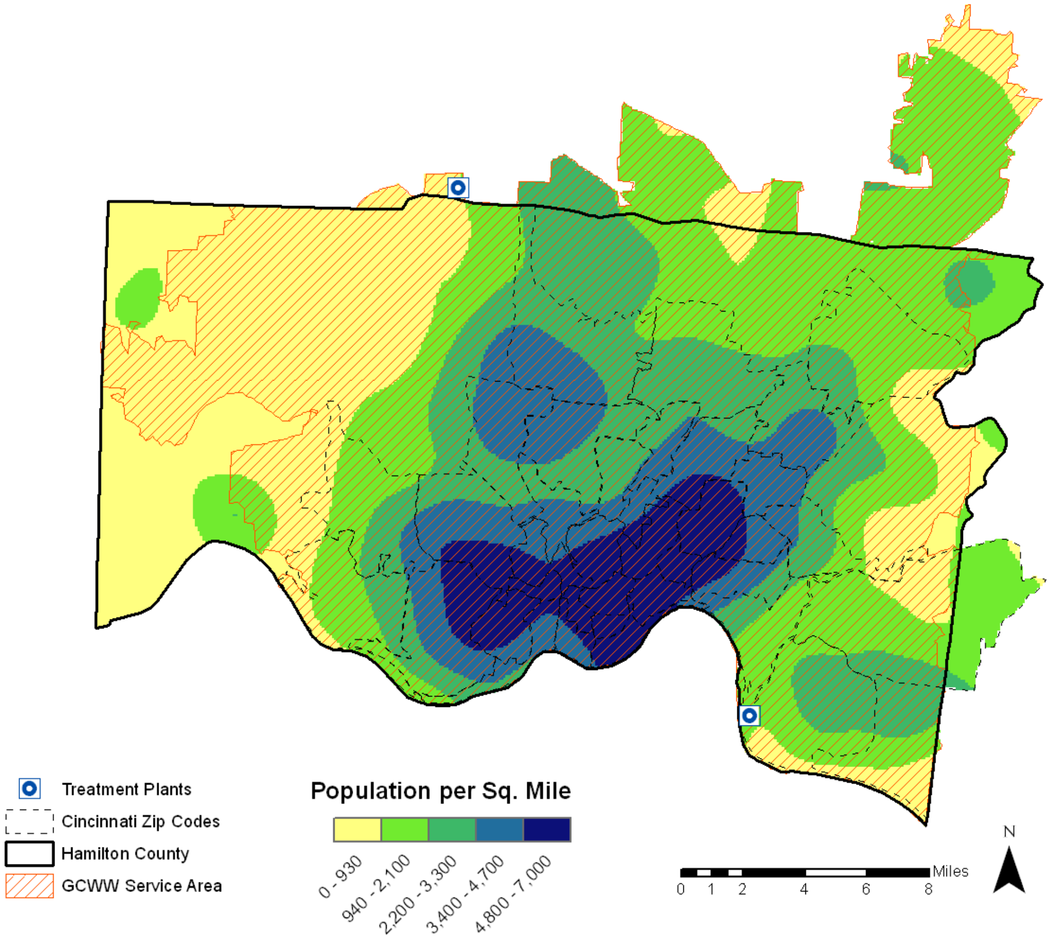

Figure ES-1. Spatial Coverage of the 911, EMS, and DPIC Surveillance Tools

Design Objective: Contaminant Coverage

Contaminant coverage is the ability to detect a wide range of water contaminants and is measured by contamination scenario coverage. Since there were no contamination incidents during the evaluation, results from the simulation study were used to assess this design objective. **Table ES-1** demonstrates the contaminants that are theoretically detectable by the PHS component based on available data in published literature regarding health-seeking behavior in response to symptoms of illness. The table presents the ratio of the critical concentration, which is the concentration that would produce adverse health effects, to the detection threshold for each contaminant. The table also shows the percent of simulated contamination incidents detected by the PHS component, as determined through analysis of simulation results. For more information on this topic, see the relevant subsections regarding contaminant coverage for each PHS surveillance tool in Sections 4.0 through 7.0 and Section 8.3 for the integrated component.

Table ES-1. Assumed Characteristics of Contaminants Detectable by the PHS Component

Type[1]	Critical Concentration/ Detection Threshold	% of Simulated Contamination Incidents Detected
Toxic Chemical 1	458	100%
Toxic Chemical 2	3,640	100%

Type[1]	Critical Concentration/ Detection Threshold	% of Simulated Contamination Incidents Detected
Toxic Chemical 3	1,640	100%
Toxic Chemical 4	290	100%
Toxic Chemical 5	668	100%
Toxic Chemical 6	850	100%
Toxic Chemical 7	950	100%
Toxic Chemical 8	300	100%
Biological Agent 1	4,500	100%
Biological Agent 2	3,940	100%
Biological Agent 3	2.40×10^4	100%
Biological Agent 4	4.54	100%
Biological Agent 5	10.0	100%
Biological Agent 6	1.74	96.6%
Biological Agent 7	1.64	96.7%

[1] Note that the contaminants being modeled in the simulation study were assigned generic IDs for security purposes.

Design Objective: Alert Occurrence

Alert occurrence tracks the frequency of alerts to determine how well the surveillance tools can discriminate between public health incidents, including water contamination and normal variability in the underlying data. Metrics for this design objective include invalid and valid alerts, which were characterized using empirical data. Invalid alerts occurred frequently at the beginning of the evaluation period due to intentionally low threshold levels which provided opportunities to train public health personnel on alert investigation procedures. Following threshold adjustments for the 911 and EMS surveillance tools, invalid alerts were reduced by approximately 90%. A total of 49 valid alerts (5 EMS and 44 Epicenter) were observed over the evaluation period which is a total of 10% relative to the total number of alerts across all of the surveillance tools. The PHS system produced valid alerts during various public health incidents including an influenza outbreak in the city. For more information on this topic, see the relevant subsections regarding alert occurrence for each PHS surveillance tool in Sections 4.0 through 7.0 and Section 8.4 for the integrated component.

Design Objective: Timeliness of Detection

For PHS, timeliness of detection refers to the timeline between when PHS data is transmitted and the time that investigation into anomalous data is completed. Factors that impact this objective include: time for data transmission, time for event detection, time to recognize alerts and time to investigate alerts. These metrics were characterized using empirical data. Data from PHS drills was used to evaluate the time to investigate valid alerts. Across the surveillance tools, most data was transmitted and uploaded in one hour or less with EMS as the exception (average of 13.2 hours), event detection typically required less than one hour, and the median time for alert recognition was between 10 and 13 hours. For invalid alerts, most investigations were completed in 20 minutes or less. Based on PHS drill data, the alert investigation time ranged from 1.5 to 2 hours for simulated valid alerts. **Figure ES-2** demonstrates the investigation timeline during PHS Drill 2 which involved both DPIC and 911 alerts.

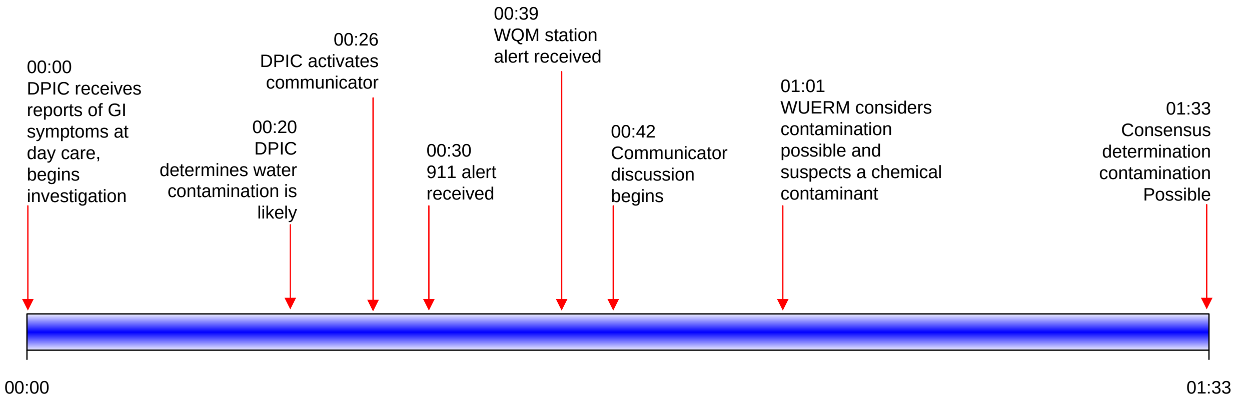

Figure ES-2. PHS Drill 2 Investigation Timeline (DPIC and 911 Alerts)

Simulation study results analysis showed an overall average time of detection for the PHS component of approximately one day across all of the contamination scenarios that were detected. For most surveillance tools, the detection timeline was generally more rapid for the toxic chemicals (within hours) in comparison to the biological agents (within days to weeks), predominantly due to the longer symptom onset time following exposure for the biological agents. For more information, see the relevant subsections regarding timeliness of detection for each PHS surveillance tool in Sections 4.0 through 7.0 and Section 8.5 for the integrated component.

Design Objective: Operational Reliability

Operational reliability metrics quantify the percent of time that the PHS tool is working as designed. Availability of the PHS component was utilized to measure operational reliability through analysis of empirical data. The PHS component exhibited excellent operational reliability during the evaluation period, and at least a portion of the component was available 100% of the time. The majority of PHS downtime was due to network instability concurrent with Water Security Data Repository database unavailability. For more information on this topic, see the relevant subsections regarding operational reliability for each PHS surveillance tool in Sections 4.0 through 7.0 and Section 8.6 for the integrated component.

Design Objective: Sustainability

Sustainability is a key objective in the design of a CWS and each of its components, which for the purpose of this evaluation is defined in terms of the cost-benefit trade-off. Empirical data as well as feedback documented during component forums were used to evaluate costs, benefits, and compliance for the PHS component. Costs were estimated over the lifecycle of the system to provide an estimate of the total cost of ownership. **Table ES-2** demonstrates the value of the major cost elements used to calculate the total lifecycle cost of the PHS component. These costs were tracked as empirical data during the design and implementation phase of project design, and were analyzed through a benefit-cost analysis. It is important to note that the Cincinnati CWS was a pilot research project, and as such incurred higher costs than would be expected for a typical large utility installation.

Table ES-2. Cost Elements used in the Calculation of Lifecycle Cost

Parameter	Value
Implementation Costs	$1,305,966
Annual O&M Costs	$17,871
Renewal and Replacement Costs[1]	$241,531
Salvage Value[1]	-

[1] Calculated using major pieces of equipment.

To calculate the total lifecycle cost of the PHS component, all costs and monetized benefits were adjusted to 2007 dollars using the change in the Consumer Price Index (CPI) between 2007 and the year that the cost or benefit was realized. Subsequently, the implementation costs, renewal and replacement costs, and annual operation and maintenance costs were combined to determine the total lifecycle cost:

PHS Total Lifecycle Cost: **$1,788,073**

A similar PHS component implementation at another utility should be less expensive when compared to the Cincinnati pilot as it could benefit from lessons learned and would not incur research-related costs.

The benefits that have been afforded from implementation of the PHS component include:

- Relationships formed and knowledge base discovered which can be employed in other areas of participant agencies,
- Improved knowledge of partner agencies' abilities and organizational structure,
- Use of 911 and EMS data for other applications, and
- Improved coordination between the public health partners and the utility during emergency response.

Compliance was demonstrated through 100% participation in drills and exercises which required substantially more effort than routine investigations, but was beneficial to the public health partners and GCWW as demonstrated by more efficient and effective communication during response to Possible water contamination. Furthermore, compliance was evidenced by a high rate of alert investigations completed by the public health partners during the evaluation period (≥75% during most months). For more information on this topic, see Section 8.7.

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Section 1.0: Introduction

The purpose of this document is to describe the evaluation of the public health surveillance (PHS) component of the Cincinnati pilot, the first such pilot deployed under the U.S. Environmental Protection Agency's (EPA) Water Security Initiative (WSI). The evaluation covers the period from January 2008 to June 2010 when the PHS component was fully operational. This evaluation was implemented by examining the performance of the PHS component relative to the design objectives established for the contamination warning system (CWS).

1.1 CWS Design Objectives

The Cincinnati CWS was designed to meet six overarching objectives, which are described in detail in *WaterSentinel System Architecture* (USEPA, 2005) and are presented briefly below:

- **Spatial Coverage**. The objective for spatial coverage is to monitor the entire population served by the drinking water utility. Spatial coverage can be considered geographically. PHS spatial coverage varies geographically based on population density, population demographics (industrial vs. residential), and/or types of surveillance tools used within a public health jurisdiction. Metrics applicable to spatial coverage include: area and population coverage, and spatial extent of an alert.
- **Contaminant Coverage**. The objective for contaminant coverage is to provide detection capabilities for all priority contaminants. This design objective is further defined by binning the priority contaminants into 12 classes according to the means by which they might be detected (USEPA, 2005). Use of these detection classes to inform design provides more comprehensive coverage of contaminants of concern than would be achieved by designing the system around a handful of specific contaminants. Contaminant coverage depends on the specific data streams analyzed by each monitoring and surveillance component, as well as the specific attributes of each component. The metric explored in this design objective is contamination scenario coverage.
- **Alert Occurrence**. The objective of this aspect of system design is to minimize the rate of invalid alerts (alerts unrelated to contamination or other anomalous conditions) while maintaining the ability of the system to detect real incidents. Metrics associated with alert occurrence include: invalid alerts and valid alerts.
- **Timeliness of Detection**. The objective of this aspect of system design is to provide initial detection of a contamination incident in a timeframe that allows for the implementation of response actions that result in significant consequences reduction. For monitoring and surveillance components, such as PHS, this design objective addresses only detection of an anomaly and investigation of the subsequent alert. Timeliness of response is addressed under consequence management and sampling and analysis (S&A). Metrics associated with timeliness of detection include: time for data transmission, time for event detection, time for alert recognition and time to investigate alerts.
- **Operational Reliability**. The objective for operational reliability is to achieve a sufficiently high degree of system availability, data completeness and data accuracy such that the probability of missing a contamination incident becomes exceedingly low. Operational reliability depends on the redundancies built into the CWS and each of its components. The metric used to evaluate operational reliability was availability.

- **Sustainability**. The objective of this aspect of system design is to develop a CWS that provides benefits to the utility and partner organizations while minimizing the costs. This can be achieved through leveraging of existing systems and resources that can readily be integrated into the design of the CWS. Furthermore, a design that results in dual-use applications that benefit the utility in day-to-day operations, while also providing the capability to detect intentional or accidental contamination incidents, will also improve sustainability. For PHS, this design objective is discussed only within the section which covers the integrated component (Section 8), and includes costs, benefits and compliance**.**

The design objectives provide a basis for evaluation of each component, in this case PHS, as well as the entire integrated system. Because the deployment of a drinking water CWS is a new concept, design standards or benchmarks are unavailable. Thus, it is necessary to evaluate the performance of the pilot CWS in Cincinnati against the design objectives relative to the baseline state of the utility prior to CWS deployment.

1.2 Role of Public Health Surveillance in the Cincinnati CWS

Under the WSI, a multi-component design was developed to meet the above design objectives. Specifically, the WSI CWS architecture utilizes four monitoring and surveillance components common to the drinking water industry and public health sector: water quality monitoring (WQM), enhanced security monitoring (ESM), customer complaint surveillance (CCS) and PHS. Information from these four components is integrated under a consequence management plan (CMP), which is supported by S&A activities, to establish the credibility of possible contamination incidents and to inform response actions intended to mitigate consequences.

The PHS component of the Cincinnati CWS includes the surveillance tools that monitor the following data streams: 911 calls, Emergency Medical Service (EMS) runs, Emergency Department (ED) patient data from local hospitals (i.e., EpiCenter), and Poison Control Center (PCC) call data from the Cincinnati Drug and Poison Information Center (DPIC). These surveillance tools were collectively monitored to identify possible contamination incidents. Surveillance was performed on the data using appropriate statistical algorithms as well as human surveillance, whereby public health personnel identify data anomalies using professional judgment (i.e., the astute clinician). System users observe alert data to identify clustering of cases, or common symptoms among cases.

When PHS generates an alert, appropriate personnel at the Greater Cincinnati Water Works (GCWW) are notified according to standard operating procedures as outlined in the Cincinnati Pilot Operational Strategy. The general process for alert investigations in the Cincinnati CWS is outlined in the document, *Water Security Initiative: Interim Guidance on Developing an Operational Strategy for Contamination Warning Systems* (USEPA, 2008a).

1.3 Objectives

The overall objective of the PHS component evaluation is to demonstrate how well the component functioned as part of the CWS deployed in Cincinnati (i.e., how effectively the component achieved the design objectives). This evaluation will describe how the surveillance tools (which are analyzed independently and collectively) could reliably detect a possible contamination incident based on the standard operating procedures established for the Cincinnati CWS. It will also characterize factors that impact the sustainability of PHS in a CWS. Although no known contamination incidents occurred during the evaluation period, the PHS component yielded sufficient data for the evaluation through information collected during routine operation, drills and exercises, and from computer modeling conducted as part of a simulation study. In summary, this document will discuss the approach for analysis and integration of this information to assess the overall operation, performance, and sustainability of the PHS component as part of the Cincinnati CWS.

1.4 Document Organization

This document contains the following sections:

- **Section 2: Overview of the PHS Component**. This section introduces the PHS component of the Cincinnati CWS and describes each of the major design elements that make up the component. A summary of significant modifications to the component that had a demonstrable impact on performance is presented at the end of this section.
- **Section 3: Methodology**. This section describes the data sources and techniques used to evaluate the PHS component.
- **Sections 4 through 7: Evaluation of PHS Surveillance Tools**. Each of these sections addresses one of the PHS surveillance tools listed in Section 2.1. The design objectives described in Section 1.1 are covered for each surveillance tool, and the supporting evaluation metrics are discussed in a dedicated subsection under each design objective. For each metric, an overview of the analysis methodology is provided followed by presentation and discussion of the results.
- **Section 8: Performance of the Integrated PHS Component**. This section includes a thorough evaluation of the integrated functionality of the PHS surveillance tools used in the Cincinnati CWS, including a comparative evaluation regarding how each tool met the stated design objectives.
- **Section 9: Summary and Conclusions**. This section provides an overall summary of the PHS component evaluation, discusses limitations of the study and describes potential additional applications.
- **Section 10: References**. This section lists all sources and documents cited throughout this report.
- **Section 11: Abbreviations**. This section lists all acronyms approved for use in the PHS component evaluation.
- **Section 12: Glossary**. This section defines terms used throughout the PHS component evaluation.

Section 2.0: Overview of the PHS Component

Per the Centers for Disease Control and Prevention (CDC), public health surveillance is the “ongoing, systematic collection, analysis, interpretation and dissemination of data about a health-related event for use in public health action to reduce morbidity and mortality and to improve health,” (Thacker and Berkelman, 1988). PHS involves the analysis of health-related data to identify disease events that may stem from various sources, in this case, drinking water contamination. Using PHS successfully requires the proper acquisition of data and application of analysis techniques, as well as effective communication practices between essential investigative personnel.

For the Cincinnati CWS, existing PHS data and infrastructure provided a solid foundation to achieve the goals of the PHS component as part of a CWS. However, following a gap analysis, a number of enhancements and modifications were identified to fully develop and/or optimize the surveillance tools and communication and coordination protocols to meet the design objectives described in Section 1.1. Specifically, automated event detection tools that could analyze PHS data (e.g., 911 calls and EMS runs) and potentially provide early indication of drinking water contamination for contaminants with rapid symptom onset had not been implemented. Therefore, the capability to provide timely detection of contamination incidents resulting from contaminants with rapid symptom onset (i.e., contaminants that produces symptoms within minutes to several hours of exposure to an acutely harmful dose) via near real-time detection was not available. In addition, the lack of consistent and reliable mechanisms for communication and coordination between the water utility and local health departments presented a challenge in terms of defining roles and responsibilities to investigate alerts produced by the PHS tools.

The PHS component of the Cincinnati CWS leveraged a variety of Health Insurance Portability and Accountability Act (HIPAA) compliant public health data sources to identify possible contamination incidents. Two new event detection tools, the 911 surveillance tool and the EMS surveillance tool, were implemented for the purposes of detecting increases in 911 calls and EMS runs which may indicate exposure of individuals to contaminants with rapid symptom onset. Existing surveillance tools were also utilized for identification of possible contamination incidents, including: 1) EpiCenter, which monitors hospital ED admission reports for a rise in medical syndromes that may indicate disease outbreaks; and 2) the DPIC surveillance tool, which monitors for chemical poisoning incidents. In addition to enhanced data acquisition and analysis, protocols were implemented to improve the efficiency of communication among Cincinnati Health Department (CHD), Hamilton County Public Health (HCPH), DPIC and GCWW.

The PHS component of the Cincinnati CWS was fully deployed and operational by the end of 2007 and a detailed description of the system at this point in the project can be found in *Water Security Initiative: Cincinnati Pilot Post-Implementation System Status* (USEPA, 2008b). During the next phase of the pilot, the evaluation period from January 2008 through June 2010, the system was modified to optimize performance and then analyzed.

The three main design elements for the PHS component are described in greater detail in **Table 2-1**. Sections 2.1 through 2.3 provide an overview of each of the three PHS design elements, with an emphasis on changes to the component during the evaluation period. Section 2.5 summarizes all significant modifications to the PHS system that are relevant to the interpretation of the evaluation results presented in this report.

Table 2-1. Public Health Surveillance Component Design Elements

Design Element	Description
Public Health Surveillance Tools	PHS data streams, including 911 calls, EMS runs, ED cases, and PCC calls are monitored using automated surveillance systems to identify possible drinking water contamination.
Communication and Coordination	A mechanism and protocol for communication and coordination between the appropriate local public health organizations and the drinking water utility which is utilized during PHS alert investigations and during other public health crises. A User's Group consisting of public health and utility meets periodically to discuss matters relevant to the PHS component of the CWS as well as other current health topics.
Component Response Procedures	Written standard operating procedures exist for every step in assessing PHS alerts and communicating with partners. These procedures outline effective and timely communications, including clear guidance on appropriate response actions.

2.1 Public Health Surveillance Tools

The surveillance tools selected for the PHS component in combination with the analysis methods used by public health personnel during ongoing surveillance of public health data aim to detect a broad spectrum of contaminants of concern. A brief description of each of the PHS surveillance tools included in this component evaluation is provided below:

- **911 Surveillance Tool**. 911 call data is collected by the Cincinnati Fire Department (CFD) and filtered based on incident code to include calls that are most indicative of possible water contamination. This data is analyzed spatially and temporally via SaTScan™ algorithms. Results from this analysis are displayed on the Public Health User Interface, an interactive web-based tool developed as part of the Cincinnati CWS to display information on 911 and EMS alerts. Automated email alerts are sent whenever analysis results exceed pre-established thresholds. Because this data is collected by CFD, the analysis only applies to the portion of the GCWW service area within Cincinnati city limits. Evaluation of the 911 surveillance tool is discussed more thoroughly in Section 4.

- **EMS Surveillance Tool**. EMS run data is collected by CFD paramedics and Emergency Medical Technicians (EMTs) upon completion of an EMS run. This data is uploaded to a database server via wireless routers at CFD fire houses, filtered for syndromes most likely to indicate water contamination, and analyzed using CDC's Early Aberration Reporting System (EARS). Like the 911 analysis, results from this analysis are displayed on the Public Health User Interface and automated email alerts are sent when thresholds are exceeded. This data also only applies to the portion of the GCWW service area within Cincinnati city limits. Evaluation of the EMS surveillance tool is discussed more thoroughly in Section 5.

- **ED Registration Data Surveillance Tool (EpiCenter)**. ED registrations are entered at local hospitals following a patient visit to the ED. Pertinent information from these records is uploaded into EpiCenter (formerly the Real-Time Outbreak Detection System [RODS]), housed at the Ohio Department of Health (ODH). Case data is categorized by syndrome, and is analyzed using a variety of algorithms. Local public health personnel are notified when thresholds are exceeded. Since all Hamilton County hospitals submit data to EpiCenter, this surveillance tool covers the Hamilton County portion of the GCWW service area. Evaluation of EpiCenter is discussed in detail in Section 6.

- **PCC Call Data Surveillance Tool (DPIC)**. Calls into DPIC are handled by trained toxicosurveillance specialists; call details are entered into the National Poison Data System (NPDS) interface. Statistical, non-statistical, and human surveillance techniques are applied to data within NPDS in order to detect anomalies possibly related to water contamination. Part of the human surveillance performed on DPIC data is observation of any calls from primary care physicians pertaining to severe or unusual symptoms exhibited by their patients. Because DPIC serves the entire Southwest Ohio region, this data source covers the entire GCWW service area. Evaluation of the DPIC surveillance tool is discussed more thoroughly in Section 7.

A fifth surveillance tool, the National Retail Data Monitor (NRDM), was considered for the Cincinnati CWS. The NRDM monitors the sales of over-the-counter (OTC) medications as a potential indicator of disease outbreaks. Unfortunately, data reporting from area pharmacies was inconsistent, and the unreliability of the underlying data minimized the utility of the NRDM surveillance tool as a means of early outbreak detection. Furthermore, it was not possible to evaluate NRDM data collected during the evaluation period, as the data provider prohibited ODH from conducting research using the data or from providing the data to a third party.

An overview of the data surveillance tools used and evaluated for the Cincinnati CWS can be found in **Table 2-2**.

Table 2-2. PHS Surveillance Tool Overview

	PHS Surveillance Tool			
	911	**EMS**	**EpiCenter**	**DPIC**
Data Source	911 call data	EMS run data	ED registration data	PCC call data
Data Owner	CFD	CFD	ODH	NPDS
Data Type	Incident Codes	Syndrome	Syndrome	Syndrome
Analysis Tool	SaTScan™	CDC EARS	EpiCenter	NPDS
Algorithms/ Analysis Methods	Space-time statistical models	Temporal statistical models	Temporal statistical models	Statistical, non-statistical, and human
Display	Public Health User Interface	Public Health User Interface	EpiCenter User Interface	NPDS User Interface
Spatial Coverage	City of Cincinnati (only locations within the jurisdiction of CFD; 22% of GCWW service area)	City of Cincinnati (only locations within the jurisdiction of CFD; 22% of GCWW service area)	Hamilton County (includes 95% of GCWW service area)	100% of GCWW service area

In addition to the PHS surveillance tools noted in **Table 2-2**, identification of unusual cases by an astute clinician at any participating agency may also produce an alert. This type of alert could occur prior to detection of any statistical anomalies in the data. While an important piece of PHS, observations by astute clinicians were not routinely documented during the evaluation period; however, the role of the astute clinician is discussed in this report where appropriate.

Figure 2-1 depicts the overlapping coverage of the various surveillance tools. As previously noted, the 911 and EMS surveillance tools monitor 911 calls and EMS runs that occur within the city of Cincinnati. The cross-hatch shows the GCWW retail service area, which is also the geographic area covered by DPIC surveillance. Zip codes that fall either partially or completely within the city of Cincinnati boundaries are represented by the dashed outline. It should be noted that because some zip codes extend beyond city limits, the zip code boundaries do not precisely depict city of Cincinnati boundaries, but is a close approximation. The black border depicts the boundary of Hamilton County, which is the area covered by the EpiCenter surveillance tool.

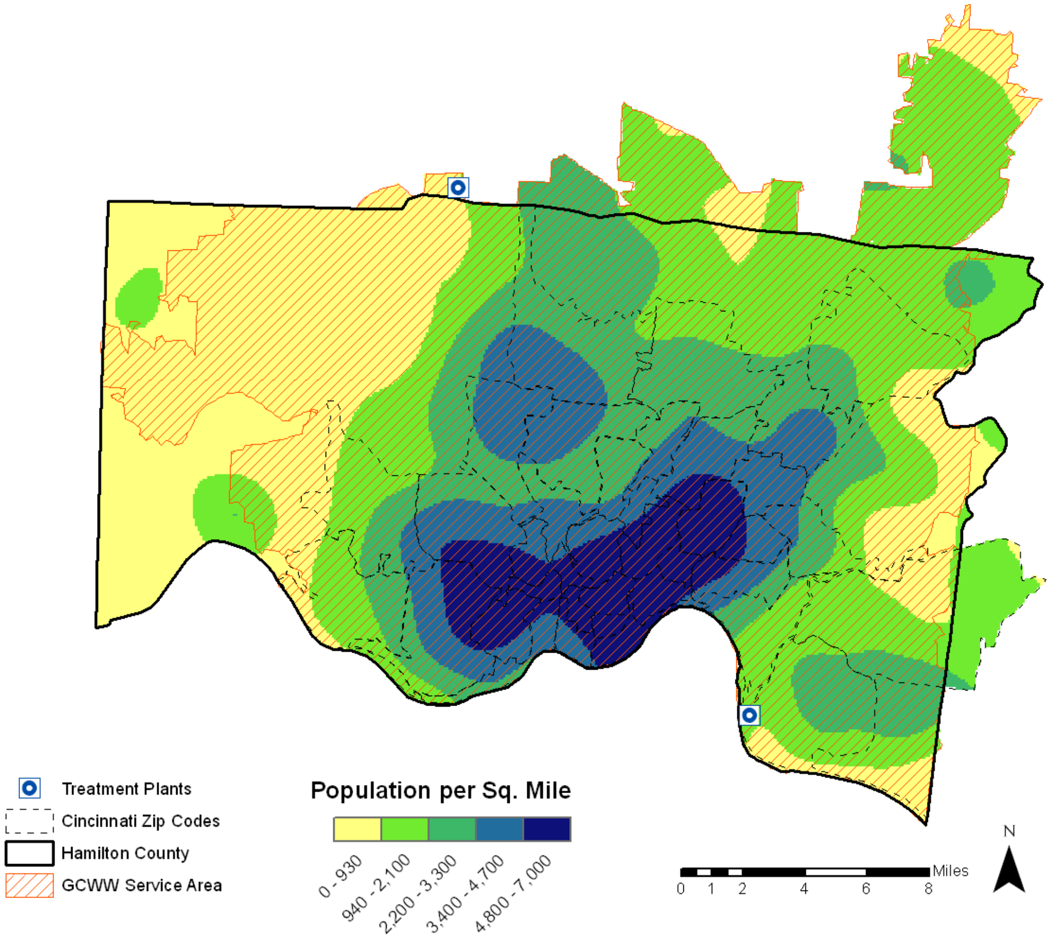

Figure 2-1. Spatial Coverage of the 911, EMS, and DPIC Surveillance Tools

Figure 2-1 shows the population density of the GCWW service area for reference in subsequent sections of this document. For example, algorithms that measure data volumes without accounting for the underlying population density may register more alerts in areas that are more densely populated.

2.2 Communication and Coordination

Prior to implementation of the PHS component, one major gap identified was the lack of a reliable link or consistent mechanism for data sharing between GCWW and the local public health partners. To overcome this gap and support PHS component design objectives, the following improvements were implemented:

- **User's Group**. A Public Health User's Group (hereafter referred to as the "User's Group") was established in order to coordinate efforts required for the PHS component across all stakeholders. The User's Group includes representatives from CHD, HCPH, CFD, DPIC, the Federal Bureau of Investigation (FBI), and GCWW. During the early stages of design and deployment, the User's Group met on a monthly basis to inform the design, use and evaluation of tools proposed for the PHS component of the Cincinnati CWS. Following the completion of implementation activities, the group transitioned to a quarterly meeting schedule. The User's Group provides a forum to discuss not only issues related to the Cincinnati CWS, but other issues that impact 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.

- **Automated Email Alerts**. In order to coordinate the distribution of PHS alerts, automated email notifications were set up to be sent to GCWW, DPIC, and local public health any time threshold alerting criteria were exceeded for the 911 and EMS data analysis. Initially, these emails included basic information on the type, date, and time of alerts (e.g., EARS alert for the water syndrome on 10/4/2008 at 8:30 am). More detail was added to these email alerts through the evaluation period based on feedback from the User's Group (see Section 2.5, Major Modifications).
- **Water Safety Hotline**. A 24-hour Water Safety Hotline was also established to improve access to the toxicological expertise available at DPIC. This hotline was distributed to necessary utility and public health personnel for use whenever consultation is necessary on symptoms or other details associated with a PHS investigation. As a result, another means of communication between GCWW, local public health, and DPIC was established.
- **Communicator Protocol**. This protocol established the use of an auto-dialer system operated by CFD to allow immediate notification to all relevant partners when a public health incident, including possible water contamination, is suspected (described below in Section 2.5).

The protocols for information sharing and communication implemented between PHS partners as part of the Cincinnati CWS aimed to achieve the design objectives described in Section 1.1. The extent to which communication and coordination efforts accomplished these goals will be discussed within the section which covers the integrated component (Section 8.0).

2.3 Component Response Procedures

To capture the routine operation of the PHS component leading up to and after issuance of an alert notification, GCWW developed detailed operational strategy procedures. The Cincinnati Pilot Operational Strategy describes the process and procedures involved in the operation of the PHS component, including the initial investigation and validation of a PHS alert. The Cincinnati Pilot Operational Strategy establishes specific roles and responsibilities, and details procedural and information flow descriptions. Health partners complete investigation checklists when investigating alerts to record data such as alert location and patient data including age, gender, location and symptom information. Development of the Cincinnati Pilot Operational Strategy provided an opportunity to better define the protocols and procedures for how GCWW would work with local public health partners to investigate alerts generated through the CWS. For PHS alerts, if investigators observe similar symptom descriptors or syndromes, the cases are clustered, and no other explanation can account for the cases, water contamination is deemed possible and the Cincinnati Pilot Consequence Management Plan is implemented. The operational strategy includes a series of checklists that were developed to support the investigation of PHS alerts.

2.4 Roles and Responsibilities

The PHS component depends on local public health agencies, emergency response personnel (e.g., 911 dispatchers and EMTs), PCC personnel and water utility staff for the purposes of providing pertinent public health data, investigating subsequent alerts and making a Possible contamination determination following alert investigations. These personnel are knowledgeable in the interpretation of alerts produced by the various surveillance tools, as described in Section 2.1. In addition, they are aware of who to contact during alert investigations, as well as following a Possible contamination determination. General responsibilities of representatives in the User's Group are outlined in **Table 2-3**.

Table 2-3. Public Health User's Group Roles and Responsibilities

Job Function	General Responsibilities (All members participate in communications)
Fire Department	• Provide HIPAA-compliant 911 and EMS data • Maintain the PHS notification system (i.e., the communicator), including monthly routine test calls • Provide supplemental information regarding 911 and EMS activity during investigation of possible drinking water contamination
Poison Control Center	• Provide HIPAA-compliant poison control data • Investigate DPIC surveillance alerts • Provide supplemental toxicological expertise during investigation of possible drinking water contamination
Local Public Health Agencies	• Investigate 911, EMS, and EpiCenter alerts • Initiate or participate in communications with water utility and other health partners regarding concern of possible water contamination • Follow-up with health care providers to obtain specific case data during investigation of possible drinking water contamination
Water Utility	• Receive notification of PHS alerts • Review recent water quality/laboratory data for correlation to PHS alerts • Notify other partners if a trigger is determined to be Possible

The roles and responsibilities described above capitalize on expertise available at the corresponding agencies. For example, public health personnel in charge of PHS alert investigations should have some previous knowledge of syndromic surveillance.

2.5 Summary of Significant Public Health Surveillance Component Modifications

Per the implementation approach outlined in the document *Interim Guidance on Planning for Contamination Warning System Deployment*, evaluation and refinement of each monitoring and surveillance component is necessary to ensure proper operation of the system relative to the design objectives (USEPA, 2007). For the PHS component, necessary modifications were identified using feedback received during User's Group meetings and lessons learned from drills and exercises. An overview of the significant component modifications implemented during the evaluation period can be found in **Table 2-4**; these modifications and will serve as a reference when discussing the results of the evaluation presented in Sections 4.0 through 8.0.

Table 2-4. PHS Component Modifications

ID	Component Modification		Date
1	Modification	**Surveillance Tools:** Adjusted database access components for more robust data acquisition and increased stability of data acquisition interface	June 12, 2008
	Cause	Request to reduce application monitoring labor hours by partners	
2	Modification	**Surveillance Tools:** Migrated from RODS to EpiCenter interface	Spring – Fall 2008
	Cause	New emergency room data event detection tool available	

ID	Component Modification		Date
3	Modification	**Communication and Coordination:** Cincinnati Pilot Operational Strategy modified: Possible water contamination determination made jointly between local public health and GCWW	September 15, 2008
	Cause	Actions observed during PHS Drill 1 differed from existing PHS alert investigation procedures	
4	Modification	**Communication and Coordination:** Created all-hours contact list	October 17, 2008
	Cause	Local partner and utility personnel contact information not readily available during drills/exercises to communicate findings during investigation process	
5	Modification	**Surveillance Tools:** To provide additional information during an investigation, the query for the Water Security Data Repository Data Detail page (EARS summary screen) was updated to include patient disposition information in the detailed record list	November 10 – 13, 2008
	Cause	Request to include additional information on record list display	
6	Modification	**Surveillance Tools:** Modified 911 incident codes being filtered for analysis	March 20, 2009
	Cause	Local public health partners question relevance of some 911 incident codes to water contamination	
7	Modification	**Surveillance Tools:** More detail added to 911 and EMS alert email notifications	May 12, 2009
	Cause	Request to include location details (latitude/longitude data converted to address location) on record list display in alert emails	
8	Modification	**Surveillance Tools:** Added case data display in Google Earth for 911 and EMS alerts	May 12, 2009
	Cause	Request to include spatial display of 911 calls and EMS runs associated with 911 and EMS alerts	
9	Modification	**Surveillance Tools:** Alerting threshold adjusted through implementation of new alerting criteria for 911 and EMS alerts	May 12, 2009
	Cause	PHS component was generating too many 911 and EMS alerts	
10	Modification	**Communication and Coordination:** Developed “communicator” protocol	May 14, 2009
	Cause	Actions observed during March 2009 PHS User Interface refresher training/contamination scenario tabletop discussion differed from existing PHS alert investigation procedures	

In general, the major modifications served to improve data access for system users, improve data analysis, and/or further refine communication procedures between public health personnel and GCWW. Examples of improving data access include added detail to email notifications and the display of case data on Google Earth in the User Interface. Data analysis was improved by refining the 911 incident codes being filtered for analysis, as well as modifying threshold levels to acceptable alerting levels. Finally, communication and coordination was improved by refinement of PHS alert investigation procedures in the Cincinnati Pilot Operational Strategy and through development of the “communicator” protocol, described below.

The need for a central communication protocol was realized during a full-scale exercise in October 2008. According to communication protocols at the time, one agency was acting as a hub between GCWW and other public health agencies to relay pertinent investigational information. However, as multiple conversations ensued between different partners, the data "hub" became isolated information channels. To compound the situation, technical issues with conference call scheduling occurred, which resulted in communication difficulties for some partners who needed to provide pertinent information during the exercise. This exercise highlighted issues with the existing communication procedures and demonstrated information flow inefficiencies among partners.

To remediate this issue, the "communicator" protocol was implemented to allow expedient communication among all members of the User's Group when an alert occurs. The communicator is an auto-dialer system operated by CFD, which can be utilized to issue an urgent message to all members of the User's Group. It can be used to notify personnel via phone and email of a possible water contamination incident or other developing public health situation. When the communicator is activated, the notification issued by the system will contain details of the incident and call-in information so that partners can begin preliminary investigation and prepare for collaborative investigation via conference call. An overview of the communicator protocol is displayed in **Figure 2-2**.

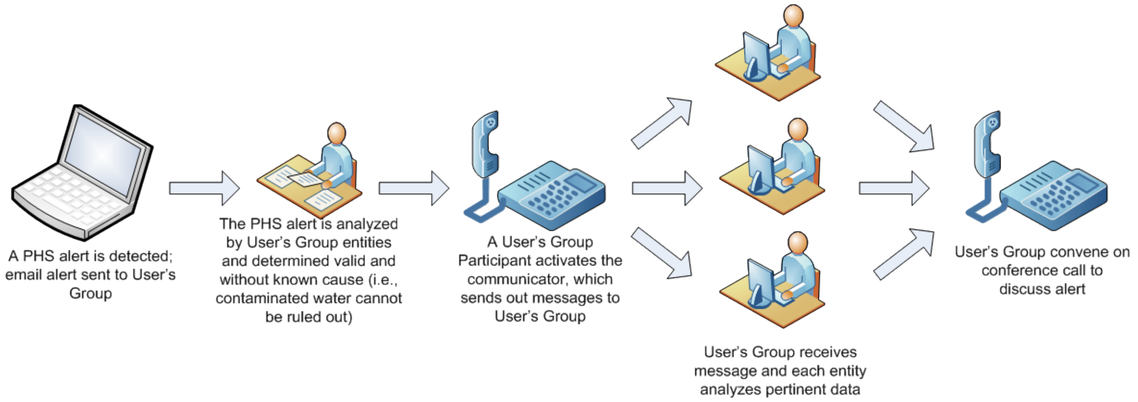

Figure 2-2. The Communicator Protocol

2.6 Timeline of PHS Development Phases and Evaluation-related Activities

Figure 2-3 presents a summary timeline for deployment of the PHS component, including milestone dates for when significant component modifications and drill and exercise evaluation activities took place. The timeline also shows the completion date for design and implementation, along with the subsequent optimization and real-time monitoring phases of deployment. The information in this figure is representative only of modifications that were implemented for the 911 and EMS surveillance tools as the EpiCenter and DPIC tools were maintained separately by external partners.

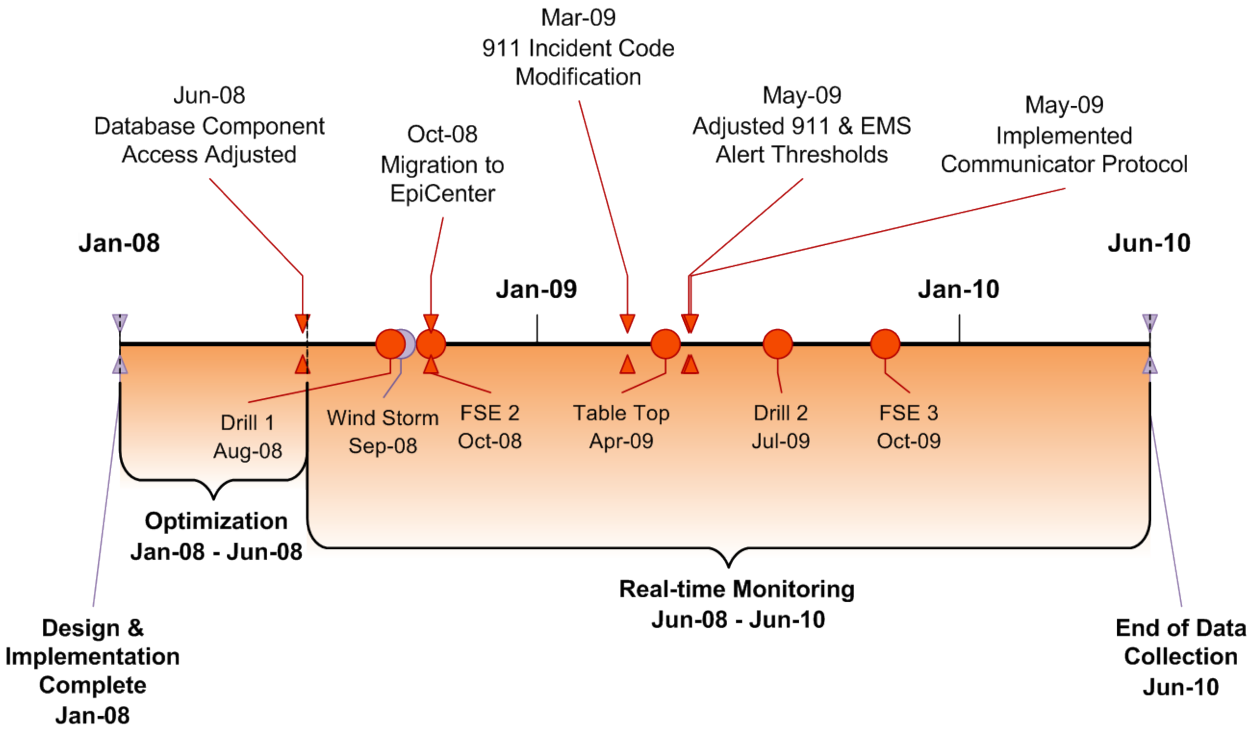

Figure 2-3. Timeline of PHS Component Activities

Section 3.0: Methodology

The following section describes the evaluation techniques that were used to fully evaluate the PHS component. The analysis of the PHS component was conducted using five evaluation techniques to assess each surveillance tool and the overall integrated component: empirical data from routine operations, results from drills and exercises, results from the CWS simulation study, findings from forums such as lessons learned workshops and results from an analysis of lifecycle costs.

3.1 Analysis of Empirical Data from Routine Operations

This evaluation includes data on the performance, operation, and sustainability of the PHS component from January 16, 2008 to June 15, 2010. In this evaluation, the term “reporting period” is used to refer to a month of data which spans from the 16th of one month to the 15th of the next month. Thus, the January 2008 reporting period refers to the data collected between January 16, 2008 and February 15, 2008.

Investigation data and timelines were provided through PHS investigation checklists. To facilitate and document PHS alert investigations, lead investigators were required to fill out an investigation checklist indicating completion of procedures, summarizing findings, and detailing the investigation time. The PHS component (specifically, the 911 and EMS surveillance tools) was modified as needed to optimize performance from January 2008 – May 2009. While some investigation checklists were completed during this optimization period, PHS investigators were not required to respond to alerts in real-time nor complete an investigation checklist during this time. For the DPIC surveillance tool, investigation checklists were completed in real-time throughout the January 2008 – June 2010 period. Finally, for the EpiCenter surveillance tool, alert data was provided for analysis in this evaluation by Hamilton County which spanned the time period March 2008 – March 2010.

3.2 Drills and Exercises

Findings from drills and exercises were used to evaluate the alert investigation process, as implemented by system users, and to determine whether timely and accurate conclusions resulted from the investigation. One main objective of the drills and exercises was to provide the local public health partners and GCWW the opportunity to practice procedures associated with recognition of and response to PHS alerts. Drills and exercises also provided an opportunity to identify which procedures required modification to improve the efficiency of the investigation and communication processes. All of the drills and exercises that were designed to test and evaluate the Cincinnati pilot were compliant with Homeland Security Exercise and Evaluation Program guidelines. A brief description of five drills and exercises conducted for the purpose of component evaluation is provided below. These drills and exercises were:

- PHS Drill 1 (August 22, 2008)
- CWS Full Scale Exercise 2 (October 1, 2008)
- PHS Table Top Exercise (April 22, 2009)
- PHS Drill 2 (July 28, 2009)
- CWS Full Scale Exercise 3 (October 21, 2009)

3.2.1 PHS Drill 1 (August 22, 2008)

Description: The objectives of the drill were to evaluate the alert investigation procedures associated with the PHS component of the Cincinnati CWS and the interactions between local public health partners and the GCWW Water Utility Emergency Response Manager (WUERM) as they investigated the alert to determine if drinking water contamination was possible. In addition to evaluating implementation of the procedures, elapsed time between drill actions was recorded to establish baseline data for future drill activities.

Relevant Participants: PHS relevant participants are listed in **Table 3-1**.

3.2.2 CWS Full Scale Exercise 2 (October 1, 2008)

Description: A Full Scale Exercise was conducted on October 1, 2008 to test all Cincinnati CWS components. Investigation time associated with the public health alert investigation procedures and the interactions between local public health partners and the GCWW WUERM were analyzed during this exercise. ***Note***: CWS Full Scale Exercise 1 took place prior to the evaluation period and did not involve the PHS component.

Role of PHS: EMS and DPIC alerts occurred after GCWW had already received a WQM alert and a CCS alert. The public health partners concluded the PHS alerts were likely related to the previous GCWW alerts. The local public health partners coordinated with GCWW on public notification and response. However, CWS Full Scale Exercise 2 demonstrated issues with communication as the public health partners were contacted by different members of the GCWW consequence management team concurrently. A key outcome of this exercise was streamlining of communications among all partners during the latter stages of incident response.

Relevant Participants: Water Utility: GCWW (WUERM), Local Public Health Agencies: CHD (Epidemiologist) and HCPH (Epidemiologist), and Poison Control Center: DPIC (Toxicologists)

3.2.3 PHS Tabletop Exercise (April 22, 2009)

Description: The main objective of the tabletop exercise was to evaluate whether the User's Group would determine if drinking water contamination was possible based on a simulated contamination scenario that involved PHS alerts. The simulated action driving the tabletop exercise scenario was the introduction of a toxic chemical into the water supply at a large reservoir. Individuals exposed to the contaminant experienced unusual symptoms which resulted in 911 calls, EMS runs and ED visits. Additionally, introduction of the contaminant resulted in WQM alerts and positive rapid field test results.

Relevant Participants: PHS relevant participants are listed in Table 3-1.

3.2.4 PHS Drill 2 (July 28, 2009)

Description: The primary objective of the drill was to provide the local public health partners (CHD, HCPH, and DPIC) and the GCWW WUERM the opportunity to practice the recognition of and response to alerts generated by the PHS component. A secondary objective was to test the communication procedures between local health partners and utility personnel during the alert investigation process. Specifically, the newly developed "communicator" protocol was tested to practice implementation of rapid communication amongst all members of the User's Group during the investigation. Drill objectives were evaluated based on a simulated call to DPIC from a day-care facility, followed by a SaTScan™ alert showing an increased number of 911 calls in the same area. In addition to evaluating implementation of the procedures, elapsed time between actions was also recorded.

Relevant Participants: PHS relevant participants are listed in Table 3-1.

3.2.5 CWS Full Scale Exercise 3 (October 21, 2009)

Description: The Full Scale Exercise was based on a simulated contamination incident in the GCWW drinking water distribution system. The scenario involved the intentional injection of a large quantity of a toxic chemical into the GCWW drinking water system through a fire hydrant in an urban neighborhood of Cincinnati. The contaminant selected for the scenario was expected to trigger CCS alerts, due to the odor associated with the toxic chemical, and would produce sufficient public illness to generate delayed PHS involvement, but not necessarily PHS alerts. Local health departments were not available to participate in the exercise due to their responsibilities in preparing for H1N1 pandemic influenza response.

Role of PHS: DPIC personnel worked closely with GCWW personnel (WUERM, Incident Command System [ICS]) and the simulated local health departments (CHD and HCPH) throughout the exercise. Conference calls were conducted as new information became available, and was shared effectively by all of the participants. Evaluators noted that public health information was used to support the development of public notices and to help identify the nature of the contaminant. Additionally, based on the professional opinion of a DPIC physician-toxicologist, the Incident Commander began evacuating the impacted area.

Relevant Participants: Water Utility: GCWW (WUERM), Local Public Health Agencies: Simulated, and Poison Control Center: DPIC (Toxicologists)

Table 3-1. PHS Drill Variations

Variations	Drill 1	TTX	Drill 2
	6/26/08	3/11/09	4/30/09
Time of Drill (N = Normal business hours, A = After hours)	N	N	N
Drill Participants			
GCWW WUERM	1	1	1
Law Enforcement: FBI	0	1	0
Local Public Health: CHD (Epidemiologist)	1	1	1
Local Public Health: HCPH (Epidemiologist)	1	1	1
Local Fire Department: CFD (Fire Chief)	0	1	1
Poison Control Center: DPIC (Toxicologists)	1	0	0

3.3 Simulation Study

Evaluation of certain design objectives relies on the occurrence of contamination incidents with known and varied characteristics. Because contamination incidents are extremely rare, there is insufficient empirical data to fully evaluate the detection capabilities of the Cincinnati CWS. To fill this gap, a computer model of the Cincinnati CWS was developed and challenged with a large ensemble of simulated contamination incidents in a simulation study. For the PHS component, simulation study data was used to evaluate the following design objectives:

- **Contaminant Coverage:** Analyses conducted for this design objective quantify the ratio of contamination scenarios actually detected by the PHS component versus those that could theoretically be detected. Simulations can also be used to understand which of the surveillance tools within the PHS component are the most valuable for detecting chemical, radiological, or biological incidents.
- **Alert Occurrence:** Analyses conducted for this design objective characterize contamination scenarios in which multiple PHS alerts occurred from different PHS data streams, and consider the order in which the alerts occurred.
- **Timeliness of Detection:** Analyses conducted to evaluate this design objective quantify the time between the start of contaminant injection and the first PHS alert.

A broad range of contaminant types, producing a range of symptoms, was utilized in the simulation study to characterize the detection capabilities of the monitoring and surveillance components of a CWS. For the purpose of the simulation study, a representative set of 17 contaminants was selected from the comprehensive contaminant list that formed the basis for CWS design. These contaminants are grouped into the broad categories listed below (the number in parentheses indicates the number of contaminants from that category that were simulated during the study). A description of the manner in which the critical concentration, which is the concentration that would produce adverse health effects (or aesthetic problems in the case of the nuisance chemicals), was derived is also provided for each contaminant category.

- Nuisance Chemicals (2): these chemical contaminants have a relatively low toxicity and thus generally do not pose an immediate threat to public health. However, contamination with these chemicals can make the drinking water supply unusable. The critical concentration for nuisance chemicals was selected at levels that would make the water unacceptable to customers, e.g., concentrations that result in objectionable aesthetic characteristics.
- Toxic Chemicals (8): these chemicals are highly toxic and pose an acute risk to public health at relatively low concentrations. The critical concentration for toxic chemicals was based on the mass of contaminant that a 70 kg adult would need to consume in one liter of water to have a 10% probability of dying (LD_{10}).
- Biological Agents (7): these contaminants of biological origin include pathogens and toxins that pose a risk to public health at relatively low concentrations. The critical concentration for biological agents was based on the mass of contaminant that a 70 kg adult would need to consume in one liter of water, or inhale during a showering event, to have a 10% probability of dying (LD_{10}).

Development of a detailed CWS model required extensive data collection and documentation of assumptions regarding component and system operations. To the extent possible, model decision logic and parameter values were developed from data generated through operation of the Cincinnati CWS, although input from subject matter experts and available research was utilized as well.

The simulation study used several interrelated models, three of which are relevant to the evaluation of PHS: EPANET, Health Impacts and Human Behavior (HI/HB), and the PHS component model. Each model is further broken down into modules that simulate a particular process or attribute of the model. The function of each of these models and their relevance to the evaluation of PHS is discussed below.

EPANET

EPANET is a common hydraulic and water quality modeling application widely used in the water industry to simulate contaminant transport through a drinking water distribution system. In the simulation study, it was used to produce contaminant concentration profiles at every node in the GCWW distribution system model, based on the characteristics of each contamination scenario in the ensemble. The concentration profiles were used to determine the number of miles of pipe contaminated during each scenario, which is one measure of the consequences of that contamination scenario.

Health Impacts and Human Behavior Model

The HI/HB model used the concentration profiles generated by EPANET to simulate exposure of customers in the GCWW service area to contaminated drinking water. Depending on the type of contaminant, exposures occurred during one showering event in the morning (for the inhalation exposure route), or during five consumption events spread throughout the day (for the ingestion exposure route). The HI/HB model used the dose received during exposure events to predict infections, onset of symptoms, health-seeking behaviors of symptomatic customers and fatalities.

The primary output from the HI/HB model was a case table of affected customers, which captured the time at which each transitioned to mild, moderate and severe symptom categories. Additionally, the HI/HB model outputs the times at which exposed individuals would pursue various health-seeking behaviors, which generate the input data for the following PHS surveillance tools: 911, EMS, DPIC, and EpiCenter (ED data). These case records were processed by the surveillance tools included in the PHS component model.

The case table was used to determine the public health consequences of each scenario, specifically the total number of illnesses and fatalities. Furthermore, EPANET and the HI/HB model were run twice for each scenario; once without the CWS in operation and once with the CWS in operation. The paired results from these runs were used to calculate the reduction in consequences due to CWS operations for each simulated contamination scenario.

Public Health Surveillance Component Model

The PHS component model is based on the component as deployed and currently operating in the Cincinnati CWS. Inputs from the HI/HB model (health-seeking behaviors from the case table) were processed by the PHS Event Detection module, which is composed of four automated event detection tools (911, EMS, EpiCenter and DPIC). The specific statistical surveillance method that was modeled for DPIC was the volume-based clinical effects algorithm, which requires four calls from the same zip code in a 24-hour window. Human surveillance detection methods were also integrated into the PHS Event Detection module, which included active monitoring by DPIC toxicosurveillance specialists of calls received (alerting threshold was set at 2 calls from the same node within a 4-hour window), and detection by the simulated Astute Clinician (via number of cases seen by primary care physicians or ED physicians). In real-world situations, astute clinician monitoring is performed by virtually at any agency involved in PHS (in addition to the active monitoring being conducted by primary care physicians or ED physicians). When the number of cases met the alerting criteria established for any of the surveillance methods, the module generated alerts which were processed by the PHS Alert Validation module.

Fifteen of the 17 contaminants evaluated in the simulation study can produce low, moderate, or severe symptoms in exposed individuals, who would then pursue various health-seeking behaviors. Thus, these 15 contaminants are theoretically detectable by PHS, while the two nuisance chemicals are not because they were assumed to not produce symptomatic cases under the scenario conditions. **Table 3-2** provides a summary of the assumed delay for onset of low symptoms, and the ratio of the critical concentration to the detection threshold for each contaminant. The ratio was calculated to determine whether the detection threshold was sufficient to detect water contaminated at concentrations equal or greater than the critical concentration. Large ratios demonstrate the contaminants that can be detected at concentrations significantly lower than the critical concentration. The detection threshold values for PHS represent the concentration of the contaminant that would result in enough illnesses to produce a signal, and were obtained from a literature review and input from subject matter experts.

Table 3-2. Assumed Characteristics of Contaminants Detectable by the PHS Component

Contaminant	Low Symptom Onset Delay[1]	Critical Concentration/ Detection Threshold
Toxic Chemical 1	10 minutes	458
Toxic Chemical 2	15 minutes	3,636
Toxic Chemical 3	15 minutes	1,640
Toxic Chemical 4	1 hour	290

Contaminant	Low Symptom Onset Delay[1]	Critical Concentration/ Detection Threshold
Toxic Chemical 5	15 minutes	668
Toxic Chemical 6	15 minutes	850
Toxic Chemical 7	10 minutes	950
Toxic Chemical 8	1 day	300
Biological Agent 1	30 minutes	4,500
Biological Agent 2	4 hours	3,940
Biological Agent 3	2 hours	2.4×10^4
Biological Agent 4	12 hours	4.5
Biological Agent 5	4 days	10
Biological Agent 6	1 day	1.7
Biological Agent 7	1 day	1.6

[1] For the toxic chemical contaminants, the time from exposure to symptom onset is dose-dependent. Time parameter values for earliest onset of symptoms were assigned based on available medical and toxicological literature.

Outputs of the PHS Event Detection module provide inputs to the PHS Alert Validation module. The primary outputs from the PHS Event Detection module are time of alert, location of alert and type of alert. This information is used by the PHS Alert Validation module, which included activation of the communicator protocol, as described in Section 2.5, to determine whether contamination is possible. During the communicator discussion, the local health partners and GCWW would conclude that water contamination is possible based on geographical clustering of cases and similarity of symptoms evident from the alert notifications. The procedures included in this module are representative of the alert investigation process that public health partners and GCWW utilize in the Cincinnati CWS.

The ability of the PHS surveillance tools to detect possible water contamination depends on the health-seeking behavior of exposed individuals, which in turn depends on the nature and timing of symptoms produced by the contaminant. The following model assumptions affect the data inputs to the PHS model, as well as the manner in which the PHS model processes data:

- A percentage of the exposed population experience symptoms, and pursue health-seeking behavior such as calling 911 (and subsequently being transported to the ED via EMS), transporting themselves to the ED, calling their primary care physician or calling DPIC. There is also a percentage of individuals who “do nothing” to seek healthcare, which decreases as symptom level increases. For each health-seeking behavior, a specific time delay occurs between the time of symptom onset and the time that individuals pursue healthcare.
- All health-seeking behavior actions recorded in the model which become inputs to the PHS model are related to water contamination.
    - Health-seeking behavior was parameterized based on a review of relevant peer-reviewed literature, input from subject matter experts, and an exercise conducted in which respondents selected their likely actions when experiencing symptoms of different types of illnesses.
- Individuals seek healthcare more aggressively when experiencing fast onset, more severe or highly unusual symptoms.

- During non-business hours, individuals cannot schedule appointments with primary care physicians.
- The number of available of toxicosurveillance specialists at DPIC varies depending on the time of day, according to their normal business hours and non-business hours capacity.
- The EMS response and transport time was parameterized using ambulance response data provided by CFD, as this is a precursor step that occurs prior to the time that EMS data is uploaded and transmitted for analysis by the EMS surveillance tool.
- There is some time delay (based on knowledge of the functional PHS component) for data to be uploaded and available for analysis by each of the surveillance tools.
- Contamination scenarios initiated at high demand times were detectable sooner than scenarios that were initiated at low demand times. A seven-hour time delay occurred between the scenarios initiated at low demand (12:00 am) and the first exposure event (7:00 am), which resulted in a time lag before detection was possible, unlike the scenarios initiated at high demand (9:00 am), which could have resulted in exposure soon thereafter at the 9:30 am or 12:00 pm exposure events.

The simulated PHS investigation reflects the procedures used by the local health partners and GCWW personnel to investigate a PHS alert. Investigators assess the underlying case data for clustering and similar symptom categories as well as possible alternative explanations for the alerts, such as a public health incident unrelated to water contamination. The PHS investigation portion of the model assumes:

- All cases investigated had similar symptom categories as the simulated PHS system analyzed only cases which resulted from exposure to contaminated water.
- All cases in an alert were clustered because of the hydraulic connectivity of the contamination scenarios.
- PHS alerts were investigated immediately upon receipt if the alert details (i.e., similar symptom categories and geographic clustering of cases) suggested possible water contamination. This assumption was based on the process applied by public health personnel responsible for investigating alerts during the evaluation period who quickly reviewed PHS alert details within minutes of receipt. If it was readily apparent that the underlying case details did not suggest water contamination, investigation checklists were not typically completed until hours later. In a few instances where alert details demonstrated possible water contamination, public health personnel responded immediately by activating the communicator protocol to involve all relevant partners in the alert investigation.
- The communicator protocol was always activated when a PHS alert occurred due to the nature of the underlying case data in PHS alerts in model runs (i.e., geographic clustering and similar symptom categories).
- No other explanations (such as a public health incident unrelated to water contamination) could be found for alerts during investigations.

The practical implication of these assumptions is that the alert validation process, once activated, proceeded to completion as alerts will not be ascribed to other unrelated public health incidents, or caused by background variability. All PHS alerts resulted in the determination that water contamination was possible.

3.4 Forums

Feedback and suggestions from the public health partners and utility personnel on all aspects of the PHS component were captured during User's Group meetings as well as the lessons learned workshop held in July 2009. Information gathered through these forums provided insight regarding which elements of the component were acceptable to the end users and highlighted others that required modification or enhancement. Forums consisted of:

- **Public Health User's Group Meetings:** Bi-monthly meetings were scheduled for the duration of the three year Cooperative Research and Development Agreement between USEPA and the city of Cincinnati. Component design, functionality and modifications/enhancements were discussed during these meetings, including component modifications (**Table 2-3**).
- **Lessons Learned Workshop:** The purpose of the lessons learned workshop was to allow the User's Group the opportunity to provide feedback regarding the performance, operation, and sustainability of the PHS component during the evaluation period. The group expressed specific feedback regarding the strengths and weakness of each of the PHS surveillance tools in the context of their effectiveness in identifying possible contamination incidents.

3.5 Analysis of Lifecycle Costs

A systematic process was used to evaluate the overall cost of the PHS component over the 20-year lifecycle of the Cincinnati CWS. The analysis includes implementation costs, component modification costs, annual operations and maintenance (O&M) costs, renewal and replacement costs, and the salvage value of major pieces of equipment at the end of the lifecycle.

Implementation costs include labor and other expenditures (equipment, supplies and purchased services) for deploying the PHS component. Implementation costs were summarized in *Water Security Initiative: Cincinnati Pilot Post-Implementation System Status* (USEPA, 2008b), which was used as a primary data source for this analysis. In that report, overarching project management costs incurred during the implementation process were captured as a separate line item. However, in this analysis, the project management costs were equally distributed among the six components of the CWS, and are presented as a separate line item for each component. Component modification costs include all labor and expenditures incurred after the completion of major implementation activities in December 2007 that were not attributable to O&M costs. These modification costs were tracked on a monthly basis, summed at the end of the evaluation period, and added to the overall implementation costs.

It should be noted that implementation costs for the Cincinnati CWS may be higher than those for other utilities given that this project was the first comprehensive, large-scale CWS of its kind and had no experience base to draw from. Costs that would not likely apply to future implementers (but which were incurred for the Cincinnati CWS) include overhead for EPA and its contractors, cost associated with deploying alternative designs and additional data collection and reporting requirements. Other utilities planning for a similar large-scale CWS installation would have the benefit of lessons learned and an experience base developed through implementation of the Cincinnati CWS.

Annual O&M costs include labor and other expenditures (supplies and purchased services) necessary to operate and maintain the component and investigate alerts. O&M costs were obtained from maintenance logs, investigation checklists, and training logs. Maintenance logs tracked the staff time spent maintaining the PHS component. To account for the maintenance of documents, the cost incurred to update documented procedures following drills and exercises conducted during the evaluation phase of the pilot was used to estimate the annualized cost. Investigation checklists and training logs tracked the staff hours spent on investigating alerts and training, respectively. The total O&M costs were annualized by calculating the sum of labor and other expenditures incurred over the course of a year.

Labor hours for both implementation and O&M were tracked over the entire evaluation period. Labor hours were converted to dollars using estimated local labor rates for the different institutions involved in the implementation or O&M of the PHS component.

The renewal and replacement costs are based on the cost of replacing major pieces of equipment at the end of their useful life. The useful life of PHS equipment was estimated using field experience, manufacturer-provided data and input from subject matter experts. Equipment was assumed to be replaced at the end of its useful life over the 20-year lifecycle of the Cincinnati CWS. The salvage value is based on the estimated value of each major piece of equipment at the end of the lifecycle of the Cincinnati CWS. The salvage value was estimated for all equipment with an initial value greater than ~$1,000. Straight line depreciation was used to estimate the salvage value for all major pieces of PHS equipment based on the lifespan of each item.

All of the cost parameters described above (implementation costs, component modification costs, O&M costs, renewal and replacement costs, and salvage value) were used to calculate the total lifecycle cost for the PHS component, as presented in Section 8.7.

Section 4.0: Performance of the 911 Surveillance Tool

The following section provides a description of the 911 surveillance tool followed by the results of the evaluation of this tool. This analysis includes an evaluation of metrics that characterize how the 911 surveillance tool achieves the design objectives described in Section 1.1. Specific metrics are described for each of the design objectives.

4.1 Description of the 911 Surveillance Tool

Cincinnati Police Department and CFD emergency dispatchers process 911 calls on a regular basis through Cincinnati's Computer Aided Dispatch system. 911 call detail data is exported from CFD’s source database to the WS application server database to support call cluster identification by SaTScan™, an automated surveillance tool which was implemented during the Cincinnati CWS. Call detail information includes the call identifier, the incident type code, the date and time of the incident (call time and dispatch time), and the incident location as latitude and longitude coordinates.

New call detail records are queried on a minute-by-minute basis. For call detail records that have incident type codes matching the subset of selected incident type codes, a corresponding record is stored on the WS application server database for later analysis by the SaTScan™ algorithm. These call detail records remain on the server for 28 days, after which they are removed.

911 Event Definitions

Local public health partners identified the likely dispatch incident types that may indicate a drinking water contamination incident; identification of the incident type is based on a caller’s complaint(s) as interpreted by the dispatcher through prompts from Priority Dispatch System™ integrated with the Motorola dispatch system. The selected incident type codes assigned for consideration as a possible water contamination indicator are listed in **Table 4-1** below.

Table 4-1. Generalized 911 Incident Codes

911 Incident Codes	
Abdominal pain, hemorrhage	Headache
Allergies, asthma, breathing problem	*Inhalation (removed from filtering March 2009)*
Burn/blister (added to filtering March 2009)	Overdose
Chest pain, heart problem	Sick person
Choking, seizures, convulsions	Possible stroke, fainting, unconscious
Eye problem (removed from filtering March 2009)	*Person down (removed from filtering March 2009)*

The group of 911 incident codes which are filtered for analysis by the SaTScan™ algorithm was modified as a result of a coding exercise conducted with 911 operators in February 2009. The exercise included five unique water contamination scenarios, some with symptoms from exposure via ingestion of contaminated water, and others with symptoms from dermal or inhalation exposure. Based on the 911 operator coding results, some incident codes that were not determined to be indicative of possible water contamination were removed from filtering, and others were added (see **Table 4-1**).

SaTScan™ Analysis

SaTScan™ is a free software package that analyzes spatial and temporal data using the spatial, temporal or space-time scan statistics. The configuration implemented for the PHS component utilizes the space-time permutation model, which leverages only case data (date of event, location of event, event count). SaTScan™ analysis is executed hourly on the half-hour; the algorithm executes on a rolling 21-day data set of 911 call detail records that are extracted from the WS application server database during each analysis cycle. The analysis results provide the location and size of likely event clusters across the entire dataset, sorted by the p-value (statistical probability that a given cluster occurred by chance).
For further information on SaTScan™, the SaTScan™ User Guide (Kulldorff, 2010) and other technical documentation can be downloaded from http://www.satscan.org/techdoc.html.

911 Surveillance Tool Alerting Criteria

A 911 alert will only be generated when the alerting criteria, as established for the PHS component, is met. The initial design included alerting criteria one through three below, to eliminate notifications from subsequent analyses that duplicated recent results. A fourth alerting criterion was later added in May 2009 to reduce the overall number of alerts. The current alerting criteria for identifying 911 alert conditions are:

1. If the SaTScan™ event detection tool identifies a candidate cluster with p-value less than 0.0250 for a given day AND
2. If PHS has not already generated an alert for the exact cluster center identifier (911 call identifier closest to cluster center) for the given day AND
3. If PHS does not measure the candidate cluster center point as being within any previously alerted cluster(s) for a given day (distance from candidate alert-worthy cluster center to previously-alerted cluster center(s) is less than said previously-alerted cluster's radius) AND
4. If the event count (number of 911 calls) associated with the candidate cluster is greater than 16.

Lower-level PHS alerts which meet the minimum settings of the SaTScan™ event detection tool (p-value less than 0.0250), but do not exceed the established event count threshold (16 calls), are displayed on the Public Health User Interface, but an email alert is not transmitted. When the alerting criteria are met, an email notification alert is transmitted to the local public health partners and GCWW. If a 911 alert is generated, the local health partners work collaboratively with GCWW utility staff to conduct an investigation to determine whether or not alerts have been generated by other PHS surveillance tools, and whether the alert is related to a potential drinking water contamination incident or other public health situation, such as a known disease outbreak.

4.2 Design Objective: Spatial Coverage

The spatial coverage is the cumulative area of the distribution system covered by the 911 surveillance tool with data provided by CFD, which is limited to the city of Cincinnati due to differences in political jurisdictions (911 calls originating from outside Cincinnati city limits are processed through the Hamilton County Communications Center). In order to evaluate how well the 911 surveillance tool met this design objective, the following metrics were evaluated: area and population coverage, and spatial extent of an alert. The following subsections define each metric, describe how it was evaluated and present the results.

4.2.1 Area and Population Coverage

Definition: Area coverage describes how 911 alerts are distributed geographically, while population coverage depicts the geographic area covered by the 911 surveillance tool.

Analysis Methodology: 911 alerts that occurred during the evaluation period were plotted on a map that depicts the geographic area covered by the 911 surveillance tool (i.e., city of Cincinnati).

Results: During the evaluation period, a total of 86 alerts were generated by the 911 surveillance tool. **Figure 4-1** illustrates that these alerts were spatially distributed across the city of Cincinnati, though clearly more concentrated in areas of higher population density. Each marker in the figure represents the geographic center of a single alert. Most alerts were contained within the spatial area where the population density is greater than 3,603 individuals per square mile.

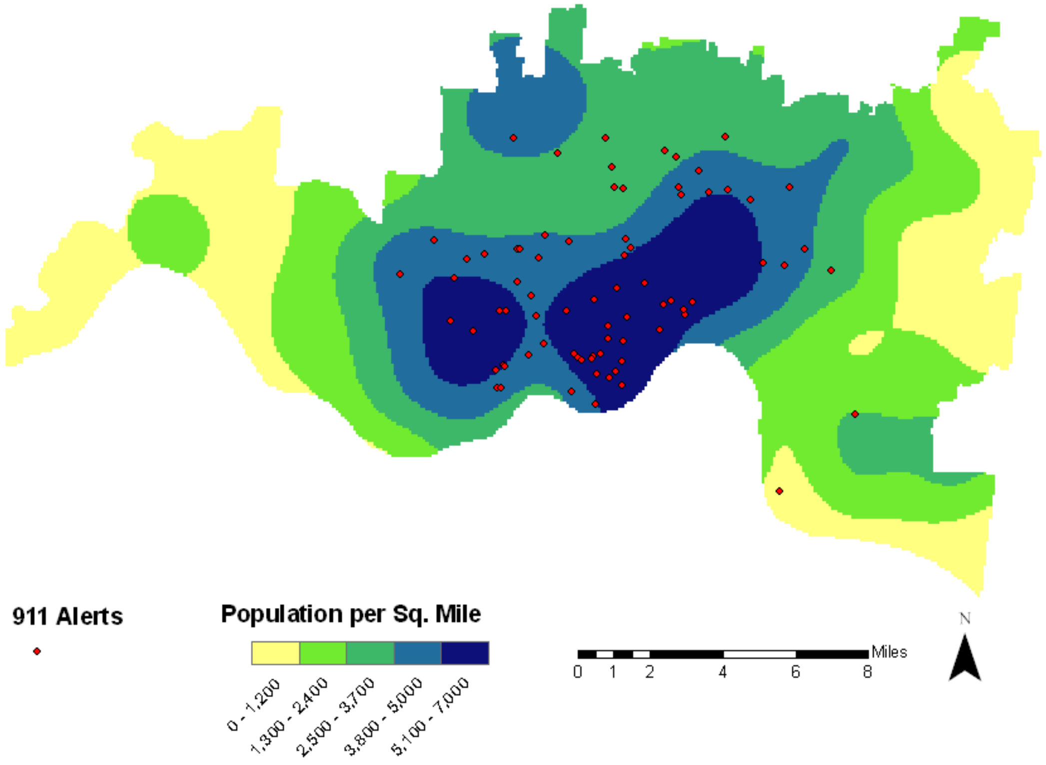

Figure 4-1. Area Coverage of 911 Alerts in City of Cincinnati (n=86)

4.2.2 Spatial Extent of an Alert

Definition: Spatial extent of an alert describes the area covered by a 911 alert. This metric is characterizes the geographic area (size) of each 911 alert.

Analysis Methodology: From the empirical data, the geographic area of an alert was calculated using the alert radius, which is the distance from the cluster center to the furthest call from the center. The analysis includes a map representing the spatial area of each 911 alert that occurred during the evaluation period. Statistical analysis of alert clusters is also presented and includes the alert area, number of calls and density of calls per unit area (square mile) per alert. Using relevant contamination scenarios from the simulation study in which 911 alerts occurred, the average radius and area of the first 911 alert was calculated for each contaminant.

Results: Figure 4-2 illustrates the spatial extent (i.e., area) of each of the 911 alerts that occurred during the evaluation period. The alert area represents the bounding circle of all calls contained in each alert.

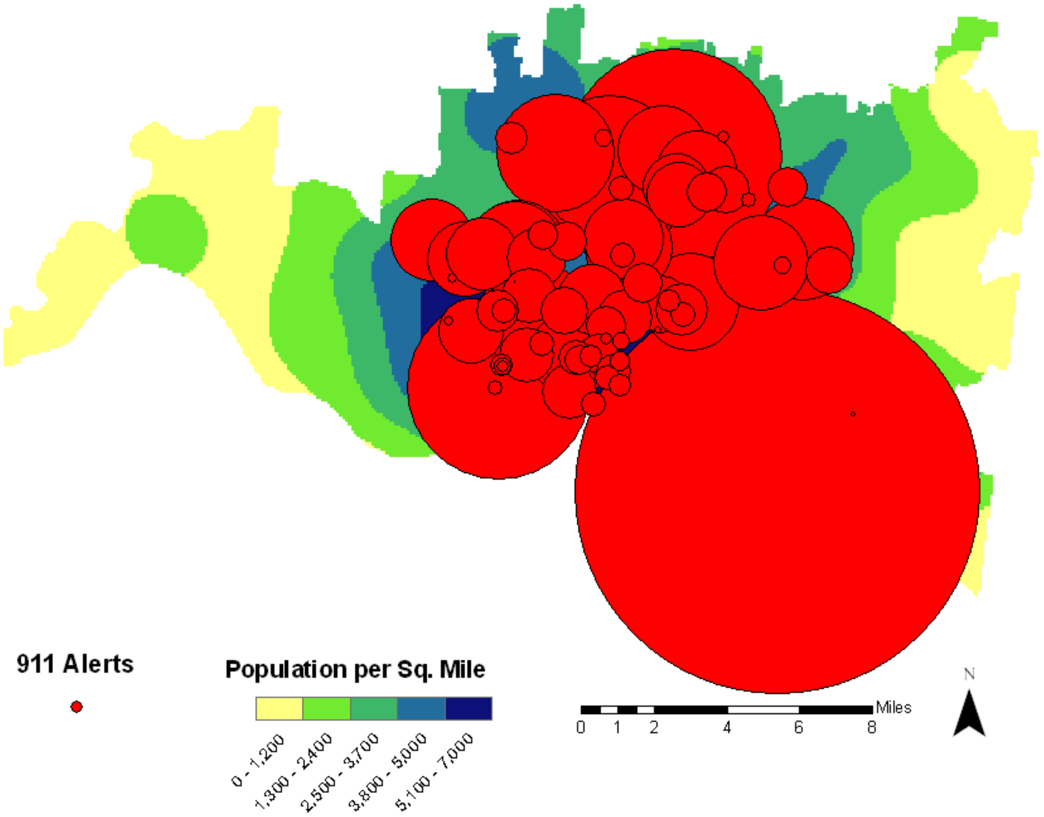

Figure 4-2. Spatial Extent of 911 Alerts (n=86, empirical data)

Table 4-2 includes a statistical analysis of the spatial extent of 911 alerts that occurred during the evaluation period; the average alert area of 3.56 square miles is small relative to the entire 911 service area of approximately 77 square miles, and the entire GCWW service area of 354 square miles. The range in call density for 911 alerts was 0.03 to 384.25 calls per square mile. This range illustrates the upper and lower bounds of sensitivity of the 911 surveillance tool based on the default alerting parameters. Tight call clustering is generally necessary for an alert to be generated. This is supported by the fact that 80% of all 911 alerts encompassed an area less than four square miles in size, or approximately 5% percent of the area covered by the 911 surveillance tool and 1% of the overall GCWW service area. Furthermore, 33% of 911 alerts covered an area less than one square mile. The 911 surveillance tool generated an alert on September 14, 2008 during a major windstorm that was caused by Hurricane Ike. This alert contained the highest number of 911 calls of any alert during the evaluation period – a total of 34 calls.

Table 4-2. Statistical Analysis of Spatial Extent of 911 Alerts (n=86, empirical data)

	Alert Area (mi^2)	Number of Calls	Density (calls/mi^2)
Average	3.56	9	11.02
Minimum	< 0.0001[1]	3	0.03
Maximum	97.76	34	384.25

[1] The minimum alert area was less than SaTScan's™ minimum distance threshold (minimum radius = 0.006 miles) which translates to a minimum alert area of 0.0001 mi^2.

The histogram presented below (**Figure 4-3**) demonstrates that the majority of 911 alerts that occurred during the evaluation period covered small geographic areas (less than five square miles). The 911 alert with the largest alert area (97.76 square miles) was excluded from the histogram for visualization purposes.

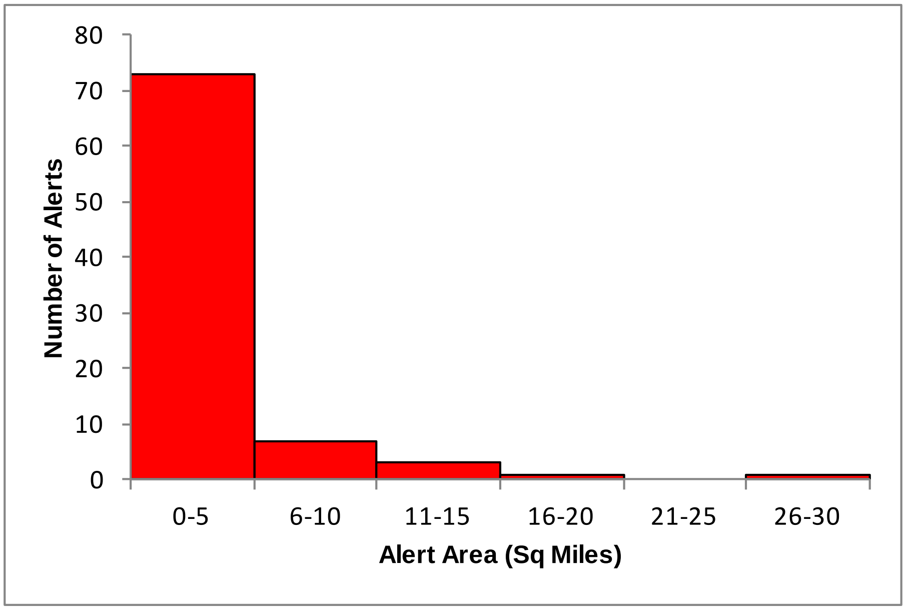

Figure 4-3. Histogram of 911 Alert Areas (n=86, empirical data)

Table 4-3 below demonstrates the average radius and area of the first 911 alert for all simulation study contamination scenarios in which a 911 alert occurred, separated by contaminant. Given that the average area is noticeably larger for Biological Agents 4, 5 and 7, it is assumed that the underlying cases were noticeably more spread out for the 911 alerts that occurred in scenarios involved these biological agents compared to the scenarios involving chemicals. Symptom progression for these contaminants is much slower than the chemical contaminants, allowing for a greater spread of the contaminant throughout the distribution system prior to detection and changes in distribution and/or consumption patterns to prevent additional exposures.

When compared to the average area of invalid alerts in the empirical data (3.56 square miles), the average area of 911 alerts for the toxic chemicals and biological agents in the simulation study are comparable, though the alert area for three of the biological agents was orders of magnitude larger (likely for the same reasons as described above). Another reason that the average alert area was larger for some of the contaminants is that many of the contamination scenarios spread widely throughout GCWW's distribution system, which resulted in a significant geographic distribution of affected individuals, and therefore alerts composed of cases spread across broader geographic areas.

Table 4-3. Average Radius and Area of First 911 Alert by Contaminant (simulation study data)

Contaminant	Scenarios Detected	Average Radius (miles)	Average Area (mi^2)
Toxic Chemical 1	41	1.41	6.25
Toxic Chemical 2	44	0.72	1.63
Toxic Chemical 3	44	0.79	1.96
Toxic Chemical 4	46	1.57	7.74
Toxic Chemical 5	44	0.95	2.84
Toxic Chemical 6	47	1.67	8.76
Toxic Chemical 7	45	1.24	4.83
Toxic Chemical 8	48	1.33	5.56
Biological Agent 1	43	1.09	3.73
Biological Agent 2	15	0.67	1.41
Biological Agent 3	51	1.73	9.40
Biological Agent 4	48	3.68	42.54
Biological Agent 5	36	3.64	41.62
Biological Agent 6	3	1.37	5.90
Biological Agent 7	6	4.95	76.98

4.2.3 Summary

911 alerts during the evaluation period were concentrated in areas with greater population densities. In addition, alert areas were relatively compact, with 80% of alerts encompassing an area less than four square miles. Analysis of the 911 alerts in the simulation study demonstrated that the average area was comparable to the empirical data for the toxic chemicals and biological agents (~3 – 8 square miles), though the alert area for three of the biological agents was orders of magnitude larger. The simulation data supports the hypothesis that case clustering will be apparent in alerts that occur during contamination incidents, and possibly more so in scenarios involving a chemical contaminant that causes rapid symptom onset.

4.3 Design Objective: Contaminant Coverage

The 911 surveillance tool monitors 911 calls that could signal a public health incident, including water contamination. For 911 call data, contaminant coverage is dependent on the health-seeking behaviors following symptom presentation, as discussed in Section 3.3. In order to evaluate how well the 911 surveillance tool met this design objective, contamination scenario coverage was evaluated. The following subsection defines the metric, describes how it was evaluated, and presents the results.

4.3.1 Contamination Scenario Coverage

Definition: Contamination scenario coverage is defined as the ratio of contamination incidents that are detected to those that are theoretically detectable based on the design of the 911 surveillance tool. Detectable contamination scenarios include those in which the contaminant injection occurred within the city limits and those which originated at distribution system attack nodes rather than facility attack nodes.

Analysis Methodology: Since no water contamination incidents occurred during the evaluation period, simulation study results were utilized to quantify this metric. The ratio of scenarios actually detected to those that were theoretically detectable (based on the assumptions regarding health-seeking behavior that were parameterized in the model) was calculated for each contaminant. Additionally, the average and median number of cases at the time of detection was calculated for each contaminant. Certain contamination scenarios that were not theoretically detectable were screened out of the analysis including those that originated at facility attack nodes (which were detected by the ESM component), those which involved the nuisance chemicals, and scenarios which originated outside of the city limits.

Results: The 911 surveillance tool detected 80% (n=561) of the contamination scenarios that were theoretically detectable (n=702). **Table 4-4** below shows the detection statistics for the 911 surveillance tool for each contaminant.

Table 4-4. 911 Detection Statistics

Contaminant	Scenarios Detected	Scenarios Not Detected	Percent Detected	Average # Cases at Time of Detection	Median # Cases at Time of Detection
Toxic Chemical 1	41	7	85%	430	354
Toxic Chemical 2	44	0	100%	268	148
Toxic Chemical 3	44	0	100%	304	137
Toxic Chemical 4	46	2	96%	1,074	550
Toxic Chemical 5	44	0	100%	645	335
Toxic Chemical 6	47	3	94%	3,923	2,280
Toxic Chemical 7	45	1	98%	947	582
Toxic Chemical 8	48	3	94%	2,417	1,297
Biological Agent 1	43	0	100%	366	230
Biological Agent 2	15	25	38%	158	150
Biological Agent 3	51	0	100%	103,304	73,503
Biological Agent 4	48	3	94%	5,143	4,934
Biological Agent 5	36	16	69%	17,677	14,949
Biological Agent 6	3	40	7%	331	353
Biological Agent 7	6	41	13%	476	505

The 911 surveillance tool generally had a high detection rate across almost all contaminants, with 100% detection for five of the fifteen contaminants and another five above 90%. Chemical contaminants have a high detection rate due to the likelihood of people taking action to receive medical treatment when symptoms progress rapidly and are quite unusual or life-threatening following ingestion of contaminated water.

The lowest detection rates are associated with biological agents which generally show a slower symptom onset and do not always progress to severe symptom levels. The slower symptom onset and less urgent health-seeking behavior provide less opportunity for the 911 surveillance tool to detect a contamination incident. Furthermore, two of the biological agents (Biological Agent 6 and Biological Agent 7) were modeled as causing illnesses from inhalation exposure rather than ingestion. Due to the design of these scenarios, wherein inhalation exposure could only occur once per day in the morning during a shower, there were fewer instances of illness, fewer calls to 911 for medical assistance, and therefore a lower rate of detection by the 911 surveillance tool.

As shown in the Table 4-4, Biological Agent 3 had a 100% detection rate and also the greatest number of cases at the time of detection. The high number of cases is due to both the extremely low dose required for symptom onset due to its potent toxicity and a substantial delay prior to symptom onset. Therefore, in scenarios that involved Biological Agent 3, the contaminant continued to spread before the first case became symptomatic. It is likely that nearly all individuals who are exposed to the contaminant will exceed the low symptom threshold.

4.3.2 Summary

The contamination scenario coverage results from the simulation study demonstrate that the 911 surveillance tool is able to detect chemical and biological agents with two-thirds of the contaminants detected in greater than 90% of scenarios.

4.4 Design Objective: Alert Occurrence

Alert occurrence addresses how well the 911 surveillance tool performs by describing the volume of alerts that occurred and the number of these alerts that were valid (i.e., public health incident, including water contamination). It should be noted that no valid alerts occurred during the evaluation period of the 911 surveillance tool. Analyses conducted and presented for the contamination scenario coverage metric reflect the occurrence of valid alerts in the simulation study (Section 4.3.1). Thus, to characterize this design objective, invalid alerts were evaluated. The following subsection defines the metric, describes how it was evaluated and presents the results.

4.4.1 Invalid Alerts

Definition: Invalid alerts include any alert generated by the 911 surveillance tool that is determined not related to a public health incident, including water contamination, following the alert investigation.

Analysis Methodology: The total number of invalid alerts was calculated for each reporting period, and is equal to the total number of alerts minus the number of valid alerts. The number of calls per invalid alert was calculated and is presented in a histogram.

Results: During the evaluation period, a total of 86 alerts were generated by the 911 surveillance tools, which were all determined to be the result of background variability. No apparent temporal trend of invalid alert frequency was observed (**Figure 4-4**).

During the majority of the evaluation period, any alerts that met the default alerting parameters of the SaTScan ™ algorithm constituted a 911 alert for the Cincinnati CWS. As a result of input received from the system users stating that the alerting frequency was too high, new alerting criteria were implemented on May 12, 2009. The impact of this modification is evident in that only one alert occurred following the change. For the purposes of comparison, if the new alerting threshold was applied to the evaluation data from before this date, only seven 911 alerts (8%) would have occurred, as illustrated below by the red bars in Figure 4-4.

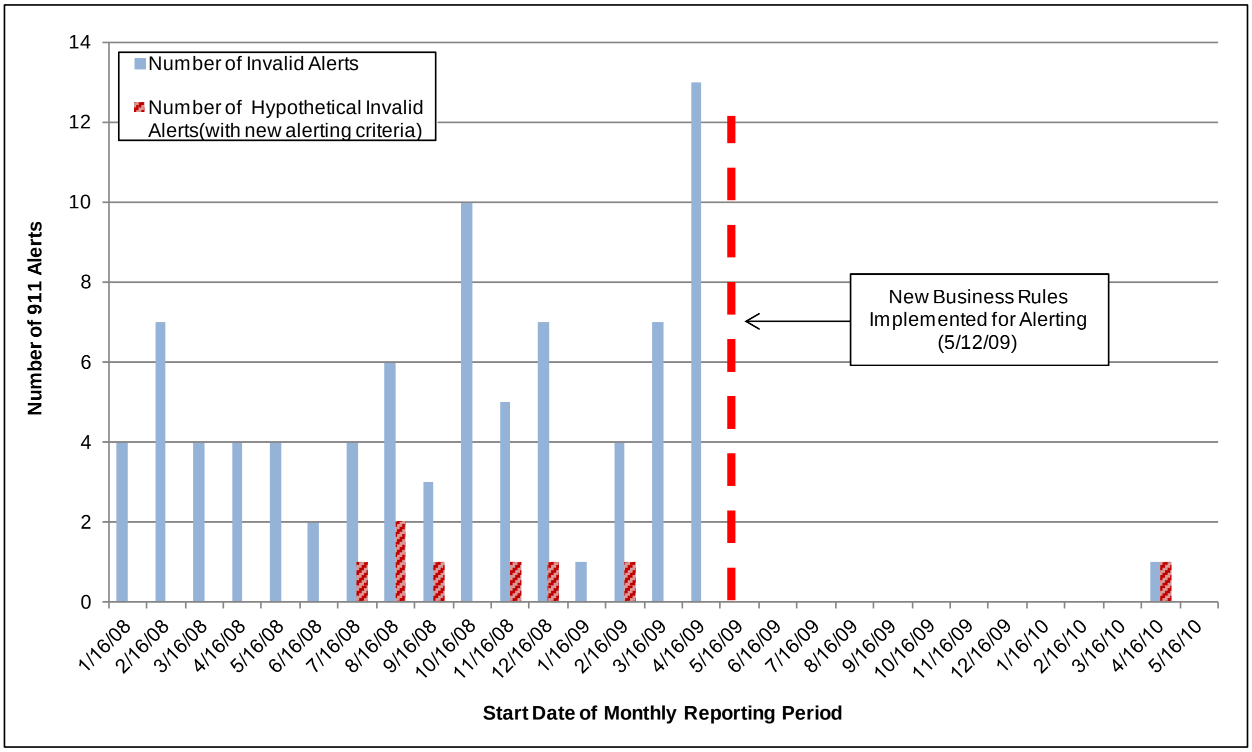

Figure 4-4. 911 Invalid Alerts per Reporting Period (n=86) and with Additional Alerting Criteria (n=7)

The histogram presented in **Figure 4-5** demonstrates the range in number of calls for all invalid alerts that occurred during the evaluation period. The majority of alerts contained between five and ten 911 calls. Over 90% of alerts contained fifteen or fewer calls, all of which were determined to be the result of background variability.

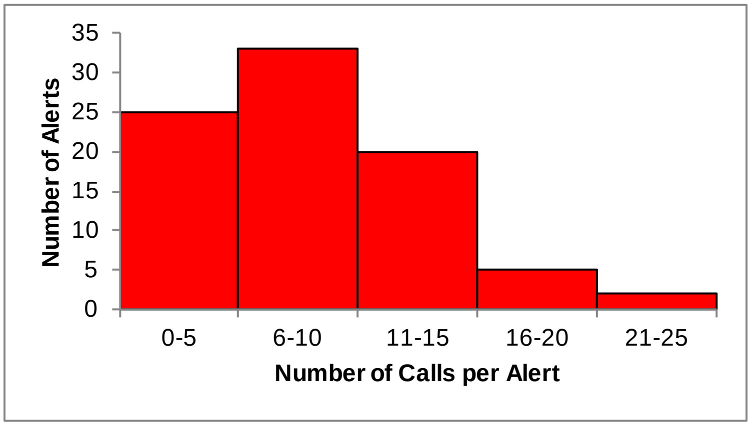

Figure 4-5. Histogram of Number of Calls per Alert (n=86)

4.4.2 Summary

Initially, the only limiting condition on alert notifications was a statistically derived threshold. This resulted in detection of many statistically significant anomalies that were of little concern to public health officials because there were so few cases in most alerts. In May 2009, an additional condition was imposed on the alert notifications limiting alerts to anomalies with greater than sixteen filtered 911 calls, which reduced the annual frequency of alerts by 99% for the 911 surveillance tool.

4.5 Design Objective: Timeliness of Detection

Timeliness of detection is the time delay for the 911 surveillance tool to detect a potential public health incident, including water contamination. The timeline begins with initial transmission of 911 call data and concludes with completion of the alert investigation. Post-exposure factors that would affect the overall timeliness of detection, such as time to symptom onset and health-seeking behaviors, are discussed in Section 3.3. These time delays occur prior to the time for data transmission.

In order to evaluate how well the 911 surveillance tool met this design objective, the following four metrics were evaluated: time for data transmission, time for event detection, time for alert recognition and time to investigate alerts. The following subsections define each metric, describe how it was evaluated, and present the results.

4.5.1 Time for Data Transmission

Definition: Time for data transmission describes the time it takes for 911 records to be available for analysis. It includes the time to transmit and filter data, as recorded by 911 dispatcher personnel in the 911 Computer Aided Dispatch system, to the WS application server.

Analysis Methodology: Each 911 record contains timestamps that can be used to calculate the time between the initial 911 call and the time it is available for analysis on the WS application. The time for data transmission was calculated from empirical data on a monthly basis through creation of a Structured Query Language (SQL) script to run against all records stored on the WS application database. Statistical analysis, including the average and range of time for data to transmit to the WS application server, is presented per month.

Results: The average time for data transmission of 911 call records from time of call to upload to the WS application server ranged from 45 to 1,706 minutes during the evaluation period. As depicted in **Figure 4-6**, the data transmission time was typically between 45 and 100 minutes during most reporting periods. Occasional long delays in data transmission were caused by network outages which caused downtime of the interface that transmits call records from the CFD server to the WS application server. Until this interface is manually restarted, data transmission cannot occur. Specifically, one notably long period of interface downtime (~9 days) occurred between November 25, 2008 and December 4, 2008, which was the result of network instability. During this time period, transmission of all records from the CFD server to the WS application server was impeded. This event noticeably increased the average transmission time for the November 2008 reporting period.

During two reporting periods later in the evaluation timeline, longer data transmission times also occurred. In the February 2010 reporting period, the 911 interface experienced a seven day outage which delayed data transmission. Later, in the April 2009 reporting period, the utility’s 911 web-services subscription expired which caused a five day delay in data transmissions between May 1, 2010, and May 6, 2010.

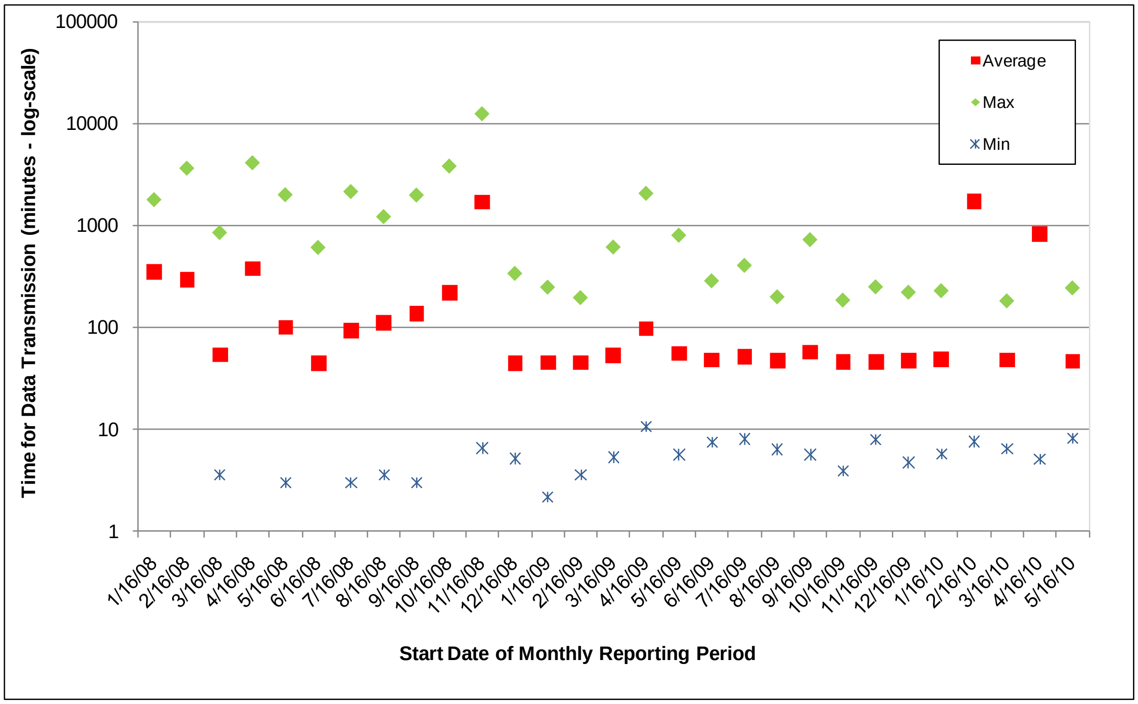

Figure 4-6. 911 Surveillance Tool Average Time for Data Transmission

This metric illustrates that there is some time delay between the time that 911 calls are placed and uploaded by call operators into source systems, and the time it takes for the data to be transferred to the WS application server for filtering. Functionally, this time delay illustrates that 911 alerts may be generated about an hour after call volumes had increased if individuals were exposed to contaminated water.

4.5.2 Time for Event Detection

Definition: Time for event detection describes the time required for the 911 surveillance tool to generate an alert using the SaTScan™ algorithm after data has been transmitted to the WS application server. This is the time for analysis of data and generation of a result by the SaTScan™ algorithm applied to 911 data.

Analysis Methodology: Time for event detection is calculated as the difference between job start and job finish. Statistical analysis, including average and range of time for event detection, is presented per month.

Results: As depicted in **Figure 4-7**, the average time for event detection for the 911 surveillance tool ranged from 0 to 1.14 minutes. With the exception of the initial reporting period, the time for event detection was consistently less than 0.6 minutes. This metric illustrates that once 911 call data is filtered and available for analysis, the SaTScan™ algorithm functions with notable efficiency to process data and generate alert notifications.

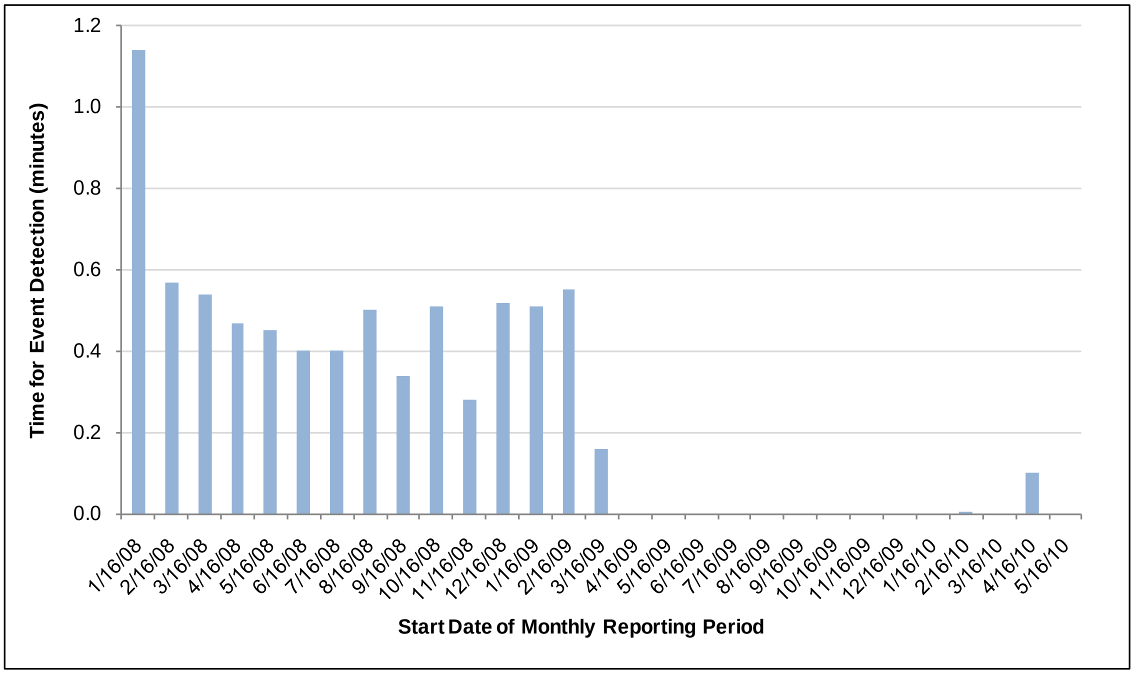

Figure 4-7. 911 Surveillance Tool Average Time for Event Detection

It should be noted that the scale at which event detection process duration is captured (minutes) is affected by the Windows operating system and its native tools. While the actual mean duration is probably in the range of 40 to 45 seconds (based on investigating details within the SaTScan™ log files), the high-level utilities provided by Windows used to capture start/stop times of the event detection cycle do not generate time values at the resolution of seconds. As a result, duration appears to be zero minutes when approximately 0.75 minutes is likely a more accurate value.

4.5.3 Time for Alert Recognition

Definition: Time for alert recognition quantifies the time it takes public health personnel (i.e., investigators) to recognize the email alert and begin the alert investigation, as determined from empirical data. For the 911 surveillance tool, this portion of the timeline begins when an alert is generated by the SaTScan™ algorithm and notification is sent via email to public health personnel, and ends when public health personnel recognize receipt of the alert.

Analysis Methodology: Statistical analysis (average, median and range) of time for alert notification was performed for each month, as well as the evaluation period as a whole.

Results: **Figure 4-8** demonstrates the average time to recognize 911 alerts per month. In many cases, the average time was affected by the time of day that alerts were produced. When alerts occurred after-hours (weekdays 5:00 pm to 9:00 am the next morning) or on the weekend, a 10- to 40-hour time lag occurred before the health partners were able to recognize and investigate the alerts. One outlier was excluded from the October 2008 reporting period, as a significant time delay occurred prior to recognition of one alert due to the public health partners being out of the office.

Following implementation of the additional alerting criteria in May 2009, only one 911 alert occurred (April 2010). Time for recognition is not reported for this alert as a formal investigation was not completed. *Note:* Asterisks in Figure 4-8 indicate that no data was available either due to an alert investigation not being conducted, or that no alerts occurred during that reporting period. See Figure 4-4 for additional data on alert occurrence.

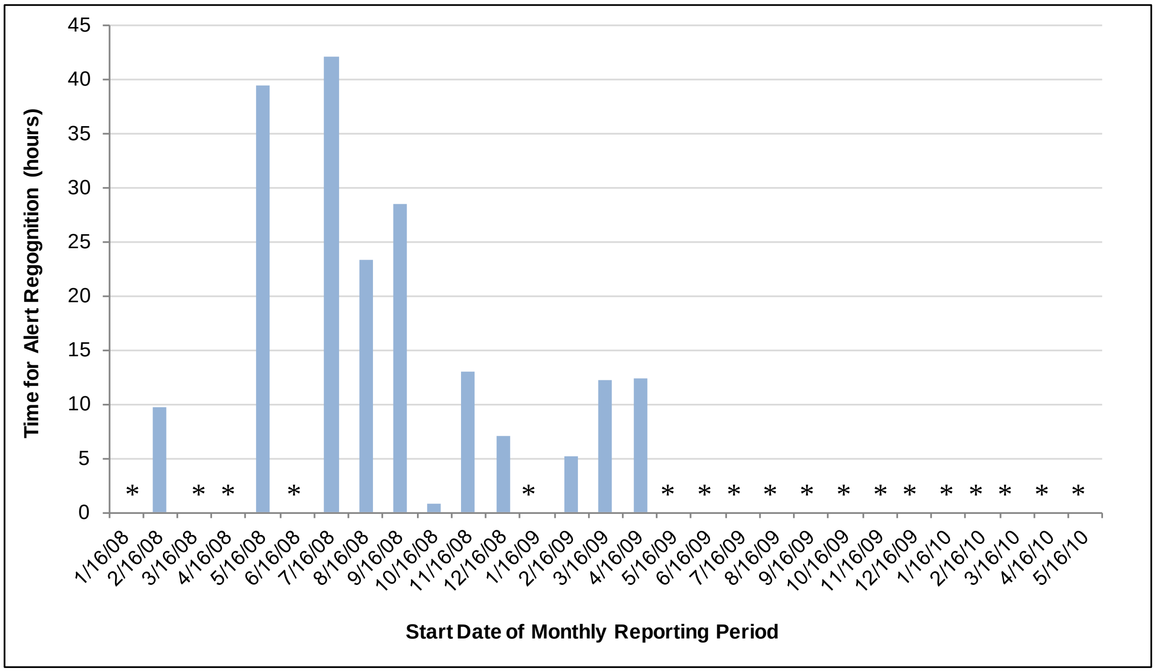

Figure 4-8. Average Time to Recognize 911 Alerts

During the first six months of the evaluation period, public health personnel were not expected to complete alert investigations in real-time; therefore, some months do not display an average even though alerts occurred, as alert investigation information was not available. In some instances, investigations could have been delayed due to unavailability of the Public Health User Interface as indicated by comments on investigations completed during the same timeframe.

Statistics for time to recognize alerts over the entire evaluation period are shown in **Table 4-5**. There is a notably broad range in times to recognize alerts, from 4 minutes (0.06 hours) to 157.48 hours. As previously noted, long delays were often due to alerts issued after-hours or inaccessibility of the Public Health User Interface.

Table 4-5. 911 Alert Recognition Time (hours)

Parameter	Time (hours)
Average	21.08
Median	9.83
Minimum	0.06
Maximum	157.48

4.5.4 Time to Investigate Alerts

Definition: Time to investigate alerts includes the portion of the incident timeline that begins with the recognition of a 911 alert, and ends with a determination regarding whether or not contamination is possible. The time to investigate alerts, as captured in the investigation checklists, is based on the nature of the alert details and the investigation procedures that must be implemented before concluding that the alert is not indicative of a possible contamination incident. For PHS drills and the simulation study, this data represents the timeline from the contaminant injection to the time that contamination is deemed possible when the 911 alert investigation is concluded. As noted in Section 3.3, no time delay for alert recognition was parameterized in the CWS model as it was assumed that alert investigations occurred immediately upon receipt of alerts based on the nature of the underlying case data (i.e., similar symptom categories and case clustering).

Analysis Methodology: Analysis of empirical data (i.e., invalid alerts) was performed to calculate the average, median, and range of times as listed in investigation checklists. Information on investigation time from PHS drills was used to describe time to investigate simulated 911 alerts that were ultimately determined to be possible contamination incidents.

Timeline data gathered from investigation of invalid alerts and during drills and exercises was used to parameterize the investigation time for PHS alerts in the simulation study. Simulation study timeline data (which, as noted above, started at the time of contaminant injection) was evaluated to illustrate the timeliness of detection overall for the 911 surveillance tool and for scenarios initiated at periods of high or low demand. Percentile values were calculated to examine the distribution of data and were examined in a box-and-whisker plot. Average detection times were calculated for individual contaminants, as well as for scenarios initiated at periods of high or low demand for individual contaminants.

Results: The results presented below are arranged in order of empirical data, drill data and simulation study data.

Empirical Data

During the evaluation period, time to investigate alerts ranged from 3 to 60 minutes. **Figure 4-9** is a graphical representation of the average time for 911 alert investigations per month. The average investigation time for 911 invalid alerts decreased over the course of the evaluation period from approximately 30 to 10 minutes per alert it represents an overall improvement of time necessary to investigate alerts that are not due to public health incidents, including water contamination. This decreased time is likely because public health partners investigating 911 alerts became more familiar with investigation procedures over time, and therefore required less time to identify invalid alerts. It should be noted that system users were not required to investigate alerts until the beginning of the June 2008 reporting period as the system was still in a development and testing phase between January and June 2008.

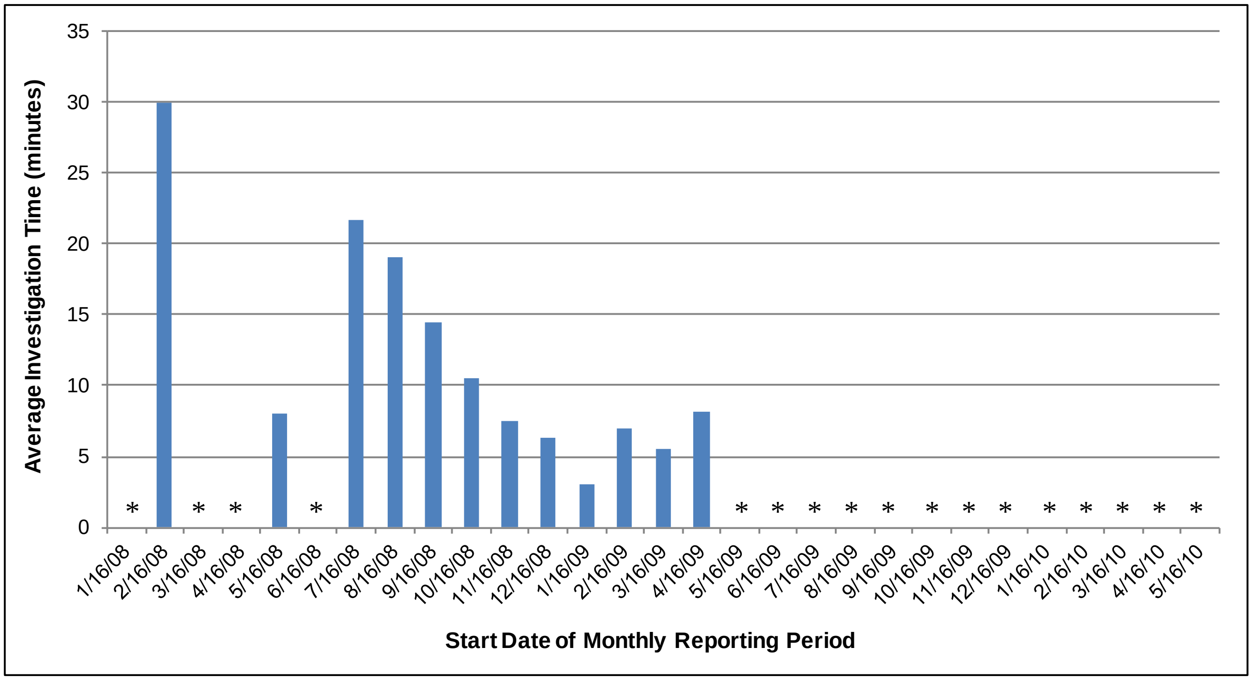

Figure 4-9. 911 Average Invalid Alert Investigation Time (n=39, empirical data)

Following the enhancement of the additional alerting criteria which adjusted the alerting threshold, only one 911 alert was produced (April 2010). Because an investigation checklist was not completed by the public health partners for this alert, the investigation time was not determined.

System users can expect to investigate approximately one to two 911 alerts per year and expend 5 to 10 minutes per investigation. In addition, it should be noted that the May 2009 component enhancements facilitate more efficient investigations, as alert data no longer needs to be manually translated from latitude/longitude to address format, and because more detailed patient data is included in the 911 alert notifications (i.e., incident code, age, gender of patient).

Statistics for time for alert investigation over the entire evaluation period are shown in **Table 4-6**.

Table 4-6. 911 Invalid Alert Investigation Time (minutes, empirical data)

Parameter	Time (minutes)
Average	12.33
Median	10
Minimum	3
Maximum	60

Drill Data

A simulated 911 alert was used to practice alert investigation procedures during PHS Drill 2; this investigation involved the examination of 911 case data of individuals who had ingested water contaminated with a toxic chemical. This exercise provided an estimate of the time for a Possible contamination determination was reached after approximately 1.5 hours. While this provided a reasonable estimate of how long it would take to investigate valid 911 alerts, the actual investigation time during a "live" incident may vary depending on other factors (e.g., personnel availability). The timeline for PHS Drill 2 is presented below in **Figure 4-10**, which displays some of the key points of the investigation that was undertaken in PHS Drill 2. The simulated 911 alert was injected 30 minutes after the start of the drill, which was initiated by a simulated DPIC alert.

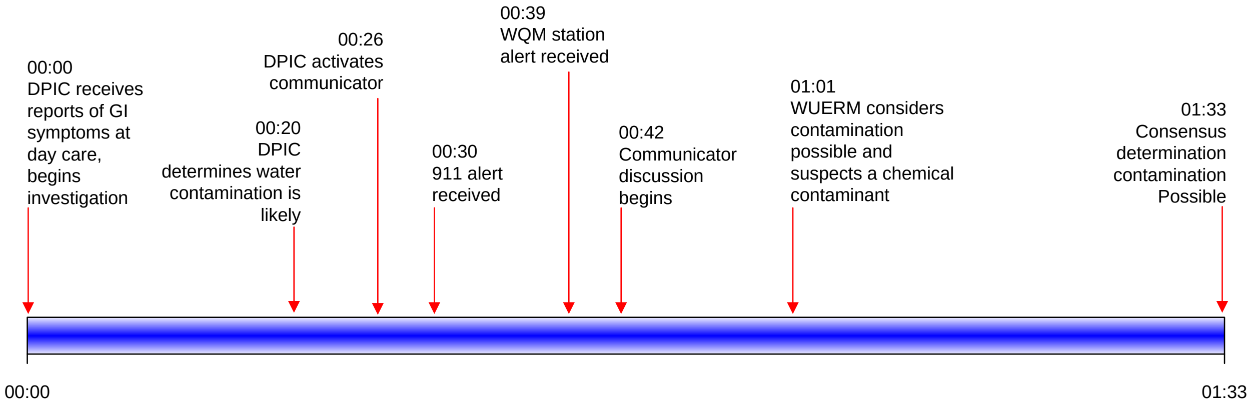

Figure 4-10. PHS Drill 2 Timeline (911 Alert)

Simulation Study Data

Figure 4-11 demonstrates the overall timeliness of detection statistics for the 911 surveillance tool and for scenarios initiated at periods of low and high demand, using percentile values to illustrate the distribution of data in a box-and-whisker plot. Scenarios initiated at high demand times were detected sooner than scenarios detected at low demand times due to the design of the CWS model. A seven-hour time delay occurred between the scenarios initiated at low demand (12:00 am) and the first exposure event (7:00 am), which resulted in a detection time lag, unlike the scenarios initiated at high demand (9:00 am), which could have resulted in exposure soon thereafter at the 9:30 am or 12:00 pm exposure events.

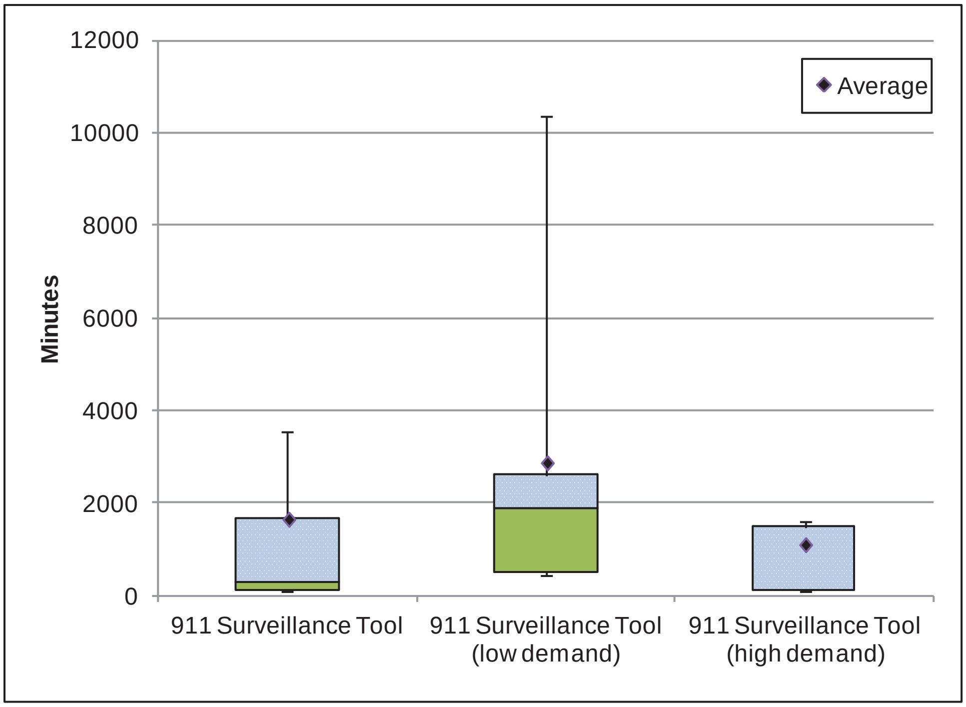

Figure 4-11. 911 Surveillance Tool Timeliness of Detection (simulation study data)

There were a total of 561 scenarios detected by the 911 surveillance tool with an average detection time of 1,644 minutes (approximately one day), as shown in **Table 4-7**. As noted above, scenarios initiated at high demand were detected sooner, with an average detection of time 1,095 minutes, whereas scenarios initiated at low demand had an average detection time of 2,865 minutes.

Table 4-7. 911 Surveillance Tool Timeliness of Detection (minutes, simulation study data)

Scenarios	Count	Average	Median
Total	561	1,644	271
Low Demand	174	2,865	1,891
High Demand	387	1,095	91

Average timeliness of detection for the 911 surveillance tool by contaminant is presented below in **Figure 4-12**, where contaminants are arranged in increasing order of timeliness of detection. For each contaminant, the overall average is presented as well as the average value for high and low demand scenarios. This figure demonstrates that scenarios involving chemical contaminants were detected rapidly (within hours) whereas a greater time delay occurred before scenarios involving biological agents were detected (days to weeks). This difference is due to the increased length of symptom onset for the biological agents. Furthermore, unlike the toxic chemicals, where exposed individuals always proceeded from mild to moderate and finally severe symptoms, a certain percentage of individuals exposed to the biological agents did not proceed beyond mild or moderate symptom levels, and therefore pursued less urgent health-seeking behavior. Note that the differences in timeliness of detection for high or low demand scenarios narrows as the overall timeline from contaminant injection to detection increases; for biological agent scenarios, there is little to no difference in timeliness of detection between high and low demand scenarios.

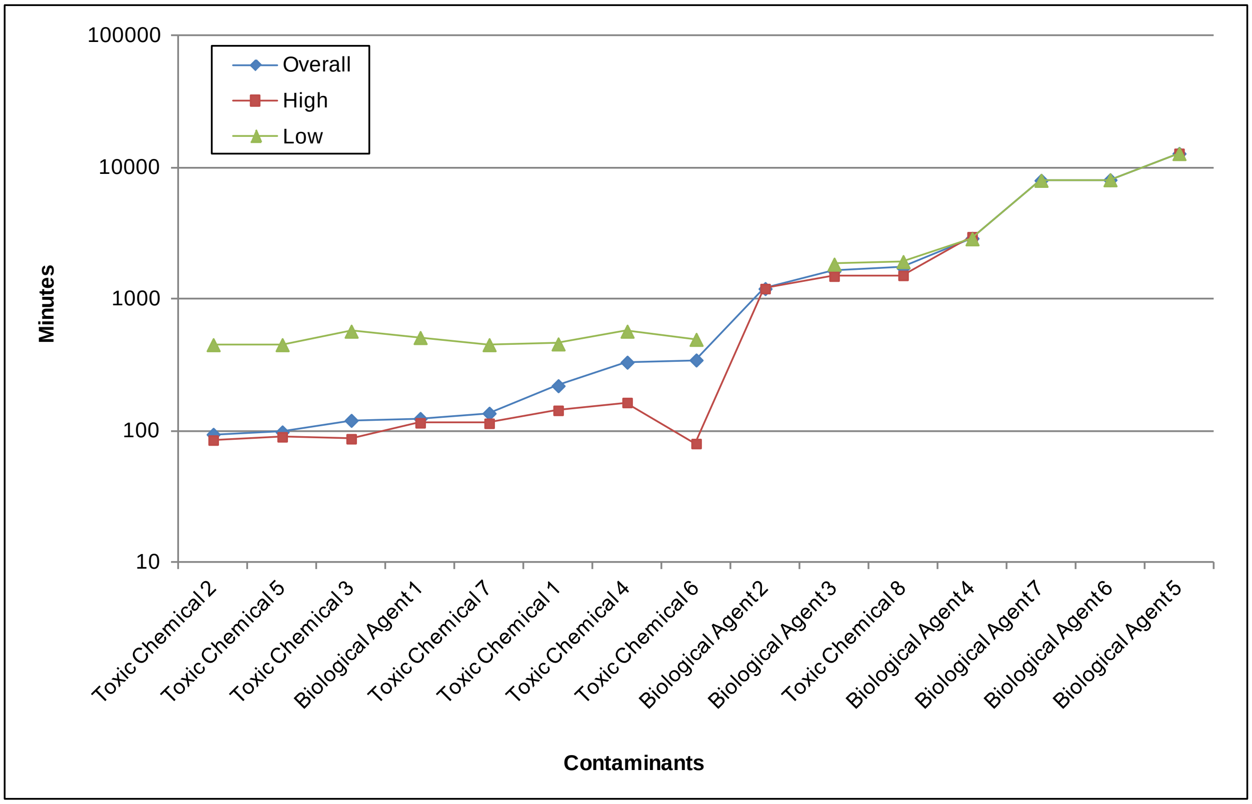

Figure 4-12. 911 Surveillance Tool Timeliness of Detection (simulation study data)

4.5.5 Summary

Timeliness of the 911 surveillance tool was affected primarily by time for alert recognition by public health personnel. As mentioned in Section 4.5.1, 911 call data is typically available one hour after entry into the Priority Dispatch System™. Time for alert recognition varied significantly, and was affected by the time when 911 alerts were sent (e.g., recognition was substantially delayed for alerts generated after business hours or over weekends). In contrast, time for alert generation was extremely short, with SaTScan™ consistently generating results in less than one minute.

Public health personnel became more efficient in 911 alert investigations following the initial implementation period; by the end of the evaluation period, invalid alert investigations were usually completed within 10 minutes, although this investigation time may be longer for valid alerts based on performance observed during PHS drills. Participants in the lessons learned workshop indicated that the speed of information (alerts containing location data) from SaTScan™ should be valuable for detecting contaminants with rapid symptom onset, especially compared to existing capabilities prior to the Cincinnati CWS.

Simulation study data analysis showed that for most chemical contamination scenarios, 911 call counts became high enough to meet or exceed the alerting criteria within only a few hours following contaminant injection. In contrast, detection of the biological agents occurred within a day or in some cases a week or more after contaminant injection.

4.6 Design Objective: Operational Reliability

Analysis of the operational reliability of the 911 surveillance tool addresses the physical operation of the surveillance tool and quantifies the percent of time that the 911 surveillance tool was working as designed. In order to evaluate how well the 911 surveillance tool met this design objective, the availability metric was evaluated. The following subsection defines the metric, describes how it was evaluated, and presents the results

4.6.1 Availability

Definition: Availability is the amount of time the 911 surveillance tool is functional and accessible. For the 911 surveillance tool to generate available data, 911 data had to be successfully transmitted from CFD's Computer Aided Dispatch server to the WS application server, filtered, analyzed via the SaTScan™ event detection tool and any alerts be displayed on the Public Health User's Interface.

Analysis Methodology: Overall downtime hours of the 911 surveillance tool per reporting period, due to downtime of alert notifications, data collection, or event detection was calculated. The measurement of availability is related to downtime hours; total downtime was subtracted from possible data hours in each reporting period to calculate percent availability.

Results: Most downtime events for the 911 surveillance tool were attributed to the inhibition of 911 data collection due to periodic network instability (see blue bars in **Figure 4-13**), which prevented data transmission from the CFD server to the WS application server. As is apparent in the figure, the lengthiest period of data collection downtime occurred during the November 2008 reporting period, which was caused by network instability (208.8 hours of downtime of the Regional Computing Center) that prevented data collection. Some data collection downtime during the September 2008 reporting period was the result of power outages and network instability caused by a windstorm that resulted in loss of electricity to 90% of Cincinnati residents for up to four days. Data collection downtime also occurred during the March and April 2009 reporting periods due to occasional connection losses with the CFD source database – the cause of which is unknown. One final period of data collection downtime occurred in the February 2010 reporting period when the 911 interface experienced a seven day outage.

Two instances of event detection downtime occurred in the April 2008 and May 2008 reporting periods due to unavailability of the WS application server database. Alert notification and event detection downtime occurred during the April 2010 reporting period when the utility's 911 web-services subscription expired, causing a five day delay in data transmissions.

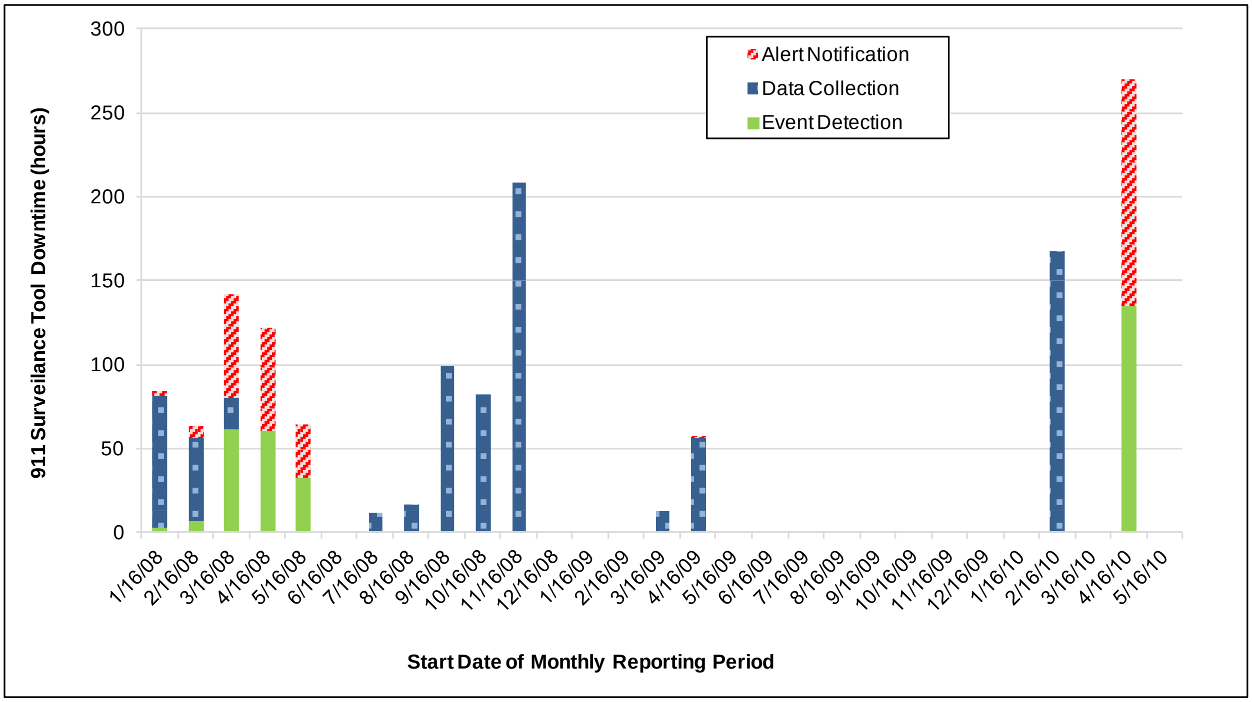

Figure 4-13. 911 Surveillance Tool Downtime (Events > 1 hour)

During the course of the evaluation period, availability generally exceeded 90% for the 911 surveillance tool, as shown in **Figure 4-14**. The lowest overall value for availability occurred during the April 2010 reporting period when the utility's 911 web-services subscription expired, causing a five day delay in data transmissions. When data transmission is inhibited, subsequent event detection processing on the most current data cannot occur. The average availability over the entire evaluation period was 93%.

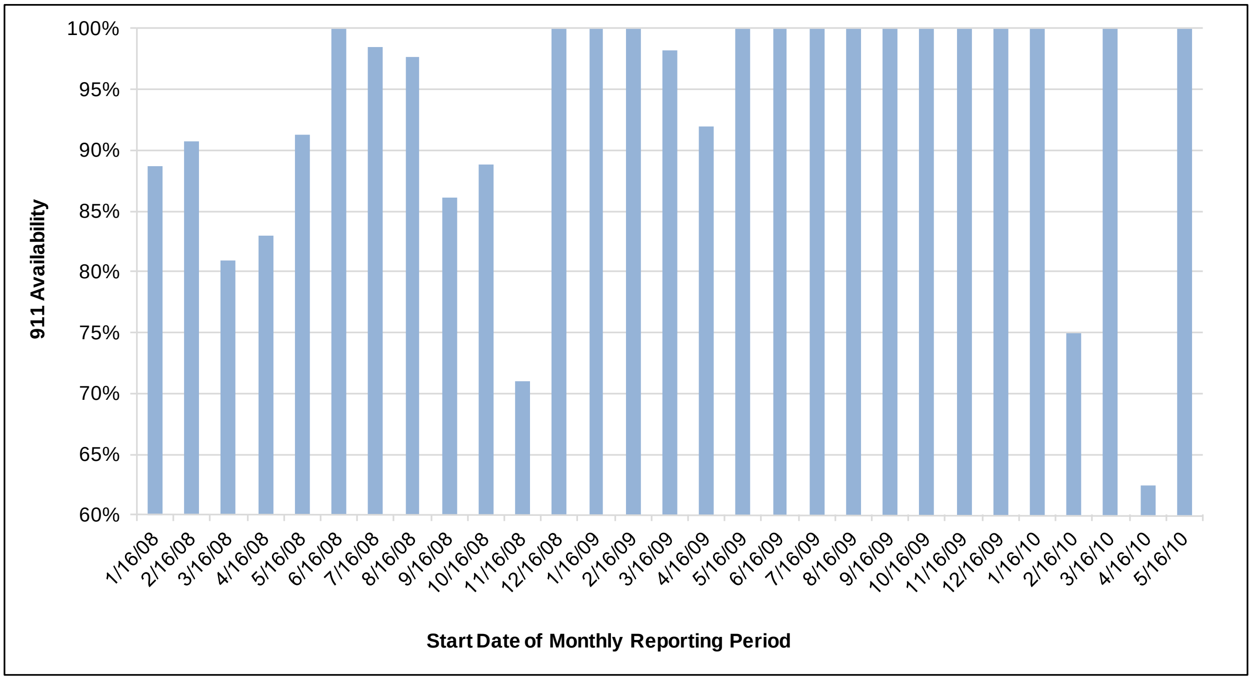

Figure 4-14. 911 Surveillance Tool Availability

4.6.2 Summary

Functionally, high availability percentages during the evaluation period demonstrate the overall stability and operational reliability of the 911 surveillance tool. Availability improved during the period, particularly after utility personnel established an automated monitoring tool which provides notification when the WS application server needs to be restarted if network instability causes it to shut down. Implementation of daily checks of the data collection system significantly reduced downtime by effectively identifying and correcting system issues, which previously could persist unnoticed for days.

Section 5.0: Performance of the EMS Surveillance Tool

The following section provides a description of the EMS surveillance tool followed by the results of the evaluation of this tool. This analysis includes an evaluation of metrics that characterize how the EMS surveillance tool achieves the design objectives described in Section 1.1. Specific metrics are described for each of the design objectives.

5.1 Description of the EMS Surveillance Tool

EMS/EARS Data

The EMS surveillance tool relies on the data-sharing partnership between CFD and GCWW. CFD EMTs and paramedics are considered data providers because they record patient information in an electronic format using EMS Tablets (i.e., portable tablet computers). Information recorded includes patient age, gender, chief medical complaint, incident zip code, medical observations made by the provider and medication and procedures provided. Upon returning to the firehouse, the EMS Tablet automatically uploads the patient data to a central CFD server via wireless routers installed as part of the Cincinnati CWS.

CFD provides access to a de-identified copy of patient data to the WS application server, located at GCWW, where one or more syndromes are assigned to the provider impression. EMS run records that indicate a possible incident based on their syndrome assignment are filtered into the system for further analysis. The filtered data are stored on the WS database server at GCWW, which will store three years of EMS run data.

EARS

EARS is a free software package provided by CDC that executes within either SAS or Microsoft Excel. EARS analyzes the EMS run data hourly using cumulative sum (CUSUM) algorithms to detect an increase in reporting activity. An increase above the EARS threshold generates an alert (EARS refers to any alert as a flag). The alert is based upon one of the three CUSUM algorithms. The C1 algorithm has the lowest sensitivity and is most useful for surveillance systems monitored daily. The C2 algorithm has a greater sensitivity than the C1 algorithm and can assist in identifying the length of an outbreak's rapid acceleration period. The C3 algorithm has the greatest sensitivity and can identify aberrations that gradually increase over short periods. The threshold for the C1 and C2 is three standard deviations above the baseline mean. The threshold for the C3 algorithm is two standard deviations above the mean and as compared to CUSUM for the previous three days (i.e., the three days prior an alert). **Table 5-1** explains the three algorithms; "t" refers to the current day of the analysis run.

Table 5-1. CUSUM Interpretation Table

Alert	Baseline (days)	What it Flags	Event Detection
C1	t-7 through t-1	First alert to an acute event	Start of outbreak
C2	t-9 through t-3	High consecutive values	Length of outbreak
C3	t-9 through t-3, with threshold based on 3-day average	Gradual increase over short time	Start of outbreak

Prior to deploying the EMS surveillance tool during the Cincinnati CWS, EMS run data was collected for a fourteen month period in 2006 and 2007 in order to validate and adjust syndrome mapping and to evaluate the various EARS flags and their frequencies. After consultation with the User's Group, C1 was determined to be the most appropriate algorithm for the CWS objectives. Furthermore, the User's Group concluded that C1 flags for specific zip codes would result in too many alerts; as a result, alert notifications are only sent for C1 flags over the entire geographic area (city of Cincinnati). Other C1 flags are displayed on the User's Interface for reference.

EARS Syndrome Categories

Based on review of the 23 EARS syndrome categories, the local public health partners identified eight categories that may indicate an incident. These categories are composed of a variety of patient chief complaints, which are diagnosed and assigned by the responding EMT. EMS run records with provider impressions categorized into one of these eight syndrome categories are filtered for analysis by the EMS surveillance tool. One of these syndromes (water) was a new custom category created as a part of the Cincinnati CWS, and includes chief complaints that would signal exposure to a variety of contaminants with rapid symptom onset. The syndromes are not mutually exclusive, allowing a complaint to be assigned to more than one syndrome. The provider impressions and syndrome categories are listed below in **Table 5-2**.

Table 5-2. EARS Syndrome Categories and Medical Complaints

Syndrome Category	Medical Complaint
Cardiac (cardiaccat)	Angina Pectoris, Cardiac Arrest, Chest Pain/Discomfort, Congestive Heart Failure, Dysrhythmia, Hypertension, Hypotension, Myocardial Infarction, Unconscious (unknown etiology)
Gastrointestinal (gicat)	Abdominal Pain (minor), Abdominal Pain (severe), Appendicitis, Dehydration, Diarrhea, Food Poisoning, Lower Gastrointestinal (GI) Bleeding, Nausea/Vomiting, Upper GI Bleeding
Neurological (neurons)	Altered Level of Consciousness, Cerebrovascular Accident/Stroke, Dizziness/Vertigo, Headache, Numbness/Tingling, Paralysis/Loss of Motion, Seizures/Convulsions (unknown), Syncope/Fainting, Transient Ischemic Attack
Poisoning (poison)	Abuse/Dependency, Alcohol Related, Drug Induced Emotional, Drug Overdose, Food Poisoning, Hematuria, Ingestion, Inhalation, Renal Failure
Psychological (psychcat)	Abuse/Dependency, Alcohol Related, Anxiety, Behavioral Disorder, Depression, Drug Induced Emotional, Drug Overdose, Psychiatric Disorder, Suicide Attempt (not DOA)
Unexplained	Blank, DOA, Other, Respiratory Arrest, Unconscious (unknown etiology)
Upper Respiratory (upperresp)	Airway Obstruction/Choking, Cold/Flu, Croup, Epiglottitis, Respiratory Distress, Respiratory Distress (acute), Respiratory Involvement, Smoke Inhalation
Water	Abdominal Pain (minor), Abdominal Pain (severe), Altered Level of Consciousness, Diarrhea, Dizziness/Vertigo, Ingestion, Nausea/Vomiting, Seizure/Convulsions (febrile), Seizures/Convulsions (unknown)

EARS analysis uses a three month rolling baseline of the filtered EMS run records and analyzes the data by syndrome and by syndrome stratified on the zip code level. The analysis process normally executes in fifteen minutes (Hutwanger L., 2003).

EMS Surveillance Tool Alerting Criteria

Based on the current alerting criteria for the EMS surveillance tool, an EMS alert will only be generated when the following EMS alert conditions are met. Condition number four (event count / affected zip count) was applied in May 2009 based on feedback from the User's Group.

1. If EARS sets C1 CUSUM flag for entire data set (Location = "_ALL_") for a given syndrome on a given day AND
2. If PHS has not already generated an alert for specified location and syndrome and day AND
3. If EARS sets C1 CUSUM flag within 48-hours of the event date (configuration based on event detection system summary output content) AND
4. If the ratio (Event count / Affected zip code count) is greater than 1.5 for a specified syndrome and day (this condition would be met when there is at least some spatial clustering of the EMS runs).

When the alerting criteria are met, an email notification alert is transmitted to the local public health partners and GCWW. Lower-level EMS alerts that are categorized as C1 alerts by the EARS tool but do not exceed the alerting criteria are displayed on the Public Health User Interface, but an email alert is not transmitted. If an EMS alert is generated, the local health partners investigate internally and work collaboratively with GCWW utility staff to conduct an investigation and determine whether the alert is related to an actual public health incident, including water contamination. Investigation procedures for PHS alerts are fully described in the Cincinnati Pilot Operational Strategy.

5.2 Design Objective: Spatial Coverage

The spatial coverage is the cumulative area of the distribution system covered by the EMS surveillance tool, which is limited to the city of Cincinnati due to jurisdictional limits (CFD only serves the city of Cincinnati). In order to evaluate how well the EMS surveillance tool met this design objective, the following metrics were evaluated: area and population coverage, and spatial extent of an alert. The following subsections define each metric, describe how it was evaluated, and present the results.

5.2.1 Area and Population Coverage

Definition: Area coverage describes how alerts are distributed geographically, while population coverage depicts the geographic area covered by the EMS surveillance tool.

Analysis Methodology: Zip code data from EMS alerts that occurred during the evaluation period was plotted on a map that depicts the geographic area covered by the EMS surveillance tool (i.e., city of Cincinnati). This involved calculating number of instances that zip codes in the city of Cincinnati were included in EMS alerts. Additionally, the total number of zip codes per EMS alert was calculated pre- and post-implementation of the additional alerting criteria described in Section 5.1.

Results: During the evaluation period, a total of 77 alerts were generated by the EMS surveillance tool. **Figure 5-1** illustrates the number of instances that zip codes in the city of Cincinnati were included in EMS alerts; this figure demonstrates that centrally-located zip codes in the downtown area of Cincinnati were included in alerts in more instances than non-central zip code locations. The underlying population density is not presented in this map as some zip codes included in the geographic area extended beyond the city limits but can be compared with the population map in Figure 2-1.

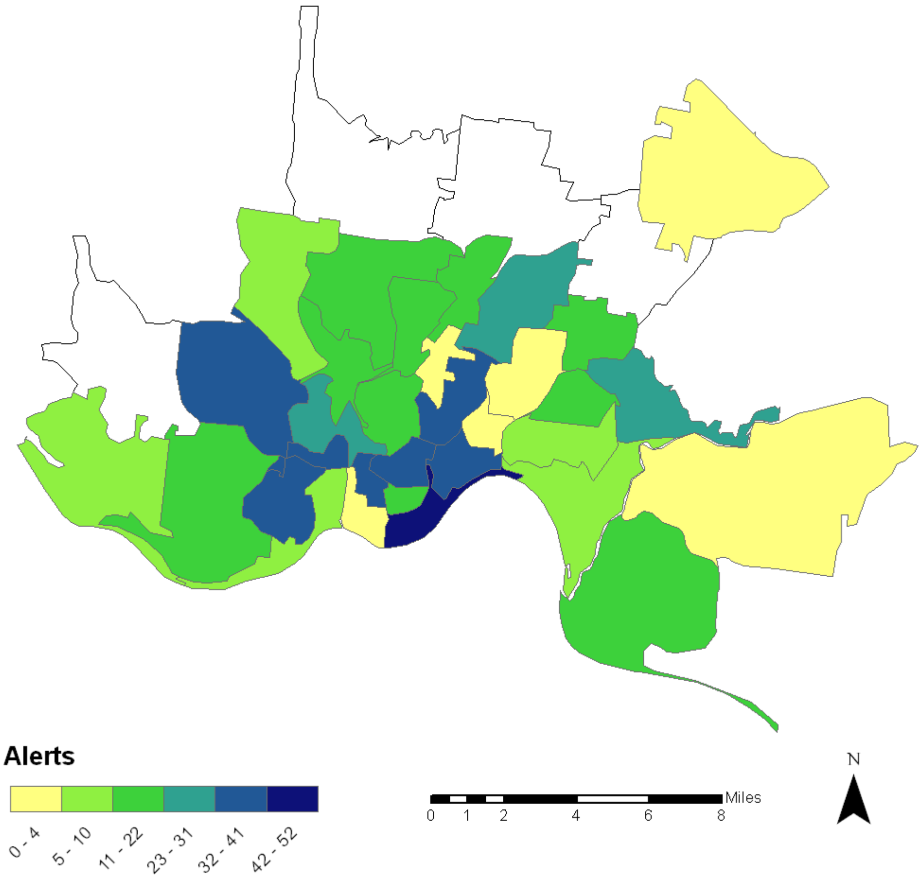

Figure 5-1. EMS Alerts per Zip Code (City of Cincinnati, n=77)

It should be noted the number of instances that a zip code was included in an alert is overestimated given that zip code data for each alert that occurred prior to the component modification on May 12, 2009 (see Table 2-4) was not captured in real-time and was analyzed retrospectively. During the retrospective analysis, EMS daily run data were filtered to estimate the number of runs specific to an alert event. On days where an EMS alert occurred, all EMS runs for that day and their associated zip codes were included in this analysis regardless of whether the EMS run occurred before or after the alert notification, as this information was unavailable. Therefore, EMS runs and zip codes were included in an alert analysis even though they did not contribute to the alert because they occurred after the alerting criteria were satisfied. Zip code data for EMS alerts that occurred after May 12, 2009 is accurate as the location data was captured in real-time.

In **Figure 5-2**, the histogram shows the number of zip codes involved in EMS alerts prior to the implementation of new alerting criteria (event count / affected zip codes > 1.5) on May 12, 2009. On average, a total of seven zip codes were involved in EMS alerts.

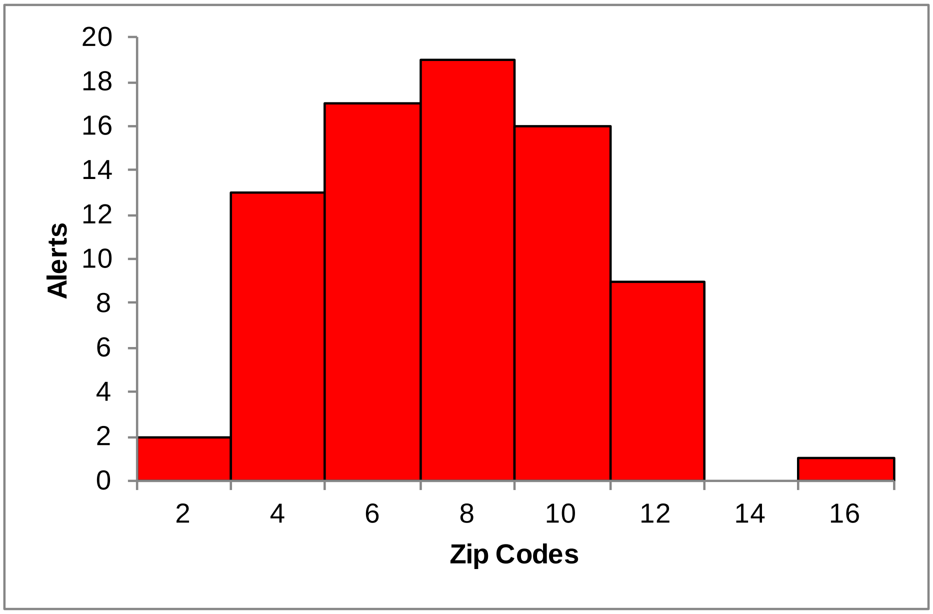

Figure 5-2. Number of Zip Codes in EMS Alerts Prior to Alerting Modification (n=62)

Figure 5-3 below captures the number of zip codes in EMS alerts post-implementation of the new alerting criteria (event count / affected zip codes> 1.5), where the average number of zip codes per alert was 7.6. Given that only fifteen EMS alerts have occurred since the implementation of the additional alerting logic, there is insufficient data to allow accurate comparison of the number of zip codes involved in alerts pre- and post-implementation of the new alerting criteria.

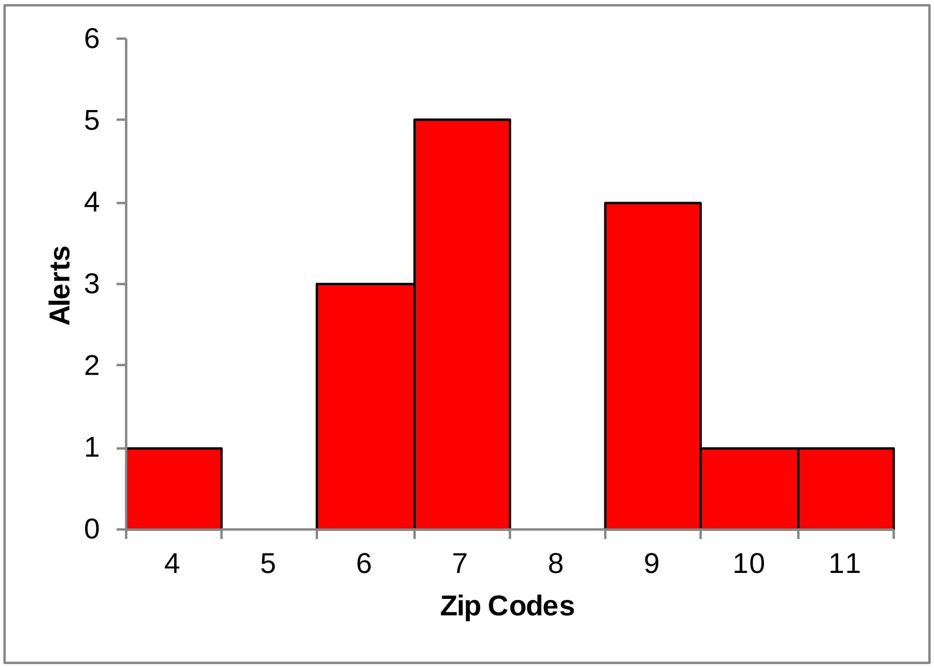

Figure 5-3. Number of Zip Codes in EMS Alerts Post Alerting Modifications (n=15)

5.2.2 Spatial Extent of an Alert

Definition: Spatial extent of an alert describes the area covered by an EMS alert. Essentially, it is the geographic area (size) of each alert as measured by the number of zip codes in each alert. For example, an alert containing ten different zip codes has a greater spatial extent than an alert containing three zip codes.

Analysis Methodology: A statistical analysis of the average, minimum and maximum number of EMS runs and number of zip codes in EMS alerts was conducted using empirical data and is presented in both tabular form and geographically.

Results: **Table 5-3** includes a statistical analysis of the EMS alert data for the evaluation period pre-implementation of the new alerting criteria in May 2009. The average ratio of event count (i.e., EMS runs) to affected zip code was 1.29 for 62 EMS alerts which occurred in this time period. This ratio is slightly less than the cut-off ratio of 1.5 imposed as a new alerting criterion in May 2009. Additionally, the average number of EMS runs involved in EMS alerts during this evaluation period was 9.06, with an average of seven zip codes involved in an alert.

Table 5-3. EMS Alert Statistics (January 16, 2008 – May 12, 2009, n=62)

	Number of Events (EMS Runs)	Number of Zip Codes	Event Count / Affected Zip Codes
Average	9.06	7	1.29
Minimum	3	2	1
Maximum	19	15	2.5

Table 5-4 presents EMS alert statistics for alerts that occurred post-implementation of the new alerting criteria in May 2009. The effect of the new alerting logic is apparent, as the number of EMS runs per alert increased by nearly 40% with little change in the average number of zip codes. The intended effect of the new alerting criterion is to require that a higher ratio of EMS runs occur per zip code in order to limit alerts to those with some degree of spatial clustering. For example, local public health partners would likely be more concerned about an alert signaling a high volume of runs in one zip code as opposed to an alert that demonstrated fewer EMS runs in a variety of zip codes. The change in alerting criteria reduced the average number of alerts per year from 47 to slightly fewer than 15.

Table 5-4. EMS Alert Statistics (May 13, 2009 – June 15, 2010, n=15)

	Number of Events (EMS Runs)	Number of Zip Codes	Event Count / Affected Zip Codes
Average	12.87	7.60	1.72
Minimum	9	4	1.55
Maximum	18	11	2.25

During the evaluation period, the 77 EMS alerts that occurred included a total of 858 EMS runs. As mentioned previously, a retrospective analysis was conducted to map the EMS runs that were relevant to each EMS alert. Therefore, the total number of runs may be a slight overestimate. For the purpose of demonstrating the spatial extent of alert data, the retrospective analysis of EMS runs is useful to illustrate the total sum of EMS runs per zip code for all EMS alerts (see **Figure 5-4**). Similar to the previous map demonstrating a one-year period of EMS data (**Figure 5-1**), this map illustrates that higher volumes of EMS runs are apparent in the central area of the city.

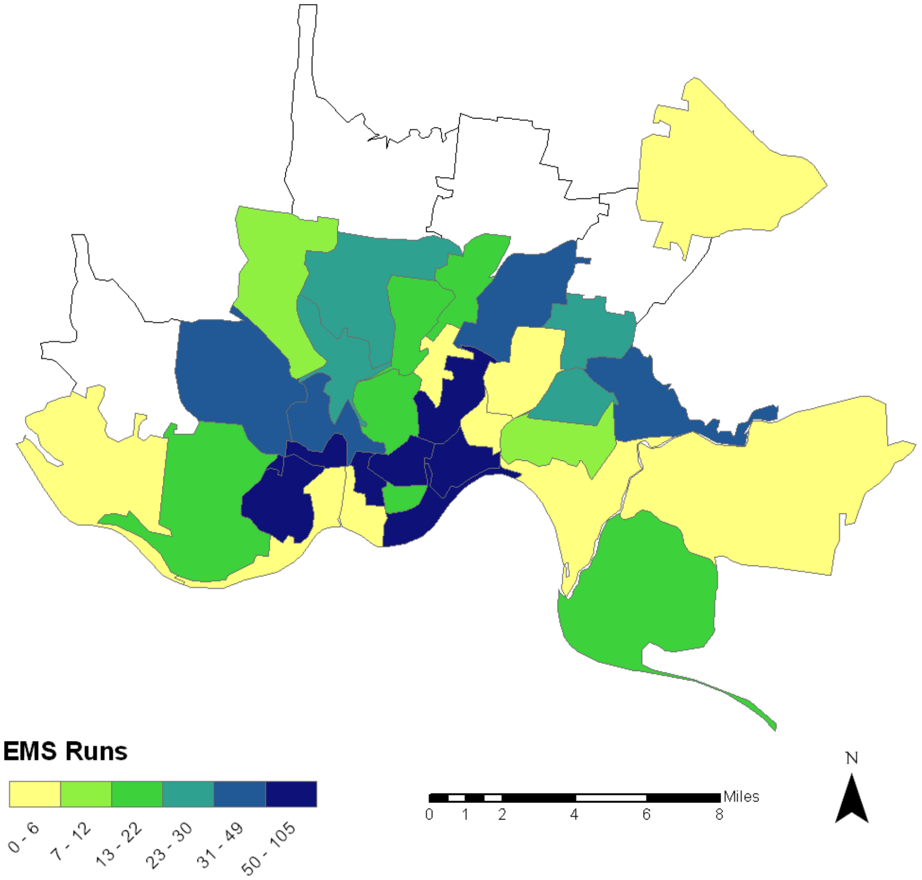

Figure 5-4. Total EMS Runs per Zip Code Associated with Alerts During Evaluation Period (City of Cincinnati, n=77)

Figure 5-5 is slightly different from the map presented in **Figure 5-4**; this figure depicts the number of instances that a zip code affected by an EMS alert contained multiple EMS runs (i.e., > 1 run). The intent of the map is to demonstrate zip codes where some spatial clustering occurred based on EMS runs in EMS alerts. For example, the centrally located zip code denoted by dark blue shading was involved in greater than sixteen alerts with multiple EMS runs. In comparison, the zip code on the southeast section of the city denoted by yellow shading was involved in fewer than three alerts that contained EMS multiple runs.

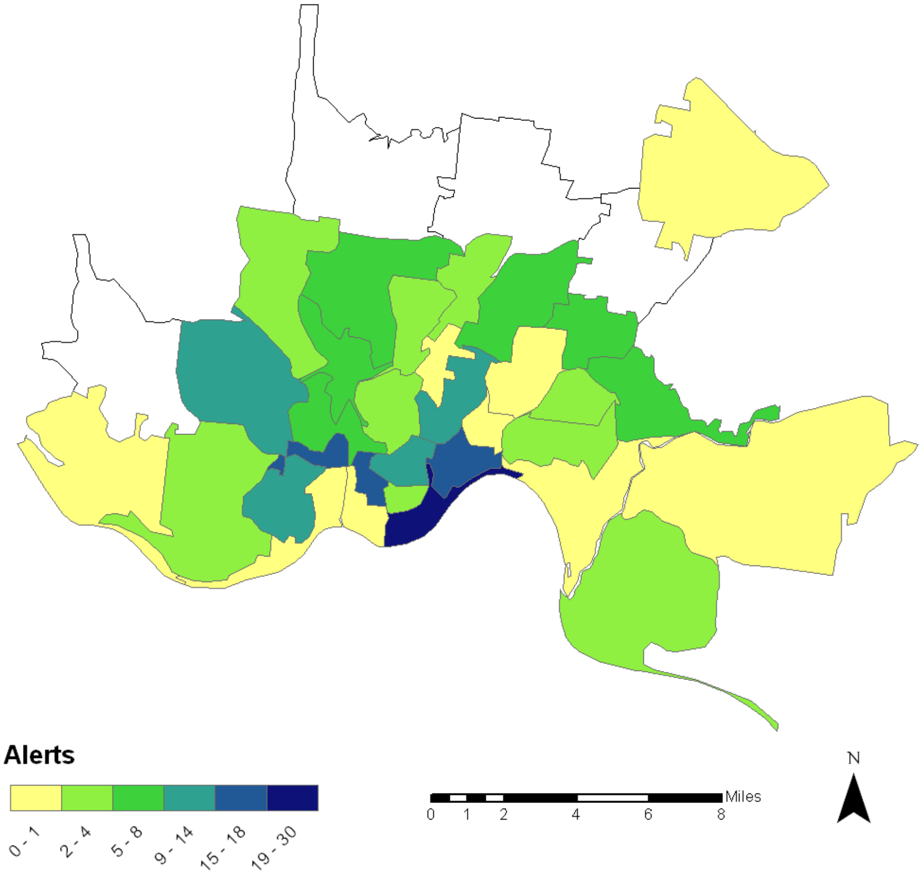

Figure 5-5. Total EMS Alerts per Zip Code with Multiple EMS Runs (City of Cincinnati, n=77)

5.2.3 Summary

Zip codes included in EMS alerts were spatially distributed across the city of Cincinnati, though it is apparent that zip codes in downtown areas of Cincinnati were involved in EMS alerts more frequently than alerts in non-central locations. In addition, higher ratios of EMS runs per zip code for alerts were also apparent in central downtown areas of the city. Both total EMS alerts as well as zip code clustering occurred in areas with higher population density.

5.3 Design Objective: Contaminant Coverage

The EMS surveillance tool monitors EMS runs that could signal a public health incident, including water contamination. For ESM run data, contaminant coverage is dependent on the health-seeking behaviors following symptom presentation, as discussed in Section 3.3. In order to evaluate how well the EMS surveillance tool met this design objective, contamination scenario coverage was evaluated. The following subsection defines the metric, describes how it was evaluated, and presents the results.

5.3.1 Contamination Scenario Coverage

Definition: Contamination scenario coverage is defined as the ratio of contamination incidents that are actually detected to those that are theoretically detectable based on the design of the EMS surveillance tool. Detectable contamination scenarios include those in which the contaminant injection occurred within the city limits, and those which originated at distribution system attack nodes rather than facility attack nodes.

Analysis Methodology: Since no water contamination incidents occurred during the evaluation period, simulation study results were utilized to quantify this metric. The ratio of scenarios actually detected to those that are theoretically detectable (based on the assumptions regarding health-seeking behavior that were parameterized in the model) was calculated for each contaminant. Additionally, the average and median number of cases at the time of detection was calculated for each contaminant. Certain contamination scenarios that were not theoretically detectable were screened out of the analysis including those that originated at facility attack nodes (which were detected by the ESM component), those which involved the nuisance chemicals, and scenarios which originated outside of the city limits.

Results: The EMS surveillance tool detected 69% (n=487) of the contamination scenarios that were theoretically detectable (n=702). **Table 5-5** below shows the detection statistics for the EMS surveillance tool for each contaminant.

Table 5-5. EMS Detection Statistics

Contaminant	Scenarios Detected	Scenarios Not Detected	Percent Detected	Average # Cases at Time of Detection	Median # Cases at Time of Detection
Toxic Chemical 1	44	4	92%	1,365	1,162
Toxic Chemical 2	25	19	57%	394	318
Toxic Chemical 3	25	19	57%	690	605
Toxic Chemical 4	38	10	79%	3,014	2,749
Toxic Chemical 5	39	5	89%	2,332	1,874
Toxic Chemical 6	45	5	90%	18,981	13,362
Toxic Chemical 7	46	0	100%	2,238	1,966
Toxic Chemical 8	39	12	76%	8,206	7,286
Biological Agent 1	33	10	77%	2,465	1,408
Biological Agent 2	21	19	53%	205	119
Biological Agent 3	51	0	100%	173,838	142,537
Biological Agent 4	32	19	63%	16,589	18,466
Biological Agent 5	45	7	87%	22,732	19,176
Biological Agent 6	4	39	9%	428	403
Biological Agent 7	0	47	0%	N/A	N/A

The EMS surveillance tool had a high detection rate above 75% for eight of the fifteen contaminants and another four above 50%. The lowest detection rates by EMS are associated with Biological Agent 6 (9%) and Biological Agent 7 (not detected). These two contaminants were modeled as producing illness through the inhalation exposure route, and thus there was only one exposure event in the morning (7:00 am showering event) that could have produced cases. Fewer exposed individuals resulted in a lower number of requests for EMS transport which contributed to lower detection rates.

While the EMS detection percentages were high for many contaminants, they were somewhat lower when compared to the 911 surveillance tool detection percentages. This is likely due to the fact that not all individuals who call 911 will receive EMS transport. In the model, some patients will decide on self-transport if an EMS unit has not arrived after a certain amount of time. This results in fewer EMS cases being logged and available for statistical analysis, whereas a case record is always recorded for all individuals who call 911. Secondly, for some of the toxic chemicals with a rapid symptom onset time, coupled with a short time delay prior to death following exposure, individuals might have died after calling 911 and prior to the time that an EMS unit arrived. This pattern likely resulted in fewer EMS cases being logged in comparison to 911, and therefore lower detection rates.

Biological Agent 3 was detected in 100% of theoretically detectable scenarios, and also had the greatest number of cases at the time of detection. Due to the extremely low dose required for symptom onset for this contaminant, it is likely that nearly all individuals exposed to the contaminant will experience symptoms. This contributes to a large number of cases overall, more calls to 911, and consequently a higher number of EMS runs. Furthermore, this contaminant has a substantial delay prior to symptom onset, which allows the contaminant to spread widely throughout the distribution system, producing many exposures before the first case becomes symptomatic.

5.3.2 Summary

The contamination scenario coverage results from the simulation study demonstrate that the EMS surveillance tool is able detect contamination scenarios involving a variety of different types of contaminants. In comparison to the 911 surveillance tool, detection rates were somewhat lower overall due to fewer EMS cases being logged and available for statistical analysis.

5.4 Design Objective: Alert Occurrence

Alert occurrence addresses how well the EMS surveillance tool performs by describing the frequency of invalid and valid alerts, and quantifying how accurate the EMS surveillance tool is at discriminating between valid alerts and normal variability in the underlying data. In order to evaluate how well the EMS surveillance tool met this design objective, the following metrics are evaluated: invalid alerts and valid alerts. The following subsections define each metric, describe how it was evaluated and present the results.

5.4.1 Invalid Alerts

Definition: Invalid alerts include any alert generated by the EMS surveillance tool that is determined as not related to a public health incident, including water contamination, following an alert investigation.

Analysis Methodology: The total number of invalid alerts is equal to the number of total alerts minus the number of valid alerts. These alerts were quantified per monthly reporting period as well as analyzed statistically by frequency, syndrome type, and probability of syndrome per zip code. In addition, geographic analysis of invalid alerts was performed to discern any possible spatial patterns.

Results: During the evaluation period, a total of 72 invalid alerts were generated by the EMS surveillance tool. Prior to implementation of a new alerting criterion in May 2009, an average of approximately four alerts were generated per month (median = 2) which were all determined to be the result of background variability. The impact of the new alerting criterion is apparent, as far fewer alerts have occurred post-May 2009 (**Figure 5-6**). No temporal trend in alert frequency was observed when the data was plotted in time-series format according to reporting period.

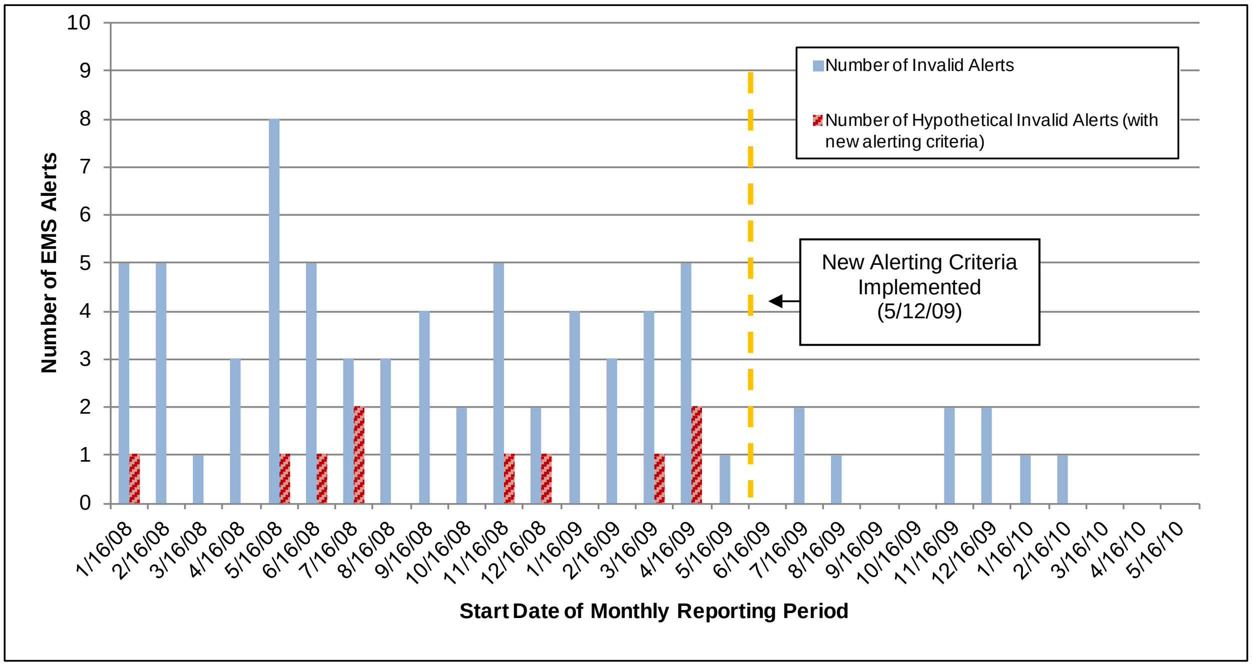

Figure 5-6. EMS Invalid Alerts per Reporting Period (n=72)

EMS run data that met the alerting criteria assigned for the EARS C1 algorithm from January 2008 to May 2009 constituted an EMS alert. As a result of input received from the system users, stating that the alerting frequency was too high, new alerting criteria for sending alert notifications were implemented on May 12, 2009. The impact of this modification is evident as fewer alerts occurred after the May 16, 2009 reporting period. If this new alerting criteria, indicated by the red bars, is applied to the pre-May 2009 alert data for the purposes of comparison, only ten EMS alerts would have occurred, compared to the actual 62.

The histogram presented in **Figure 5-7** demonstrates the range in number of EMS runs for all alerts that occurred between January 15, 2008 and May 12, 2009. Alerts that occurred after May 12, 2009 were excluded from the analysis given that additional alerting criteria were applied to the data.

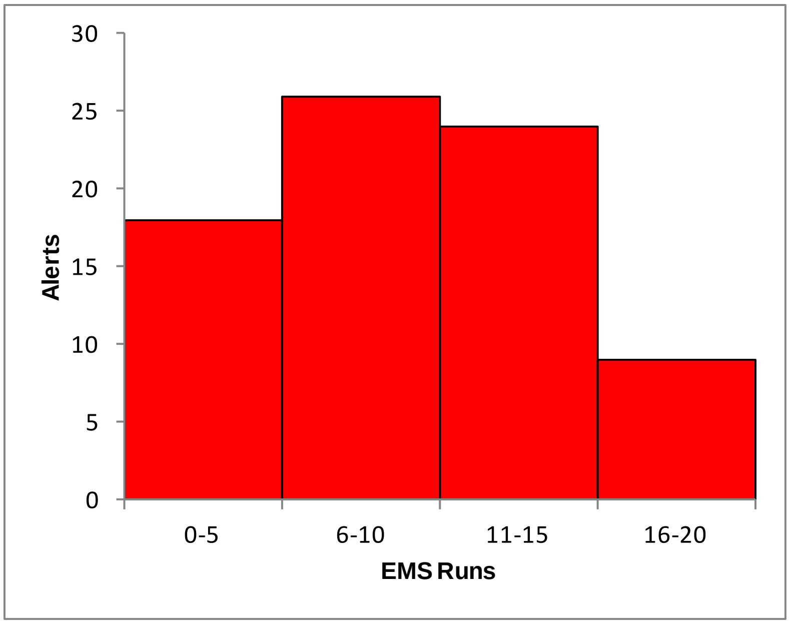

Figure 5-7. EMS Runs Per Alert (n=62)

Figure 5-8 shows data from the 15 EMS alerts which occurred between May 13, 2009 and the end of the evaluation period on June 15, 2009. After the implementation of the new alerting criteria, the number of EMS runs per alert increased from an average of 9.06 to 12.87.

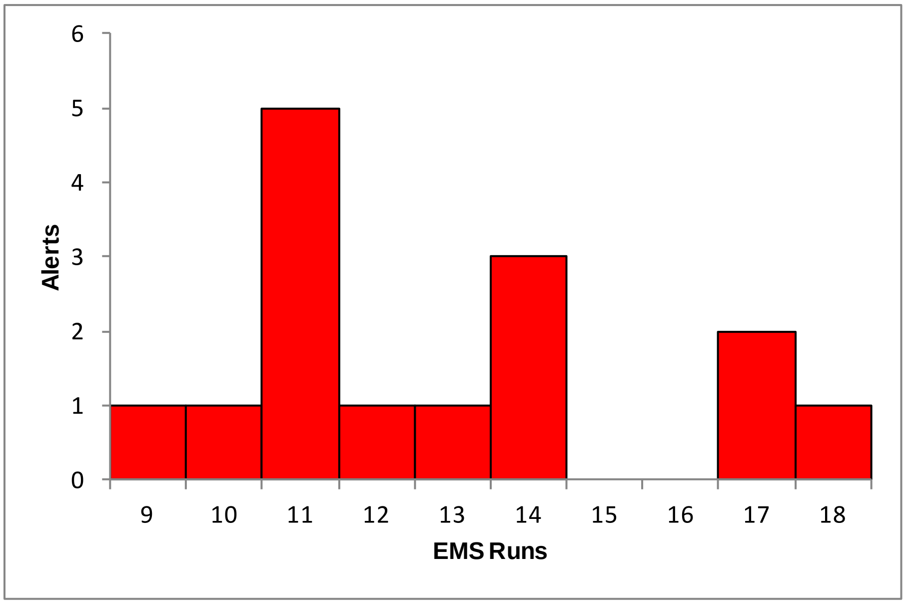

Figure 5-8. EMS Runs Per Alert (n=15)

The histogram presented in **Figure 5-9** compares the ratio of EMS runs to affected zip codes for all alerts that occurred before and after the new alerting criteria. Most of the alerts prior to May 12, 2009 contained an event count to zip code ratio of less than 1.5. Alerts occurring after May 12, 2009 had additional alerting criterion applied, as discussed in Section 5.1; following the implementation of this new criterion, the event count to zip code ratio had to be greater than 1.5 in order to issue an alert. Fifteen alerts occurred following the new criterion, as compared to 62 prior to May 12, 2009.

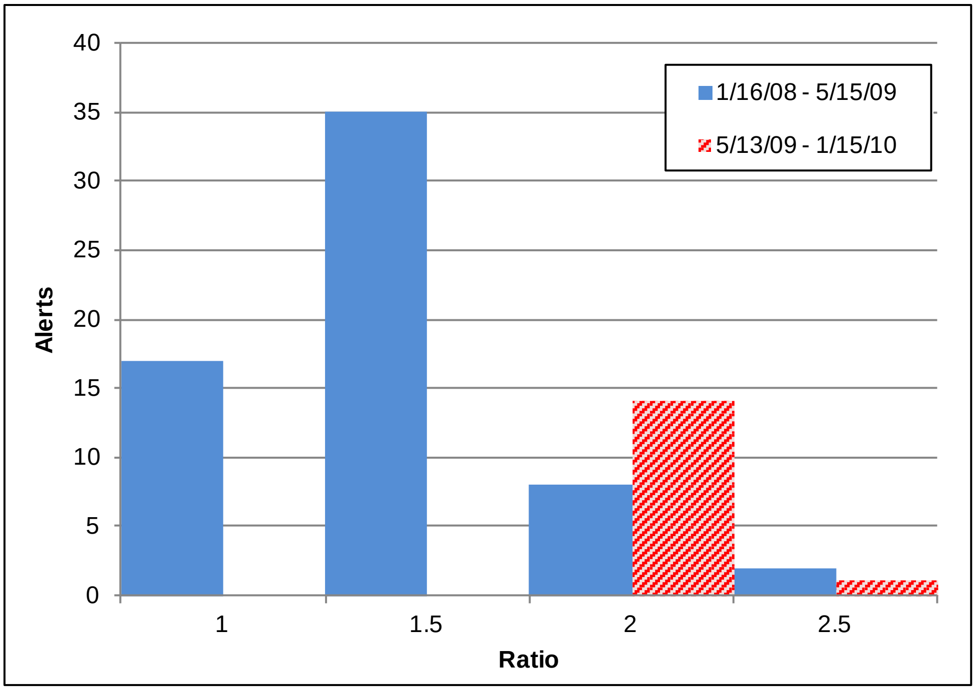

Figure 5-9. Ratio of EMS Runs/Affected Zip Codes per Alert: Pre-updated Alerting Criteria (n=62) and Post-updated Alerting Criteria (n=15)

Figure 5-10 demonstrates the percentage of EMS alerts per syndrome category for all alerts that occurred during the evaluation period. The four highest categories were *cardiac*, *neurons*, *poison* and *upper respiratory*.

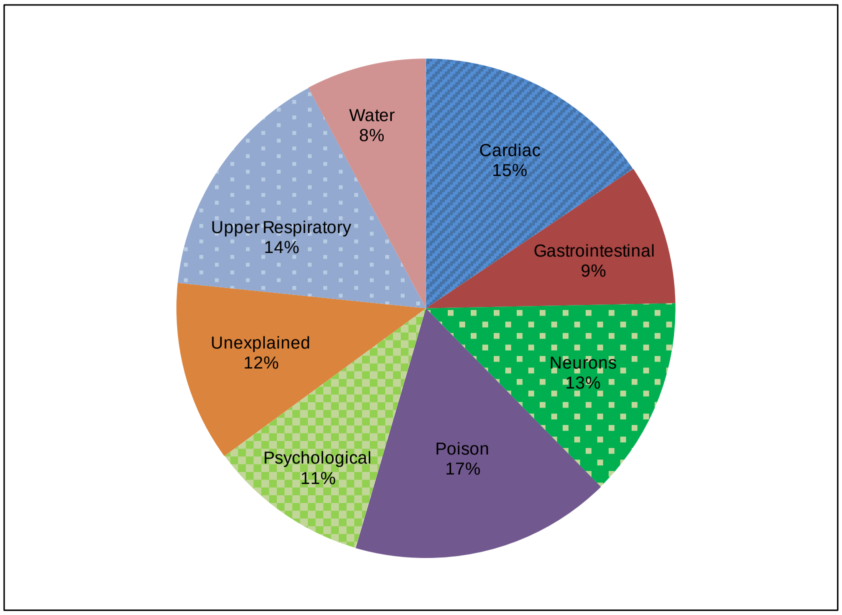

Figure 5-10. Percentages of Syndromes for EMS Alerts (n=77)

Alerts for the entire evaluation period, categorized by syndrome are depicted in **Figure 5-11**. In the 16 months preceding the new alerting criteria, all eight syndrome categories were represented by the 62 alerts that occurred. In the next seven months, eleven alerts occurred, which fell into six of the eight syndrome categories (i.e., no *poison* or *psychat* syndrome category alerts).

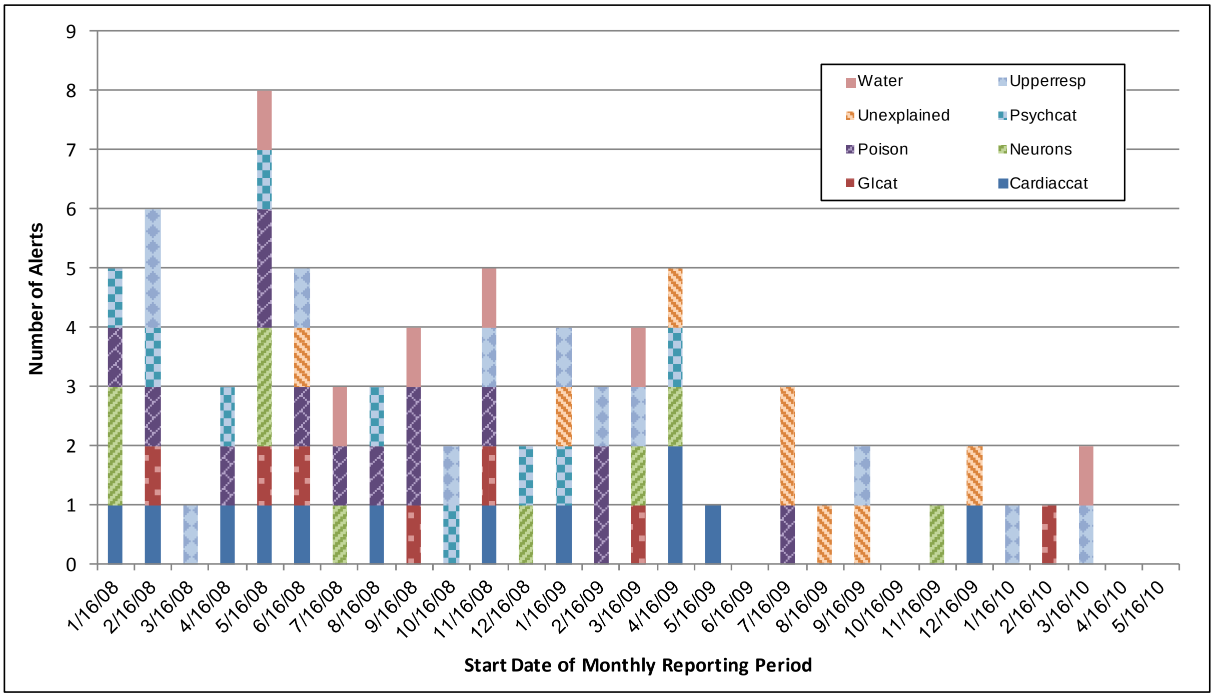

Figure 5-11. Syndrome Categories for EMS Alerts (n=77)

Background knowledge of trends and occurrence of alerts by zip code may be useful during alert investigations. EMS syndrome categories from 2009 were compared to the total EMS runs to determine whether specific syndrome categories would be statistically likely or unlikely to occur in each of 35 zip codes. The results highlight why cognizance of community demographics and provider behavior is important when investigating public health alerts.

Most zip codes had statistically high or low probabilities for at least one syndrome category; only eight zip codes did not have statistically significant probabilities for any syndromes. Two zip codes, 45224 and 45229, had statistically high probabilities in four syndrome categories. While the reasons for this are not certain, for the 45224 zip code this could be caused by high EMS utilization due to an aged population. Zip code 45224 had a median age of 40.2 and 20.2% of its population is older than 65, compared to the city of Cincinnati with a median age of 35.7 and 12% of its population over the age of 65. In the case of 45229, poverty status may play a role in increased EMS utilization. Zip code 45229 has 26.8% of families living in poverty, compared to the city average of 20.9%.

How providers code patient records and understanding syndrome definitions is also important to consider when interpreting results. For example, four of the five zip codes with lower probabilities of EMS runs for *neurological* complaints were on the west side of the city; these same zip codes were more likely to have EMS runs coded as unexplained, indicating that neurological complaints may have been coded as unexplained in this area. When considering syndrome definitions, zip codes with high probabilities of *poison* runs generally had a high probability of *psychcat* calls as well; this occurred in 75% of zip codes with statistically high poison probabilities. This is likely due to the large overlap in provider impressions from chief complaints in the two syndrome categories (Table 5-2).

5.4.2 Valid Alerts

Definition: A valid alert is a result generated by the EMS surveillance tool indicating a public health incident, including possible water contamination, is occurring in the location where the alert is observed.

Analysis Methodology: The total number of valid alerts was characterized qualitatively using empirical data reports. Because of the low number of valid alerts, no statistical analysis was performed. Analyses conducted and presented for the contamination scenario coverage metric reflect the occurrence of valid alerts in the simulation study (Section 5.3.1).

Results: A total of five separate valid alerts attributable to three different public health incidents occurred during the evaluation period; none of these alerts were due to possible water contamination. The public health incidents included a heat-related event (July 2009), the H1N1 influenza outbreak (September 2009), and an allergy-related event (May 2010). These determinations were made following standard alert investigation procedures, which in some cases included consultation with other members of the User's Group.

During the July 2009 reporting period, two EMS alerts occurred; symptoms associated with these alerts included chest pain, fainting and weakness/fatigue. An email alert from ODH received by local public health personnel during this time indicated a rise in ED cases of "weakness" in older adults that did not trigger an EpiCenter alert. Because two alerts occurred at once along with the email from ODH, the communicator protocol was activated to discuss the matter with public health partners. No GCWW system repairs were occurring, and DPIC reported no unusual cases. This alert coincided with the occurrence of hot and humid weather; hence, this alert was determined a heat-related public health incident.

Two EMS alerts occurred in the September 2009 reporting period consistent with the increase in illness in the population due to the H1N1 influenza outbreak. This corresponds to several valid alerts observed in ED patient data via surveillance with the EpiCenter tool, as discussed in Section 6.4.2. These alerts were in the *upperresp* syndrome, and over half of cases indicated "cold/flu" as their chief complaint. One-third of the cases were college age (i.e., 18 to 25 years old), consistent with recent H1N1 activity at the time. Hence, these alerts were classified as public health incidents due to an infectious disease outbreak. Finally, one EMS alert occurred in the March 2010 reporting period which was investigated and determined to be linked to a rise in allergy-related illness, as it occurred when pollen counts were extremely high in the Cincinnati area.

5.4.3 Summary

During the evaluation period, a total of 72 invalid alerts occurred, with the highest percentage occurring in the *cardiaccat* and *poison* syndrome categories. The new alerting criteria imposed on the alert notifications limiting alerts to anomalies which exceed a ratio of 1.5 for event count to affected zip codes reduced the annual frequency of alerts by approximately 70% for the EMS surveillance tool. A total of five valid EMS alerts occurred that were linked to public health incidents.

5.5 Design Objective: Timeliness of Detection

Timeliness of detection is the time it takes to detect a potential public health incident, including water contamination via the EMS surveillance tool, beginning with EMS data transmissions and ending with the conclusion of the alert investigation. Post-exposure factors that would affect the overall timeliness of detection, such as time to symptom onset and health-seeking behaviors, are discussed in Section 3.3. These time delays occur prior to the time for data transmission.

In order to evaluate how well the EMS surveillance tool met this design objective (timeliness of detection), the following four metrics were evaluated: time for data transmission, time for event detection, time to recognize alerts, and time to investigate alerts. The following subsections define each metric, describe how it was evaluated and present the results.

5.5.1 Time for Data Transmission

Definition: Time for data transmission describes the time it takes for EMS records to be available for analysis. It includes the time to transmit and filter data, as recorded by EMT personnel, to the WS application server.

Analysis Methodology: Each EMS record contains timestamps that can be used to calculate the time between the initial EMS incident and the time it is available for analysis on the WS application server. Statistical analysis, including the average and range of time for data to transmit to the WS application server, was calculated per month.

Results: The average time for data transmission of EMS run records from time of run until upload to the CFD server and transfer to the WS application server ranged from ~515 – 1,100 minutes (7 to 29 hours) per month during the evaluation period (**Figure 5-12**).

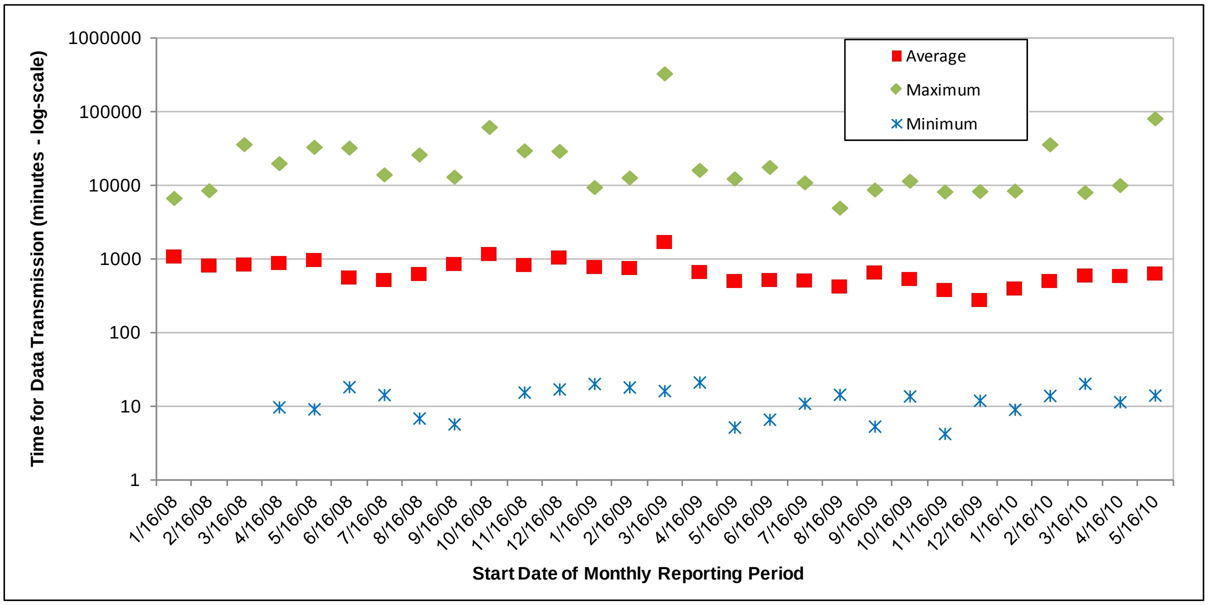

Figure 5-12. EMS Surveillance Tool – Average Time for Data Transmission

The significant delay associated with this metric is a function of secondary data use. Under certain circumstances, CFD personnel hold EMS run records on the wireless tablets until extensive documentation is completed before allowing transfer to the EMS server (and, in turn, to the WS application server). As a result, these held records are not available for retrieval by the WS application server, resulting in extended transmission times from the initial EMS run. This factor is the main cause of the 12.2 hour average time for data transmission, and is not a function of technological limits or errors. If a modification was implemented to the EMS System software to allow transmission of a run record's applicable data subset from the wireless tablet only for WSI use, the data transmission time would likely be reduced significantly.

5.5.2 Time for Event Detection

Definition: Time for event detection describes the time required for the EMS surveillance tool to generate an alert using the EARS algorithms after data has been transmitted to the WS application server. It is based on the time it takes the EARS algorithms applied to EMS data to compute a result.

Analysis Methodology: The time for event detection was calculated as the difference between job start and job finish for the EARS algorithms. Statistical analysis, including average and range of time for event detection, is presented per month.

Results: As depicted in **Figure 5-13**, the average time per month for event detection ranged from 12.6 to 16.5 minutes. This metric illustrates the efficiency and consistency of the EMS surveillance tool in analyzing data once it has been transmitted from the CFD source system and is available for analysis.

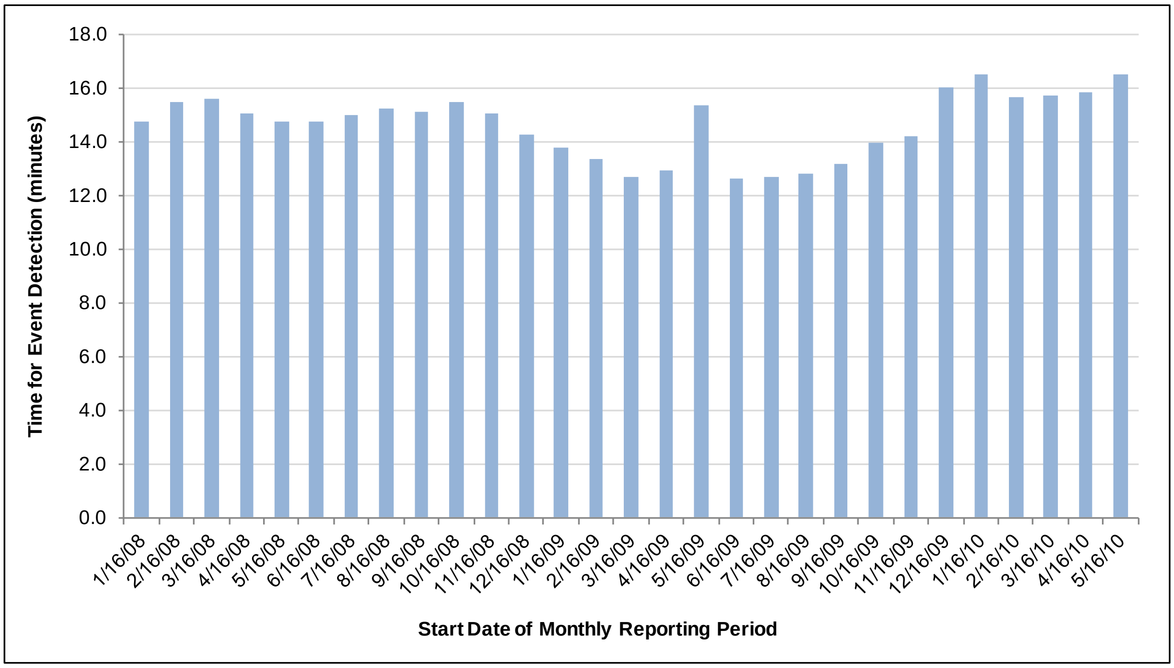

Figure 5-13. EMS Surveillance Tool – Average Time for Event Detection

5.5.3 Time for Alert Recognition

Definition: Time for alert recognition quantifies the time it takes public health personnel (i.e., investigators) to recognize the email alert and begin the alert investigation, as determined from empirical data. For the EMS surveillance tool, this portion of the timeline begins when an alert is generated by the EARS algorithms and notification is sent via email to public health personnel, and ends when public health personnel recognize receipt of the alert.

Analysis Methodology: The time for alert recognition was calculated as the difference between the start time of the alert and the start time of the investigation. Statistical analysis of time for alert recognition was performed for each month, and over the evaluation period as a whole.

Results: Because GCWW and the local partners were not required to respond to alerts in real-time prior to June 2009, data gathered between January 2008 and June 2009 in **Figure 5-14** was not an accurate representation of a typical alert recognition timeline. In some cases, alerts were retrospectively investigated in batches to systematically analyze potential alert causes rather than to detect an event in real-time. In other cases, the average time to recognize an alert was affected by the time of day that alerts were produced. When alerts occurred after-hours or on the weekend, a 10- to 20-hour time lag occurred before the health partners were able to recognize and investigate the alerts. Though a total of eight EMS alerts occurred post-October 2009, a formal investigation was not completed for any of these alerts. Therefore, data for alert recognition time is not available for analysis. *Note:* Asterisks in Figure 5-14 indicate that no data was available either due to an alert investigation not being conducted, or that no alerts occurred during that reporting period. See Figure 5-6 for additional detail on alert occurrence.

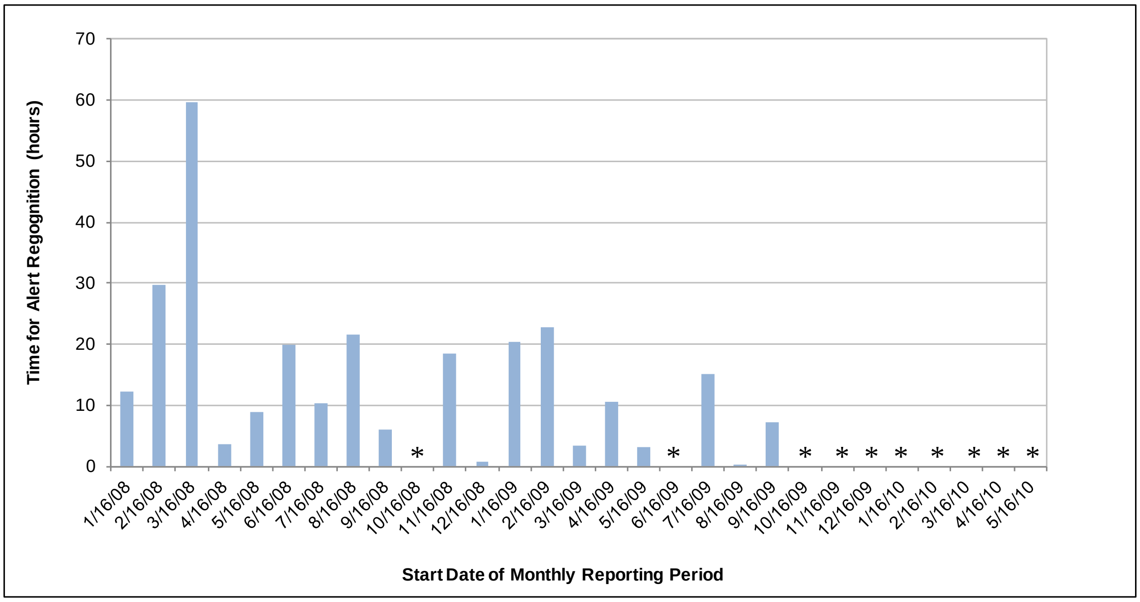

Figure 5-14. Average Time to Recognize EMS Alert

Analysis of the time for EMS alert recognition for the entire evaluation period shows a wide range, from 0.05 to 61.3 hours. As mentioned earlier, lags in alert recognition are sometimes due to the occurrence of alerts on weekends or after-hours. The overall alert recognition statistics are presented in **Table 5-6**.

Table 5-6. EMS Alert Recognition Time (hours)

Parameter	Time (hours)
Average	15.30
Median	8.79
Minimum	0.05
Maximum	61.30

5.5.4 Time to Investigate Alerts

Definition: Time to investigate alerts includes the portion of the incident timeline that begins with the recognition of an EMS alert, and ends with a determination regarding whether or not contamination is Possible. The time to investigate alerts, as captured in the investigation checklists, is based on the nature of the alert details and the investigation procedures that must be implemented before concluding that the alert is not indicative of a possible contamination incident. For PHS drills and the simulation study, this data represents the timeline from the contaminant injection to the time that contamination is deemed

Possible. As noted in Section 3.3, no time delay for alert recognition was parameterized in the CWS model as it was assumed that alert investigations occurred immediately upon receipt of alerts based on the nature of the underlying case data (i.e., similar symptom categories and case clustering).

Analysis Methodology: Analysis of empirical data (invalid alerts) was performed to calculate average, median, and range of times as listed in investigation checklists. The time to investigate valid alerts was described using several public health incidents that occurred during the evaluation period as well as timeline data collected from PHS drills.

Timeline data gathered from investigation of EMS valid alerts and PHS drills was used to parameterize the investigation time for EMS alerts in the simulation study. Simulation study timeline data (which, as noted above, started at the time of contaminant injection) was evaluated to illustrate the timeliness of detection overall and for scenarios initiated at periods high or low demand. Percentile values were calculated to examine the distribution of data, and are presented in a box-and-whisker plot. Average detection times were calculated for individual contaminants, as well as for scenarios initiated at high or low demand for individual contaminants.

Results: The results presented below are arranged in order of empirical data, drill data, and simulation study data.

Empirical Data

Because only a few public health incidents occurred during the evaluation period, the majority of investigation times represent time to investigate invalid alerts. **Figure 5-15** shows the average invalid alert investigation time for each monthly reporting period. System users were not required to actively investigate alerts until the beginning of the June 2008 reporting period as the system was still in a development and testing phase between January and June 2008. Two outliers are included in this dataset (an EMS alert investigation on March 14, 2008 which took 17.17 hours and the investigation on April 24, 2008 which took 22.25 hours) which are thought to be the result of instances where personnel were interrupted during the investigation process by regular job duties, and completed the investigation checklists many hours after the investigation had been initiated. Though a total of eight EMS alerts occurred after October 2009, a formal investigation was not completed for any these alerts. Therefore, data for alert investigation time was not available for analysis. *Note:* Asterisks in Figure 5-15 indicate that no data was available either due to an alert investigation not being conducted, or that no alerts occurred during that reporting period.

This bar chart shows the average invalid alert investigation time for each monthly reporting period beginning on January 16, 2008 and ending on May 16, 2010. Average investigation times during these reporting periods are approximately 43 minutes; however there were two outlying investigation times of 17.17 hours and 22.25 hours. Data was unavailable for several reporting periods, and many were clustered at the end of the evaluation period, from October 16, 2009 through May 16, 2010, due to either an alert investigation not being conducted, or no alerts occurring during that reporting period.

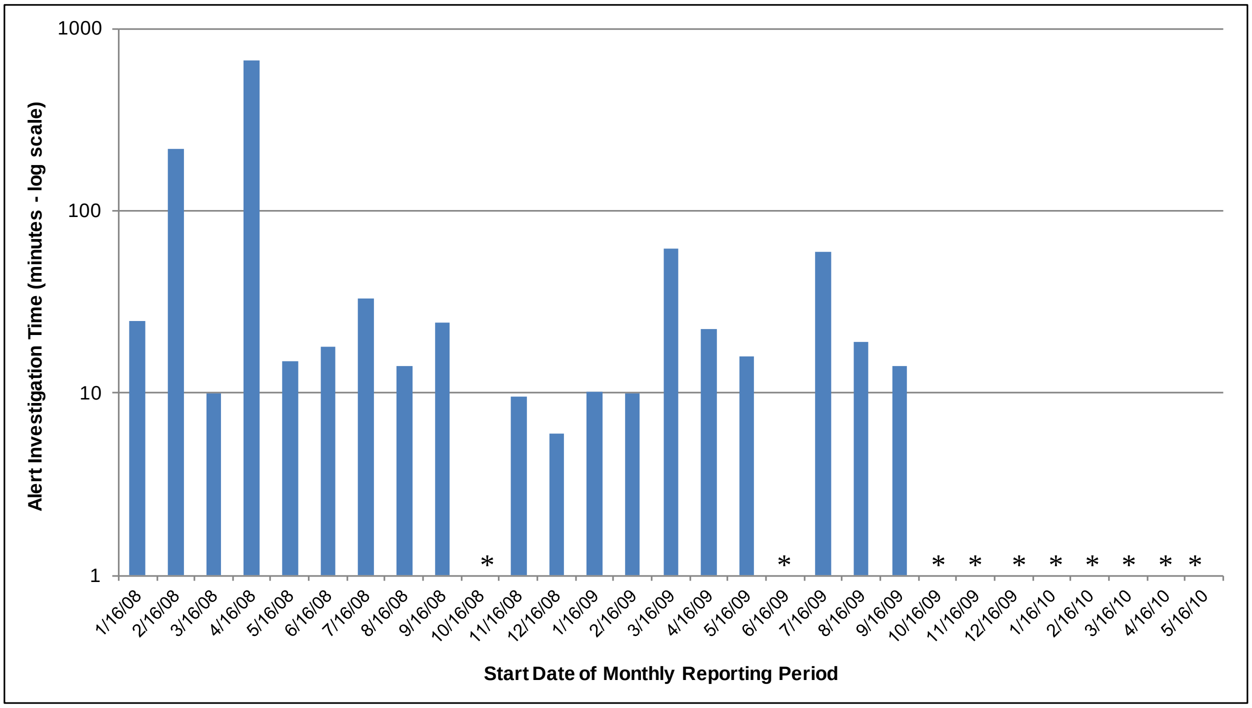

Figure 5-15. EMS Average Invalid Alert Investigation Time (n=43, empirical data)

The time to investigate valid alerts (public health incidents) varied during the evaluation period. It took 100 minutes (1 hour, 40 minutes) to investigate an alert that was due to heat-related illness in July 2009. During this time, local public health personnel received two EMS alerts; the communicator was then activated, during which it was determined the alerts were due to heat-related symptoms. Nearly an hour of this time elapsed between the activation of the communicator and investigation close out. For the two alerts representing the H1N1 outbreak in September 2009, public health personnel were able to rule out possible water contamination as a cause of the alerts in less than 20 minutes because knowledge of the ongoing outbreak helped to determine these alerts were due to H1N1 illness.

Statistics for time for alert investigation over the entire evaluation period are shown in **Table 5-7**.

Table 5-7. EMS Invalid Alert Investigation Time (minutes, empirical data)

Parameter	Time (minutes)
Average	22
Median	9
Minimum	2
Maximum	153

Drill and Exercise Data

During the evaluation period, simulated EMS alerts were used during the August 22, 2008 PHS drill as well as the October 2008 full-scale exercise to practice alert investigation. These drills serve as a proxy for time to investigate alerts caused by possible water contamination. The time to investigate these simulated alerts was approximately 1.5 hours for the PHS drill, and about one hour during the full-scale exercise. The differences in these times reflects the variability of scenarios that may occur, as represented by the different contamination scenarios, as well as other factors that influence alert investigation, such as personnel availability and clarity of the data. These factors would also influence the time to complete an alert investigation during an actual water contamination incident. The timeline for the August 2008 PHS drill is presented below in **Figure 5-16**, which displays some of the key points of the investigation following receipt of a simulated EMS alert.

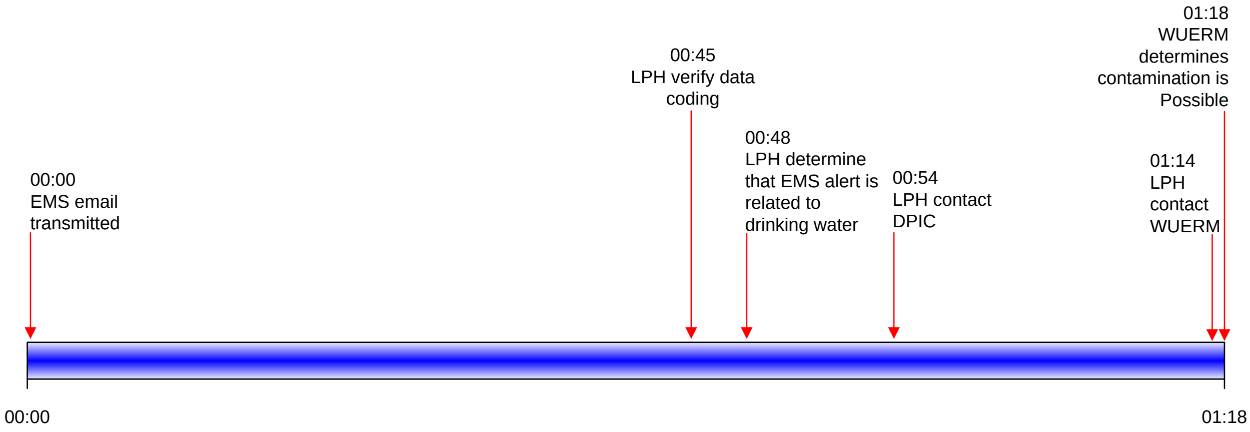

Figure 5-16. PHS Drill 1 Timeline (EMS Alert)

Simulation Study Data

Figure 5-17 demonstrates the overall timeliness of detection statistics for the EMS surveillance tool and for scenarios initiated at periods of low and high demand, using percentile values to illustrate the distribution of data in a box-and-whisker plot. Scenarios initiated at high demand times were detected sooner than scenarios initiated at low demand times due to the design of the CWS model. A seven-hour time delay occurred between the scenarios initiated at low demand (12:00 am) and the first exposure event (7:00 am), which resulted in a detection time lag, unlike the scenarios initiated at high demand (9:00 am), which could have resulted in exposure soon thereafter at the 9:30 am or 12:00 pm exposure events.

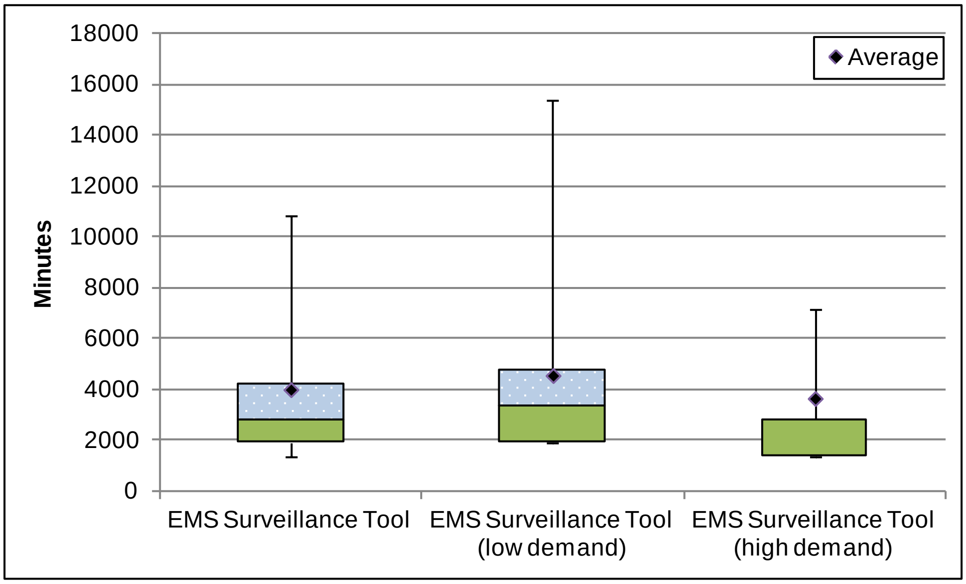

Figure 5-17. EMS Data Stream Timeliness of Detection (simulation study data)

There were a total of 487 scenarios detected by the EMS surveillance tool with an average detection time of 4,012 minutes (nearly three days), as shown in **Table 5-8**. A longer delay was observed for scenarios detected by the EMS surveillance tool compared to the 911 surveillance tool, likely due to the fact that EMS cases would be logged after 911 calls were placed, and that fewer EMS cases were logged overall compared to 911 calls (as discussed in Section 5.3.1). Furthermore, there is a 732 minute time delay for the EMS data upload before it becomes available for statistical analysis, which contributes to the longer time delay prior to detection.

Table 5-8. EMS Data Stream Timeliness of Detection (minutes, simulation study data)

Scenarios	Count	Average	Median
Total	487	4,012	2,850
Low Demand	147	4,820	3,390
High Demand	340	3,663	2,850

Average timeliness of detection for the EMS surveillance tool by contaminant is presented below in **Figure 5-18**, where contaminants are arranged in increasing order of timeliness of detection (no data is presented for Biological Agent 7 as EMS did not detect any scenarios involving this contaminant). For each contaminant, the overall average is presented as well as the average value for high and low demand scenarios. This figure compares the timeliness of detection of the toxic chemicals and biological agents, where the chemicals were typically detected within a day or two, and the biological agents ranged from within a day or two to until a week or more after injection of the contaminant. This difference is likely due to the longer symptom onset time for some biological agents. Unlike the 911 surveillance tool, the differences in timeliness of detection of various contaminants by the EMS surveillance tool for high or low demand scenarios are minor as the overall timeline from contaminant injection to detection is delayed by the time required for data transmission (~12 hours). This delay diminishes the impact of differences between contaminant injection and exposure times in high and low demand scenarios.

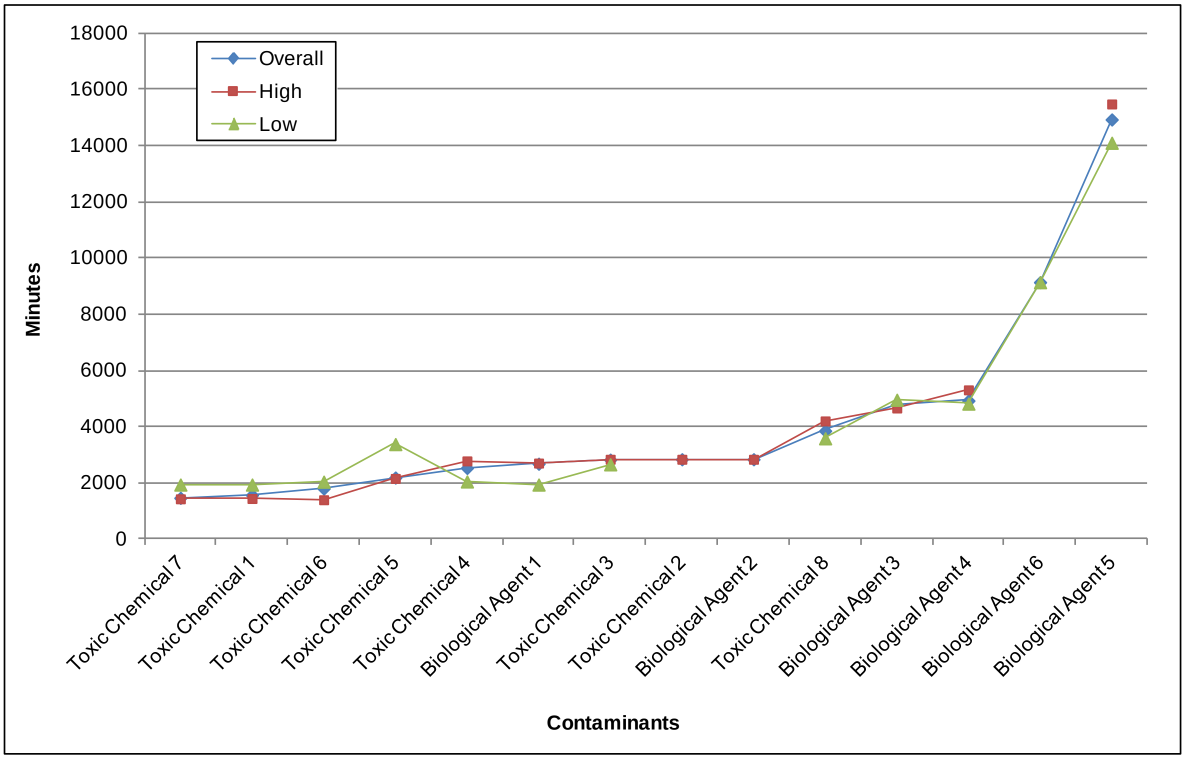

Figure 5-18. EMS Surveillance Tool Timeliness of Detection (simulation study data)

5.5.5 Summary

For the EMS surveillance tool, one of the lengthiest processes is the time for data transmission because of delays that occur in data upload to the ESM server, due to the CFD requirements that must be completed before closing and uploading an EMS run. Delays can also occur when data is stored in EMS tablets during multiple runs for many hours before EMTs return to the firehouse and are able to upload the data. Once EMS run data is filtered and available for analysis, the tool quickly and consistently analyzes the run data and determines if events meet the algorithm's requirements for producing an alert. Although this efficiency allows local public health partners and GCWW personnel to quickly obtain alert data and begin the investigation process in a timely manner, timely recognition of EMS alerts did not always occur. When alerts occurred after-hours or on the weekend, a 10 to 20 hour time lag occurred before the health partners started the investigation of the alert. Overall, time to complete EMS invalid alert investigations stabilized to approximately ten minutes per alert.

Simulation study data analysis showed that for most chemical contamination scenarios, it took one to two days for EMS run counts to become high enough to exceed the detection thresholds for the relevant syndrome categories monitored by the EMS surveillance tool. In contrast, weeks elapsed before detection of some of the biological agents occurred.

5.6 Design Objective: Operational Reliability

Analysis of the operational reliability of the EMS surveillance tool quantifies the percent of time that the EMS surveillance tool was working as designed. In order to evaluate how well the EMS surveillance tool met this design objective, the availability metric was evaluated. The following subsection defines the metric, describes how it was evaluated and presents the results.

5.6.1 Availability

Definition: Availability is the amount of time the EMS surveillance tool is functional and accessible, expressed in terms of the percent of usable data hours per reporting period. In order for available data to be generated for the EMS surveillance tool, data must be successfully loaded from EMS tablets to the WS application server, filtered, and analyzed using the EARS event detection tool.

Analysis Methodology: Availability is expressed in terms of the percent of usable data hours per reporting period. The measurement of availability is related to downtime events; the available hours were calculated by subtracting the total downtime from possible data hours in each reporting period. Percent availability was analyzed per reporting period, as well as for the entire evaluation.

Results: Most downtime events (see blue bars in **Figure 5-19**) for the EMS surveillance tool were attributed to the inhibition of EMS data collection due to periodic network instability, which prevented data transmission from the CFD server to the WS application server. The lengthiest period of data collection downtime occurred during the March 2009 reporting period. This was the result of a loss of connectivity with the CFD source database, the cause for which is unknown. Some data collection downtime during the September 2008 reporting period was the result of power outages and network instability caused by a windstorm, which resulted in loss of electricity for 90% of Cincinnati for up to four days.

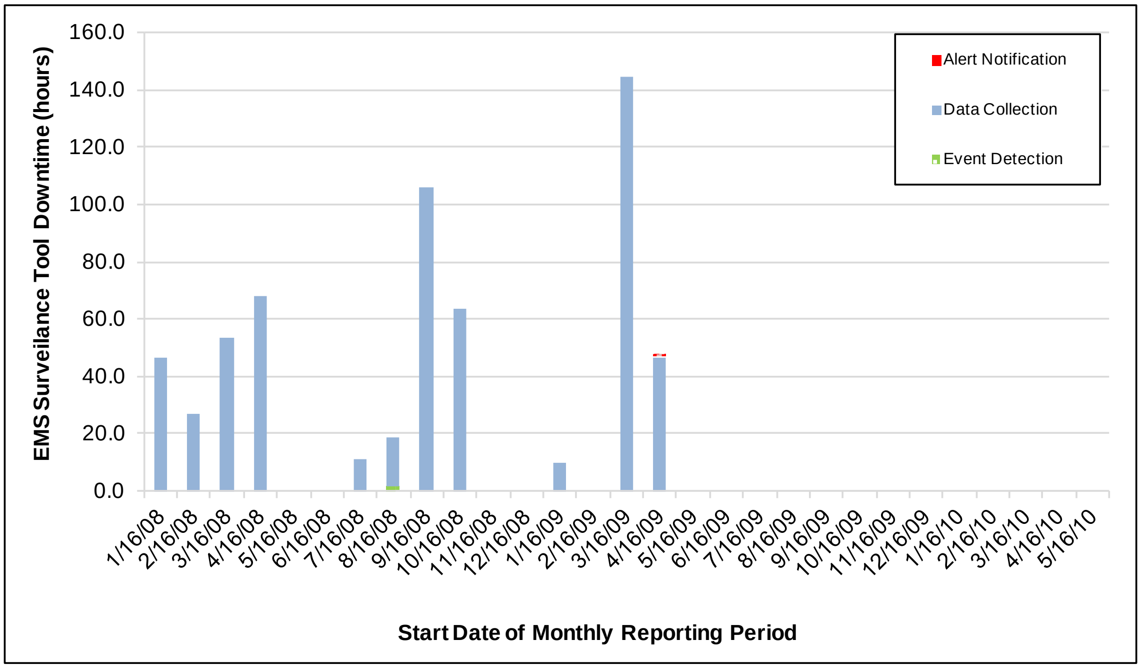

Figure 5-19. EMS Surveillance Tool Downtime (Events > 1 hour)

During the evaluation period, availability generally exceeded 90% for the EMS surveillance tool, with an average value of 97% availability. Overall, the lowest value for availability occurred during the March 2008 reporting period and was caused by network instability which prevented data collection (**Figure 5-20**). When data collection is inhibited, subsequent event detection processing on the most current data cannot occur.

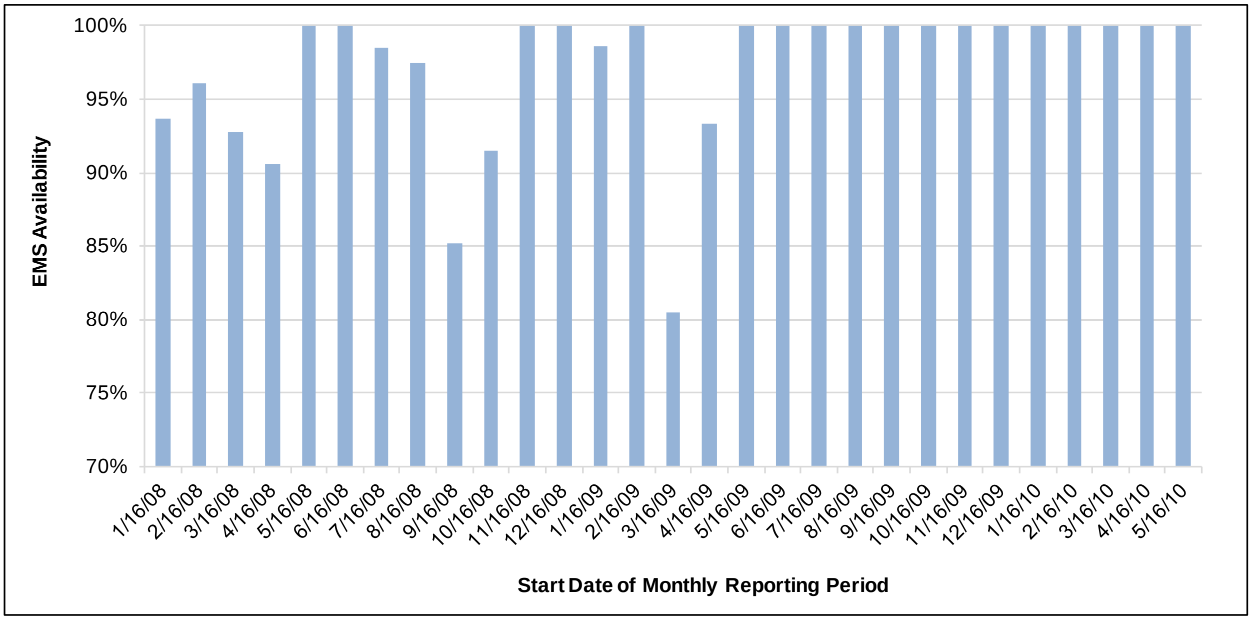

Figure 5-20. EMS Surveillance Tool Availability

5.6.2 Summary

The high availability percentages during the evaluation period depict the overall stability and reliability of the EMS surveillance tool. Availability increased post-July 2009, as utility personnel established an automated monitoring tool which provides notification when the WS application server needs to be restarted if network stability causes it to shut down, providing for consistently reliable transfer of data from the CFD server to the WS application server for filtering and analysis.

Section 6.0: Performance of the EpiCenter Surveillance Tool

The following section provides a description of the EpiCenter surveillance tool followed by the results of the evaluation of this tool. This analysis includes an evaluation of metrics that characterize how the EpiCenter surveillance tool achieves the design objectives described in Section 1.1. Specific metrics are described for each of the design objectives.

6.1 Description of the EpiCenter Surveillance Tool

ED hospital admission records were included as a part of the PHS component of the CWS to enhance situational awareness during events and provide early detection of outbreaks. These records are managed and analyzed via the EpiCenter surveillance tool, a syndromic surveillance system operated by the Situational Monitoring and Event Detection Unit at ODH. Health Monitoring System's (HMS) EpiCenter replaced the RODS system starting in March 2008 (HMS, 2009 and ODH, 2009).

Patients arriving in the ED are triaged using reported chief complaint(s); these chief complaints are coded into an electronic medical record along with other demographic variables. The electronic records are uploaded into the EpiCenter system and categorized into syndromes based on chief complaints, and algorithms built into the program generate alerts any time patient volume (per syndrome or symptom) exceeds alerting criteria (i.e., statistical thresholds). Alerts are sent to the local health department(s) at the appropriate jurisdiction(s). Epidemiologists and disease investigators can access data from their jurisdiction for purposes of alert investigation, outbreak management and day-to-day monitoring. The volume, location and demographics of this data are available to the local health departments at all times for analysis via an interactive computer module.

It should be noted that EpiCenter (and previously, RODS), differs from other PHS surveillance tools in that the tool itself was not modified for the Cincinnati CWS because it is a state-wide, and not local, surveillance tool. Instead, emphasis was placed on how the data was utilized to initiate or augment investigations into a possible water contamination incident. Evaluation of this surveillance tool will focus not only on its ability to detect valid alerts due to possible water contamination, but also to identify valid alerts due to public health incidents unrelated to drinking water.

For purposes of the EpiCenter data, a valid alert due to a public health incident was defined as any alert categorized as "seasonal illness health event" or "naturally occurring disease outbreak" by public health personnel responsible for the anomaly investigation within the EpiCenter system. This differs slightly from the other PHS data tools, because these categories are set at the state and not local level, but are analogous to the alerting criteria for the other PHS tools deployed as part of the Cincinnati CWS. The 911, EMS and DPIC surveillance tools define a valid alert as any alert indicative of a public health incident, including water contamination, as explained in their respective sections (Sections 4.0, 5.0, and 7.0). Examples of these classifications include seasonal influenza outbreaks, respiratory issues related to allergies and pandemic events such as the 2009 H1N1 outbreak. The data included in this evaluation period was provided by ODH, and includes EpiCenter alerts produced between March 2008 and March 2010 in Hamilton County, Ohio.

EpiCenter Syndromes

EpiCenter categorizes symptoms into approximately 25 classification groups. Categories are not mutually exclusive; hence, one patient may be included in more than one syndrome. For purposes of the CWS, only syndromes pertaining to possible incidents as determined by local public health were included for investigation. Symptoms contained within these syndromes are listed in **Table 6-1**.

Table 6-1. EpiCenter Syndromes

Syndrome	Symptoms Included
Botulinic	Blurry, difficulty speak, diplopia, double vision, eye problem, language problem, loss of vision, photophobia, slurred speech, visual difficulties
Constitutional	Aches, body pain, difficulty walking, loss of appetite, chills, does not feel well, fatigue, fever, flu-like, fussiness, generalized pain, swollen glands, illness, increased sleep, lethargic, low blood pressure, lump in groin/neck/underarm, malaise, mumps, muscle aches, polycythem, septic shock, sluggish, sweats, swollen gland, viral syndrome, sick, ear/head/stomach ache
Gastrointestinal	Abdominal pain, appendicitis, cramps, gastric pain, quadrant pain, stomach pain, blood in stool, dark stool, diarrhea, food poisoning, loose stool, nausea, tarry stool, upset stomach, vomiting
Hemorrhagic	Abortion, blood in stool/urine/sputum, bloody sneeze/cough, dysent, hematuria, hemoptysis, passing clots, petechiae, rectal bleeding, vaginal bleed, bleeding, hemorrhoid
Neurological	Altered mental state, aphasia, ataxia, back pain radiating, Bell's palsy, blacking out, cannot focus eyes, can't move/remember/see/speak, cephalgia, confused, convulsions, delirium, disoriented, droopy eyelids, dystonic reaction, ear ringing, epileptic, face droop, numbness, flaccid, floaters, headache, hearing loss, incoherent, ischemia, light headed, loss of consciousness, loss of coordination, memory loss, meningitis, muscle stiffness, neck pain/stiffness, nerve pain, paresthesia, pinched nerve, presenile dementia, sciatic, shakes, side weak, skin sensation, slurred speech, stroke, syncope, tingling, tremors, twitching, unresponsive, seizure, hallucinations
Rash	Angioderma, blister, blotch, boil, buboes, bumps, burning to skin, candidiasis, chickenpox, eczema, facial sore, flesh eating, hives, itchiness, lesion, lumps, measles, Methicillin-resistant Staphylococcus aureus, non-specified skin, open sore, pox, red and swollen/painful/sore/spots/streak, redness, ring worm, scabies, shingles, skin burning/eruption/inflammation/irritation/lesions/problems, sores, splotch, spots, staph infection, thrush, cyst, rash, ulcer
Respiratory	Apnea, breathing pain, barky, breathing difficulty/problems, breathing fast, bronchitis, cannot swallow, cannot breathe, chest congestion, chest discomfort, chest tightness, chest pressure, chest heaviness, cold, croup, decreased oxygen, dyspnea, ear ache, ear drain, ear infection, ear swelling, emphysema, flu-like, hoarse, hyperventilation, low oxygen, lung pain, not breathing, otitis media, pertussis, pneumonia, pulmonary congestion, respiratory arrest/failure/distress, runny nose, shallow breath, sinus, sore throat, strep, stuffy, swollen tonsils, wheezing, nasal, asthma, Chronic Obstructive Pulmonary Disease, bronchospasm, gasping

EpiCenter Analysis

EpiCenter has various algorithms available for the analysis of ED hospital admissions data, as shown in **Table 6-2**.

Table 6-2. EpiCenter Algorithms

Algorithm	Description
Constant Threshold	Sets a fixed threshold; commonly used to detect immediately reportable conditions
CUSUM with Exponential Moving Average (EMA)	Threshold set at 4 standard deviations (default) above predicted count, based on 14 previous days of data
EMA	Computes predicted count as a weighted average of actual counts for 17 days previous

Algorithm	Description
Simple Moving Average	Predicted count based on average counts for past 14 days
Recursive Least Squares (RLS)	Computes predicted count from a weighted sum of the actual counts of the current day and the past p-1 days (7 days default); has an adjustable training window (default 60 days)

Algorithms are applied to the data using a rolling 24-hour analysis window. Syndrome counts that exceed threshold for any of the above algorithms may generate an alert if all of the following alerting criteria are met:

1. The observed count is greater than or equal to ten AND
2. The observed count is greater than the threshold AND
3. If other data conditioning algorithms are applied (i.e., normalized or day-of-week), these threshold(s) are exceeded AND
4. No anomaly using identical parameters has been created in the past 24 hours.

Alerts generate automated email notifications that are sent to designated personnel at the appropriate local health department(s). Upon receipt of these alerts, staff can begin investigating the cause of the alert using data within the EpiCenter module as well as other information at their disposal (e.g., reportable disease counts, knowledge of current outbreaks, etc.) to determine whether or not the alert represents a public health incident. In addition, users have the option of applying data conditioning techniques to account for certain confounders, such as day-of-week effects, during their investigations.

For the Cincinnati CWS, staff at the local health department(s) review EpiCenter data during alert investigations to determine if recent hospital admission data support evidence of a possible water contamination incident. In addition, staff consider water contamination as a possible cause of any EpiCenter alerts generated.

6.2 Design Objective: Spatial Coverage

The spatial coverage is the cumulative area of the water distribution system monitored by ED hospital admissions data in EpiCenter. In order to evaluate how well the PHS component met this design objective, the following metric was evaluated: area and population coverage. The following subsections defines the metric, describes how it was evaluated, and presents the results.

6.2.1 Area and Population Coverage

Definition: Area coverage describes how alerts are distributed geographically, while population coverage depicts the geographic area covered by the EpiCenter surveillance tool.

Analysis Methodology: EpiCenter alerts, by nature, indicate a county-wide rise in a certain syndrome category. Therefore, no geographic analysis of alert location data was conducted.

Results: Although specific hospital location data was not available from the data provider, data was collected from all Hamilton county hospitals. Thus, it can be concluded that area coverage spans the entire county. This represents 95% population coverage of the total GCWW retail service area (see Figure 2-1).

6.3 Design Objective: Contaminant Coverage

The EpiCenter tool monitors ED visits that could signal a public health incident, including water contamination. For ED patient data, contaminant coverage is dependent on the health-seeking behaviors following symptom presentation, as discussed in Section 3.3. In order to evaluate how well the EpiCenter surveillance tool met this design objective, the contamination scenario coverage and contaminant detection threshold metrics were evaluated. The following subsections define each metric, describe how it was evaluated, and present the results.

6.3.1 Contamination Scenario Coverage

Definition: Contamination scenario coverage is defined as the ratio of contamination incidents that are actually detected to those that are theoretically detectable based on the design of the EpiCenter surveillance tool. Detectable contamination scenarios include those which originated at distribution system attack nodes rather than facility attack nodes.

Analysis Methodology: Since no water contamination incidents occurred during the evaluation period, simulation study results were utilized to quantify this metric. The ratio of scenarios that were actually detected to those that were theoretically detectable (based on the assumptions regarding health-seeking behavior that were parameterized in the model) was calculated for each contaminant. Additionally, the average and median number of cases at the time of detection was calculated for each contaminant. Certain contamination scenarios that were not theoretically detectable were screened out of the analysis including those that originated at facility attack nodes (which were detected by the ESM component) and those which involved the nuisance chemicals.

Results: The EpiCenter surveillance tool detected 71% (994 scenarios) of the theoretically detectable scenarios (n=1,402). **Table 6-3** below shows the detection statistics for the EpiCenter surveillance tool for each contaminant.

Table 6-3. EpiCenter Detection Statistics

Contaminant	Scenarios Detected	Scenarios Not Detected	Percent Detected	Average # Cases at Time of Detection	Median # Cases at Time of Detection
Toxic Chemical 1	76	18	81%	1,196	1,087
Toxic Chemical 2	94	0	100%	382	246
Toxic Chemical 3	67	27	71%	713	554
Toxic Chemical 4	78	16	83%	2,593	2,509
Toxic Chemical 5	54	40	57%	217	1,972
Toxic Chemical 6	73	21	78%	16,139	12,444
Toxic Chemical 7	46	48	49%	2,088	1,767
Toxic Chemical 8	94	0	100%	6,756	6,147
Biological Agent 1	92	2	98%	1,608	858
Biological Agent 2	43	51	46%	250	134
Biological Agent 3	94	0	100%	68,707	43,443
Biological Agent 4	94	0	100%	2,402	2,300
Biological Agent 5	89	5	95%	2,561	1,919
Biological Agent 6	0	88	0%	-	-
Biological Agent 7	0	92	0%	-	-

The EpiCenter surveillance tool demonstrated a high detection rate across almost all contaminants, with 100% detection for four of the fifteen contaminants and another five above 71%. No contamination scenarios were detected for Biological Agent 6 or Biological Agent 7. These two contaminants were modeled as producing illness through the inhalation exposure route, and thus there was only one exposure event in the morning (7:00 am showering event) that could have produced cases. Fewer exposed individuals resulted in a lower number of patients requiring treatment at the ED, which contributed to lower detection rates. It is also possible that scenarios involving these biological agents were detected early enough by Astute Clinician surveillance that not many individuals had advanced to the moderate or severe symptom level and did not yet require care at an ED. During these scenarios, if enough collective information was available to advance the threat level to Confirmed, public notification would have been issued which would have directed individuals to pursue prophylactic treatment.

6.3.2 Contaminant Detection Threshold

Definition: The contaminant detection threshold is the number of exposed individuals who are symptomatic necessary to generate an alert through the EpiCenter surveillance tool. This metric is intended to characterize the size of the smallest contamination incident, expressed in terms of the number of symptomatic people, which can be detected through this surveillance tool.

Analysis Methodology: Empirical data provided by Hamilton County was used to characterize this metric. The two types of historical counts that were used to quantify the number of cases necessary to detect contaminants that cause symptoms as described in Section 6.3.1 are total case counts and counts above threshold.

Total case counts represent the number of cases observed during historical alerts. This count gives an indication of the total volume that may be expected during a contamination incident. However, given the variable nature of ED utilization, total counts may not be the best benchmark for determining detection limits. Total case counts that trigger an alert one day may not trigger an alert during another time of year due to seasonality and other natural fluctuations in the data.

Threshold values are determined by the algorithm applied, and generally represent a certain value above the predicted count. The default thresholds in EpiCenter are four standard deviations above the calculated predicted value, although these can be adjusted. In theory, the minimum number of cases necessary to generate an alert would be one case above the threshold. The average and minimum counts above the threshold necessary to generate an alert give an indication of the contamination detection limit for contaminants causing symptoms typical of the various syndromes.

Average and minimum values for case count and counts above the threshold were calculated per syndrome for all alerts between January 2008 and September 6, 2009. Alerts after September 6, 2009 were excluded because these occurred during the H1N1 outbreak in Cincinnati and contained counts significantly higher than normal. Therefore, they would not be useful for determining detection limits under typical circumstances. The cut-off date was calculated by a statistical analysis which determined when natural break points occurred in the data.

Results: The average and minimum case count values per syndrome can be seen in **Figure 6-1**. Average and minimum counts above the threshold are depicted in **Figure 6-2**.

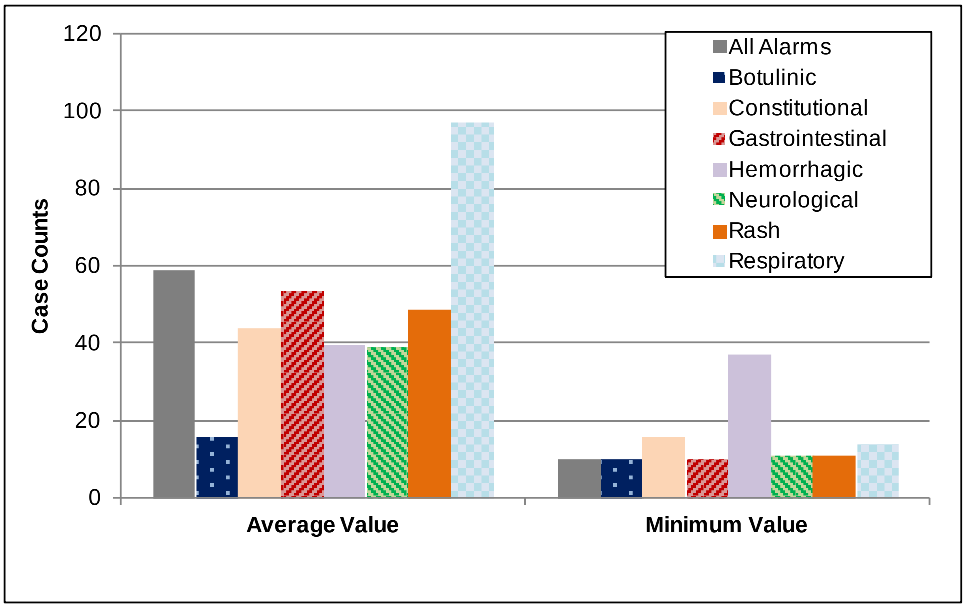

Figure 6-1. Average and Minimum Case Counts per Syndrome Alert

Figure 6-1 shows the average case counts that typically occur during the various syndrome alerts, as well as the minimum value of cases that have elicited an alert. Note that in Figures 6-1 and 6-2, "All Alerts" represents the overall average case counts or the minimum value or cases for all alerts, regardless of syndrome. For example, the average Respiratory alert consisted of 97 cases, although case counts as few as 14 respiratory cases (the minimum case count observed per alert) have also triggered an alert. There is a wide range of average observed values, from an average of just 16.2 cases per Botulinic alert to 97 for the Respiratory syndrome. As mentioned previously, case counts may fluctuate depending on current events. Therefore, the observed values above the threshold counts must also be taken into account.

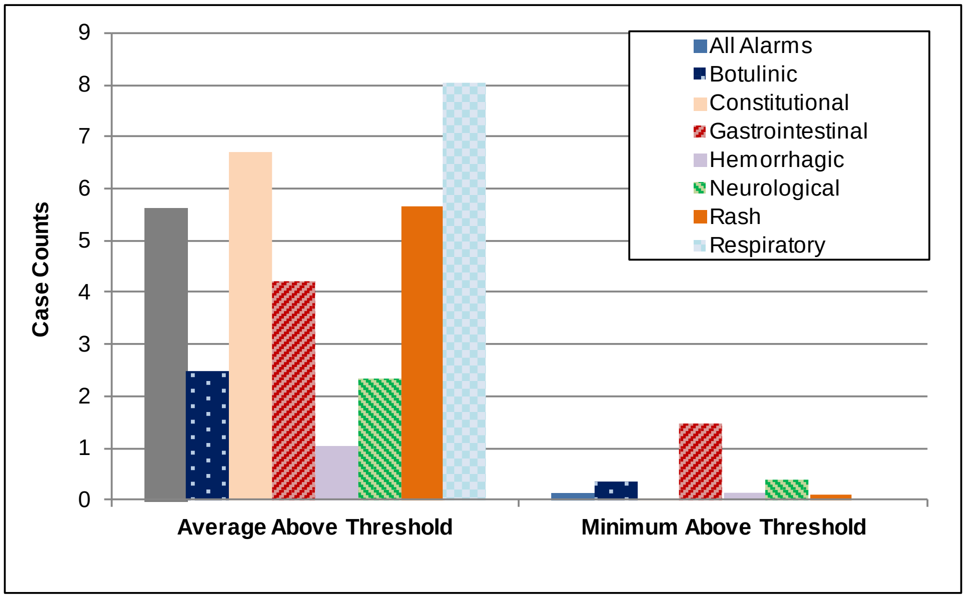

Figure 6-2. Average and Minimum Case Counts above Syndrome Thresholds per Alert

As seen in Figure 6-2, the average number of cases above threshold to trigger an alert ranged from one case for the Rash syndrome, to eight cases for the Respiratory syndrome. As such, for a contaminant that causes respiratory symptoms, it could be assumed that the typical detection limit would be eight cases above the daily threshold. While minimum values also generate an alert, utilizing the average above threshold provides a more realistic estimate of the number of cases required to register an EpiCenter alert in the event of water contamination.

It should be noted that the limits described above are for normal public health circumstances. In the event of an outbreak, these limits may not be applicable due to the increased volume of cases due to the public health incident. Cases presenting due to water contamination may be masked due to this increased volume. Under these circumstances, extra dependence on the expertise of astute public health personnel will be necessary to help identify cases that may be caused by water contamination.

6.3.3 Summary

The contamination scenario coverage results from the simulation study demonstrate that the EpiCenter surveillance tool is able to detect a variety of different types of contamination scenarios, involving both chemical and biological.

Utilization of historical case counts and counts above threshold are useful for quantifying estimates of contaminant detection thresholds. Although average counts above threshold may give the best estimate of cases needed to produce an alert for that syndrome, observation of total case counts and counts above "normal" should not be discounted as they also provide useful information to the public health personnel investigating the alert. Public health expertise will be especially valuable during disease outbreaks, when increased case volumes may mask cases reported due to water contamination.

6.4 Design Objective: Alert Occurrence

Alert occurrence addresses aspects of system performance, including the frequency of invalid alerts in order to ascertain the accuracy of the EpiCenter surveillance tool in discriminating between valid alerts (public health incidents, including water contamination) and normal variability in the underlying data. In order to evaluate how well the EpiCenter surveillance tool met this design objective, the following two metrics were evaluated: invalid alerts and valid alerts. The following subsections define each metric, describe how it was evaluated, and present the results.

6.4.1 Invalid Alerts

Definition: Invalid alerts include any alert generated by the EpiCenter surveillance tool that is determined as not related to a public health incident, including water contamination, following alert investigation.

Analysis Methods: The total number of invalid alerts is equal to the number of total alerts minus the number of valid alerts. These invalid alerts were analyzed by frequency and syndrome type, both by monthly reporting period and for the entire evaluation period.

Results: **Figure 6-3** shows the frequency of invalid alerts and their syndrome types per reporting period. Invalid alerts peaked in July of 2009, when there were a total of fifteen alerts encompassing five different syndromes (constitutional, gastrointestinal, neurological, rash and respiratory). On average, each reporting period experienced 2.7 invalid alerts and a median of 2 alerts. The majority of reporting periods experienced three or fewer alerts. The peak in invalid alerts during July 2009 corresponds to Cincinnati Children's Hospital coming back on-line after an upgrade to their data system which prohibited them from submitting data for one year. Therefore, this increase in alerts is due to the EpiCenter algorithms readjusting to a sudden influx of ED cases.

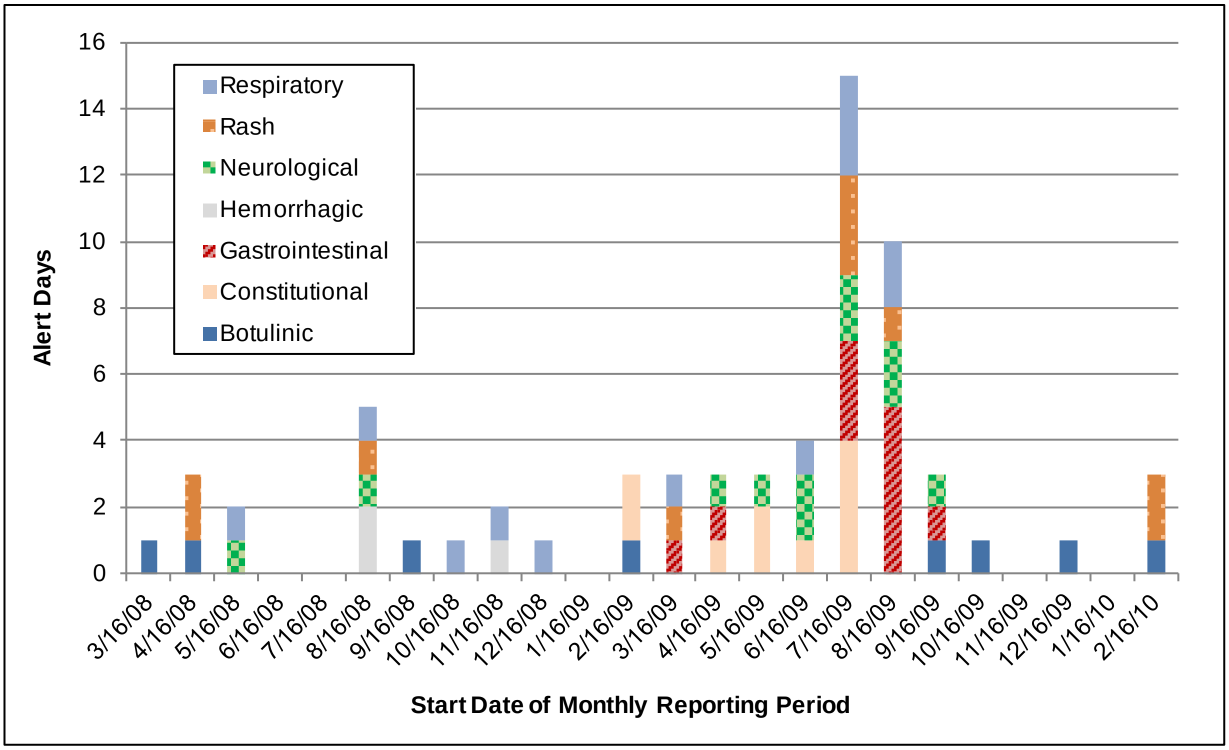

Figure 6-3. EpiCenter Invalid Alerts per Reporting Period

Invalid alerts were fairly evenly distributed by syndrome; with the exception of the Hemorrhagic syndrome (5%), each syndrome contributed between 11-19% of invalid alerts (**Figure 6-4**).

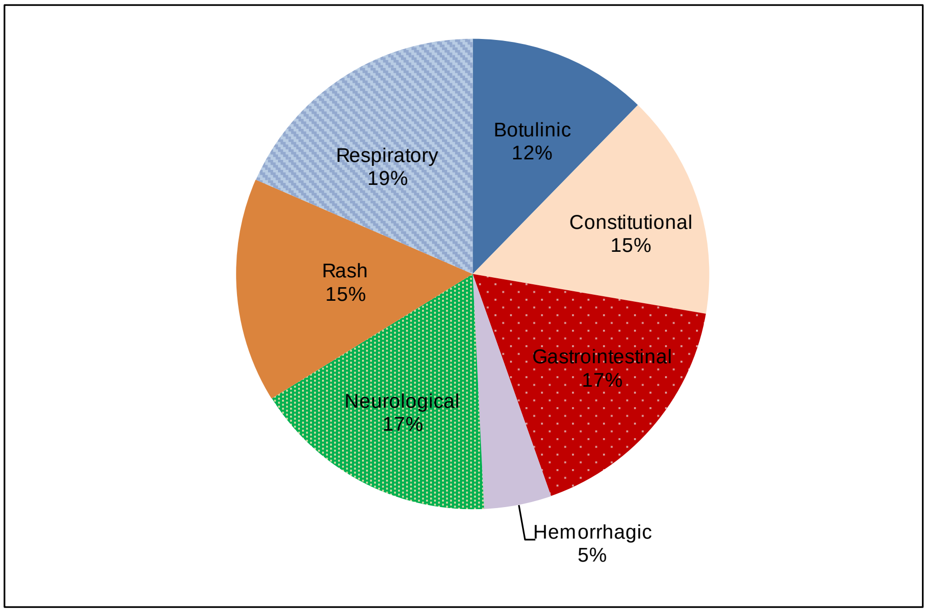

Figure 6-4. Percent of EpiCenter Invalid Alerts by Syndrome

Overall, the number of cases per invalid alert varied (range 10 to 172), although the majority of invalid alerts were caused by 50 or fewer cases (**Figure 6-5**). The average and median number of cases per invalid alert was 45.3 and 29.5 cases, respectively. In general, this is lower than the average cases per valid alert (**Figure 6-6**).

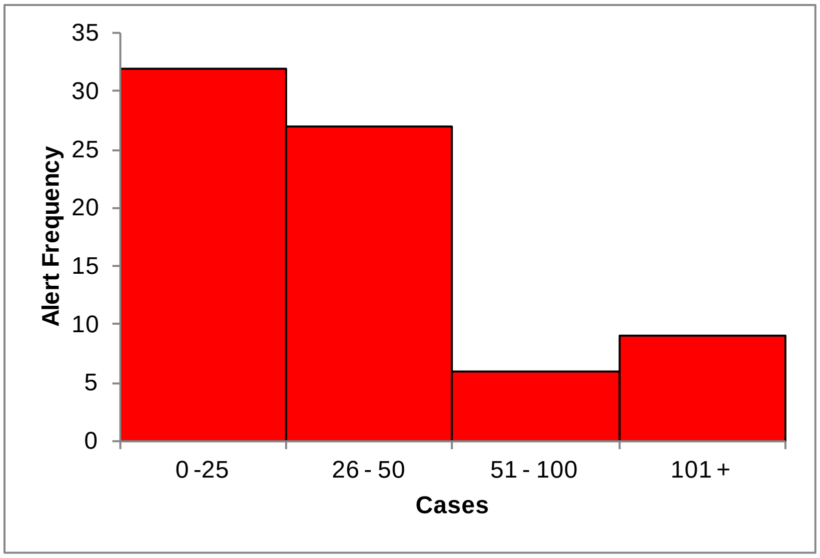

Figure 6-5. Cases per Invalid Alert

6.4.2 Valid Alerts

Definition: Valid alerts are data anomalies generated by the EpiCenter algorithm that are due to public health incidents, including possible water contamination, in the location where the alert is observed. Public health incidents in EpiCenter are denoted as "seasonal illness health event" or "naturally occurring disease outbreak" by investigators at the local health department.

Analysis Methodology: The total number of valid alerts was analyzed by frequency and type, including the alert duration and count per reporting period. In addition, a statistical analysis to determine natural breakpoints in alert count data was performed; these breakpoints were characterized by average daily counts by syndrome. Analyses conducted and presented for the contamination scenario coverage metric reflect the occurrence of valid alerts in the simulation study (Section 6.3.1).

Results: The majority of valid alerts (89.5% of all valid alerts) occurred during the fall of 2009, corresponding with H1N1 influenza activity in the Cincinnati area. The H1N1 influenza outbreak was declared a pandemic by the World Health Organization in June 2009 (World Health Organization, 2009). This outbreak was caused by a new strain of influenza virus, and circulated worldwide; persons most affected by this virus were pregnant women and otherwise healthy adults. It is estimated that 59 million people in the U.S. were affected by the H1N1 virus (CDC, 2010b). In Hamilton County, a major uptick of suspected H1N1 cases was observed around the end of August 2009, corresponding to the beginning of a new school year. Symptoms indicative of H1N1 include fever, sore throat, malaise and other general flu-like symptoms.

Due to the impact of H1N1 on the Cincinnati region, schools experienced higher than normal rates of absenteeism, EDs and medical providers saw an influx of patients, and HCPH and CHD held vaccination clinics. Because of the increased patient volume seen in EDs, EpiCenter issued numerous alerts during this timeframe. Nearly all of the alerts during this timeframe were categorized as due to "naturally occurring disease outbreak" by public health investigators. The duration and frequency of these alerts can be seen in Figure 6-6.

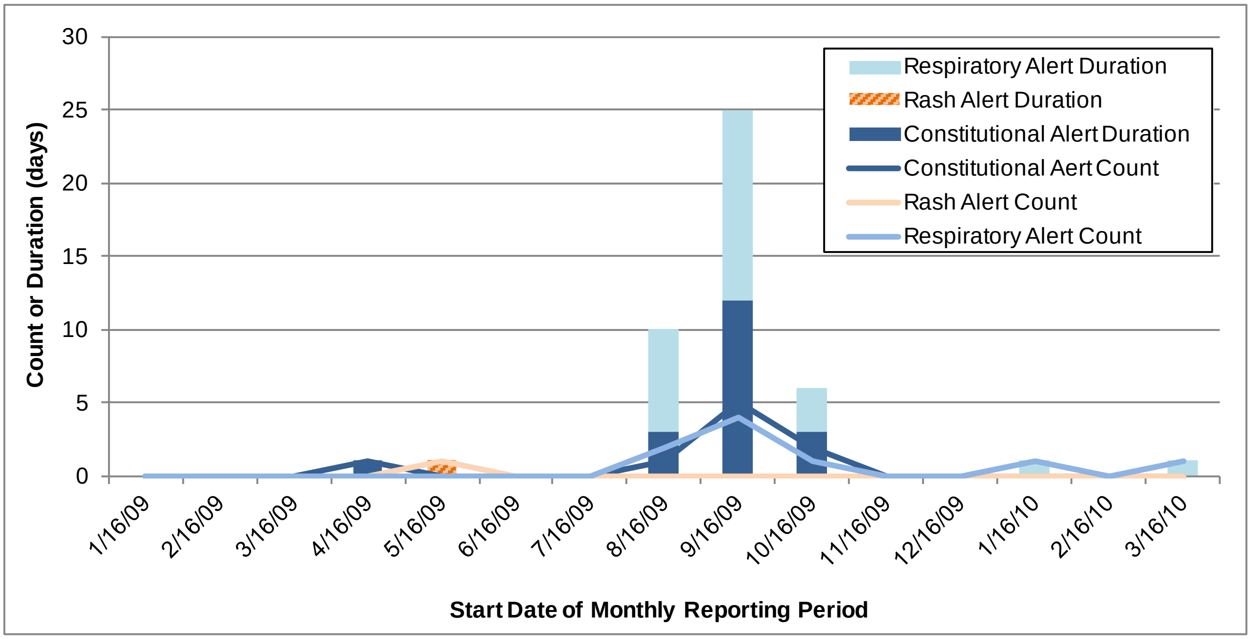

Figure 6-6. Valid Alert Count and Duration (in cumulative days) per Reporting Period

Valid alerts were an average of one day longer than invalid alerts. This is mainly attributed to the duration of alerts during the H1N1 outbreak. Alerts during this time period averaged 2.73 days in duration versus one day for other valid alerts. The longer alert duration is indicative of the breadth of the outbreak and the volume of patients affected; unlike other health incidents that resolve fairly quickly, the H1N1 outbreak is an example of an extended public health incident.

A statistical analysis of EpiCenter daily syndrome counts was performed to ascertain breakpoints in the data indicating the start and end of the H1N1 outbreak in Cincinnati. It was determined that there was a statistical increase in EpiCenter data beginning in September 6, 2009 and continuing through November 9, 2009. Average daily counts for the constitutional and respiratory syndromes were significantly higher during this timeframe, as indicated in **Figure 6-7**. It should also be noted that the data in the September 6, to November 9, 2009 timeframe demonstrated much greater variation than the other two time periods. Increases of this nature may present difficulties in detecting possible water contamination during that timeframe due to increased “noise” in the data.

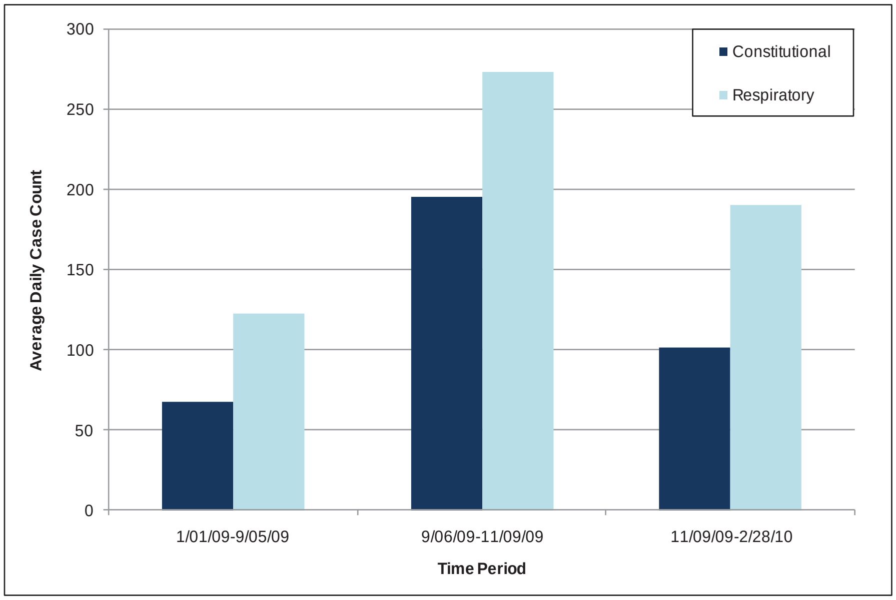

Figure 6-7. Average Daily Counts by Syndrome during Different Time Periods

6.4.3 *Summary*

While three or fewer invalid alerts occurred during most reporting periods, some months had numerous invalid alerts. The invalid alerts were distributed fairly evenly between syndrome types. Valid alerts were detected during the evaluation period, the majority of which corresponded to H1N1 influenza activity in the Cincinnati area. On average, valid alerts remained above threshold one day longer than invalid alerts.

6.5 Design Objective: Timeliness of Detection

Timeliness of detection refers to the time it takes for a potential public health incident, including water contamination, to be detected by the EpiCenter surveillance tool; the timeline begins with initial transmission of ED patient data and concludes with completion of the alert investigation. Post-exposure factors that would affect the overall timeliness of detection, such as time to symptom onset and health-seeking behaviors, are discussed in Section 3.3. Following ED data entry at participating hospitals, patient data is available for transmission and analysis in EpiCenter. In order to evaluate how well the EpiCenter surveillance tool met this design objective, the following metrics were evaluated: time for data transmission, time for event detection and time to investigate alerts. The following subsections define each metric, describe how it was evaluated, and present the results.

6.5.1 *Time for Data Transmission*

Definition: Time for data transmission describes the time it takes for ED records to be available for analysis; this includes the time it takes for coded medical record data to be transferred from the hospital data servers to the EpiCenter surveillance tool.

Analysis Methodology: Estimation of the time necessary to upload ED records into the EpiCenter surveillance tool, as supplied by the data provider (ODH).

Results: For Hamilton County, patient data is uploaded in batches from Health Bridge every ten minutes. There were no recorded incidents of delayed batch data transmission from Health Bridge to EpiCenter, however, it is important to note that data transmission from the hospital data servers to EpiCenter effectively occurs once per day in the morning after paper case records from the previous day are entered electronically as a batch in the morning.

6.5.2 Time for Event Detection

Definition: Time for event detection describes the time required for the EpiCenter surveillance tool to generate an alert using its algorithms after data has been transmitted from HealthBridge to the EpiCenter surveillance tool. This is the time for analysis of data and generation of a result by the EpiCenter algorithm.

Analysis Method: Time for event detection was calculated by subtracting the detection timestamp from the event timestamp. Statistical analysis including the average, median and range of time for event detection was calculated per month and for the entire evaluation period.

Results: Time for event detection averaged around 60 minutes for most reporting periods (**Figure 6-8**). The overall average and median time for event detection was 60.22 and 60 minutes, respectively. The range is relatively narrow, indicating that there is little variability in the time for event detection. This indicates that most events were detected by the system in the minimum amount of time possible. See Figure 6-3 for additional details on alert occurrence.

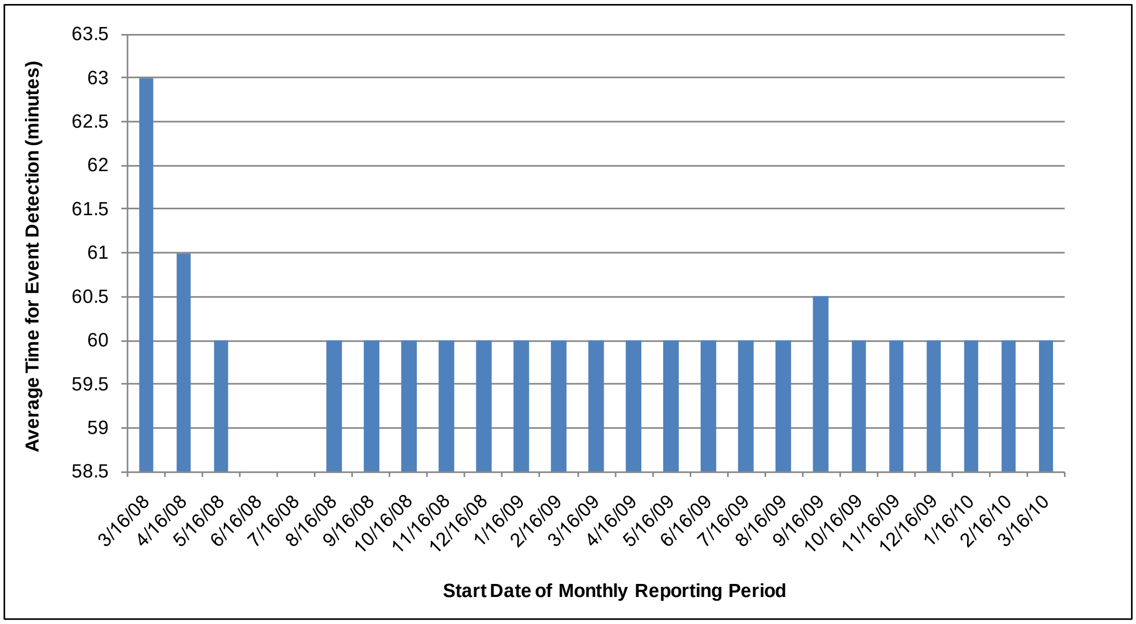

Figure 6-8. EpiCenter Time for Event Detection

6.5.3 Time to Investigate Alerts

Definition: Time to investigate alerts includes the portion of the incident timeline that begins with the recognition of an EpiCenter alert, and ends with a determination regarding whether or not contamination is possible. The time to investigate alerts is based on the nature of the alert details and the investigation procedures that must be implemented before concluding that the alert is not indicative of a potential public health incident, including water contamination. For the simulation study, this data represents the timeline from the contaminant injection to the time that contamination is deemed Possible. As noted in Section 3.3, no time delay for alert recognition was parameterized in the CWS model as it was assumed that alert investigations occurred immediately upon receipt of alerts based on the nature of the underlying case data (i.e., similar symptom categories and case clustering).

Analysis Methodology: Statistical analysis of empirical data was not possible, as investigation time was not formally recorded by public health investigators. However, personnel responsible for investigating the alerts provided an approximation of the typical investigation time.

This information was used to parameterize the investigation time for EpiCenter alerts in the simulation study. Simulation study timeline data (which, as noted above, started at the time of contaminant injection) was evaluated to illustrate the timeliness of detection overall and for scenarios initiated at periods of high or low demand. Percentile values were calculated to examine the distribution of data, and are presented in a box-and-whisker plot. Average detection times were calculated for individual contaminants, as well as for scenarios initiated at periods of high or low demand for individual contaminants.

Results: Based on feedback from local public health, it is estimated that EpiCenter alerts require approximately fifteen minutes of investigation time. The exact time spent per investigation was not documented.

The remainder of this section focuses on simulation study results. **Figure 6-9** demonstrates the overall timeliness of detection statistics for the EpiCenter surveillance tool and for scenarios initiated at periods of low and high demand, using percentile values to illustrate the distribution of data. Scenarios initiated at high demand times were detected sooner than scenarios initiated at low demand times due to the design of the CWS model. A seven-hour time delay occurred between the scenarios initiated at low demand (12:00 am) and the first exposure event (7:00 am), which resulted in a detection time lag, unlike the scenarios initiated at high demand (9:00 am), which could have resulted in exposure soon thereafter at the 9:30 am or 12:00 pm exposure events. The high demand box plot is not displayed in Figure 6-9 due to the frequency of detections at 1,380 minutes creating no distinction between percentiles in the plot.

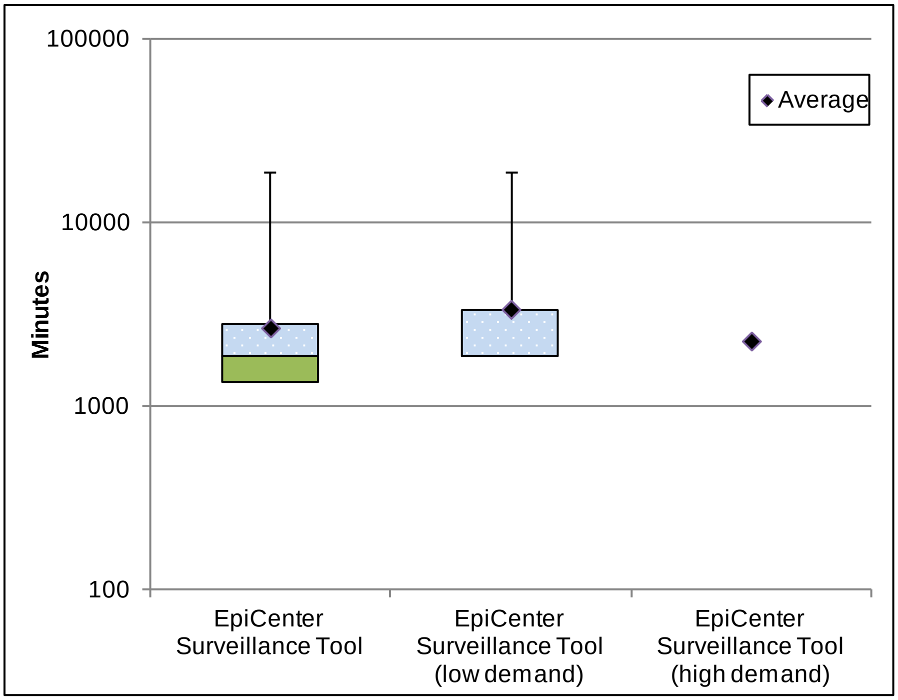

Figure 6-9. EpiCenter Surveillance Tool Timeliness of Detection (simulation study data)

There were a total of 994 scenarios detected by the EpiCenter data stream with an average detection time of 2,668 minutes (approximately two days), as shown in **Table 6-4**. As noted above, scenarios initiated at high demand were detected sooner, with an average detection of time 2,281 minutes, whereas scenarios initiated at low demand had an average detection time of 3,396 minutes.

Table 6-4. EpiCenter Surveillance Tool Timeliness of Detection (minutes, simulation study data)

Scenarios	Count	Average	Median
Total	994	2,668	1,920
Low Demand	363	3,396	1,920
High Demand	631	2,281	1,380

The low and high demand scenarios are further compared, along with the overall detection timeliness in **Figure 6-10**, where contaminants are arranged in increasing order of timeliness of detection by the total set of component scenarios. This figure illustrates that for most chemical and biological agent contamination scenarios, it took about one day for case counts to become high enough to exceed the detection thresholds for the relevant syndrome categories monitored by the EpiCenter surveillance tool. For one toxic chemical and one biological agent, two or more days elapsed before enough cases had occurred to produce EpiCenter alerts. Therefore, the type of contaminant may not have an impact on the timeliness of detection by EpiCenter. Biological Agents 6 and 7 are not presented in this figure as they were not detected by the EpiCenter surveillance tool, as discussed in Section 6.3.1.

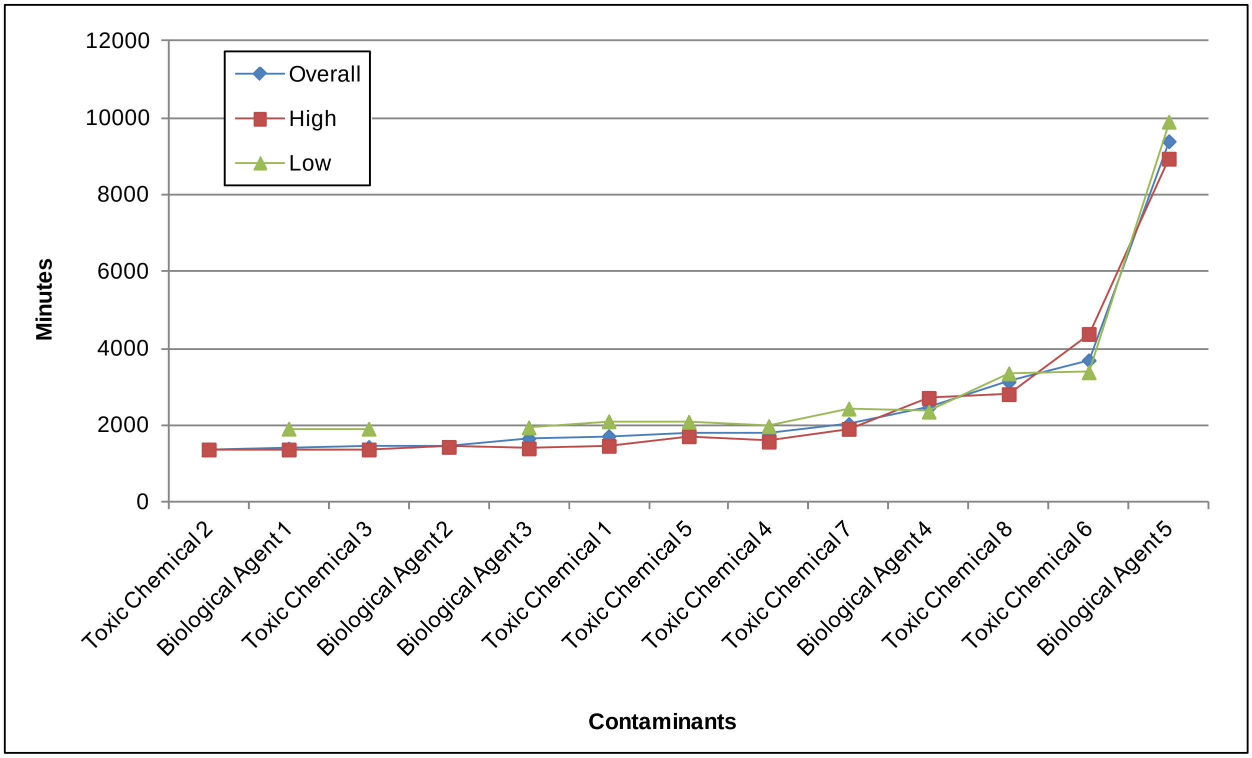

Figure 6-10. EpiCenter Surveillance Tool Timeliness of Detection (simulation study data)

6.5.4 Summary

Data transmission for EpiCenter is dependent on batch uploads of data from HealthBridge, which occur every ten minutes. Technically, new data is available for analysis once every 24 hours in the morning due to the fact that paper records from the previous day are entered electronically in batches every morning. The time for event detection is extremely consistent in the EpiCenter surveillance system, averaging around 60 minutes. In general, EpiCenter alerts require about fifteen minutes for investigation.

Simulation study data analysis showed that for most contamination scenarios, it took one day for case counts to become high enough to exceed the detection thresholds for the relevant syndrome categories monitored by the EpiCenter surveillance tool.

6.6 Design Objective: Operational Reliability

Analysis of the operational reliability of the EpiCenter surveillance tool addresses aspects of surveillance tool operation and quantifies the percent of time that the EpiCenter surveillance tool was working as designed. In order to evaluate how well the EpiCenter surveillance tool met this design objective, the availability metric was analyzed. The following subsection defines the metric, describes how it was evaluated, and presents the results

6.6.1 Availability

Definition: Availability is the amount of time the EpiCenter surveillance tool is functional and accessible, expressed in terms of the percent of usable data hours per reporting period. In order for available data to be generated for the EpiCenter surveillance tool, data must be successfully collected from participating hospitals, analyzed using EpiCenter's algorithms, and any alert information made available on the EpiCenter User's Interface.

Analysis Methods: Information on the number of hospitals submitting data per reporting period was gathered from ODH. From this, availability was calculated as a percent of all potential data collected for that reporting period.

Results: At least a portion of data within the EpiCenter surveillance tool was available during the entire evaluation period. However, some data was unavailable during part of the evaluation period due to a hospital data system upgrade, during which Cincinnati Children's Hospital was unable to report data to EpiCenter. The total data availability during this timeframe (July 2008 to July 2009) was still high at 92%.

During times when data availability is less than 100%, it is important for the public health investigators to be aware of these issues. In this instance, Cincinnati Children's Hospital was unable to report during the July 2008 – July 2009 timeframe; therefore, children may have been underreported in the EpiCenter data during this time.

6.6.2 Summary

EpiCenter received almost all potential data during the evaluation period, contributing to high overall reliability of the surveillance tool. Public health investigators should be notified when possible issues with data availability may occur (e.g., hospitals going off-line), so that these periods of downtime can be taken into account during analysis.

Section 7.0: Performance of the DPIC Surveillance Tool

The following section provides a description of the DPIC surveillance tool followed by the results of the evaluation of the tool. This analysis includes an evaluation of metrics that characterize how the DPIC surveillance tool achieves the design objectives described in Section 1.1. Specific metrics are described for each of the design objectives.

7.1 Description of the DPIC Surveillance Tool

DPIC is a PCC serving southwest Ohio. DPIC offers emergency and technical information 24-hours a day via telephone service staffed by pharmacists, pharmacologists, nurses, paramedics and students. Any questions about poisonings, environmental contamination, drugs (including drug abuse), product contents, substance identification and adverse reactions are handled by the DPIC hotline. Call information is captured in Toxicall®, a specialized medical database. In addition, under a contract with the Southwest Ohio Public Health Departments, reportable diseases and other potential public health incidents detected during evenings, weekends, and holidays are reported to DPIC. Protocols exist to report potential food or waterborne outbreaks and unusual disease incidence, as well as to notify public health officials if a potential biological terrorist incident is detected.

As part of the Cincinnati CWS, DPIC was integrated into the PHS component of the CWS to determine how local PCCs can contribute to early detection, notification, and rapid response to a possible drinking water contamination incident. DPIC implemented a multi-tiered approach to event detection based on existing surveillance strategies that include statistical, non-statistical, and human surveillance as illustrated in **Figure 7-1**. Throughout this section of the report, the phrase “DPIC surveillance tool” represents the collective detection strategies applied by DPIC for identification of a possible contamination.

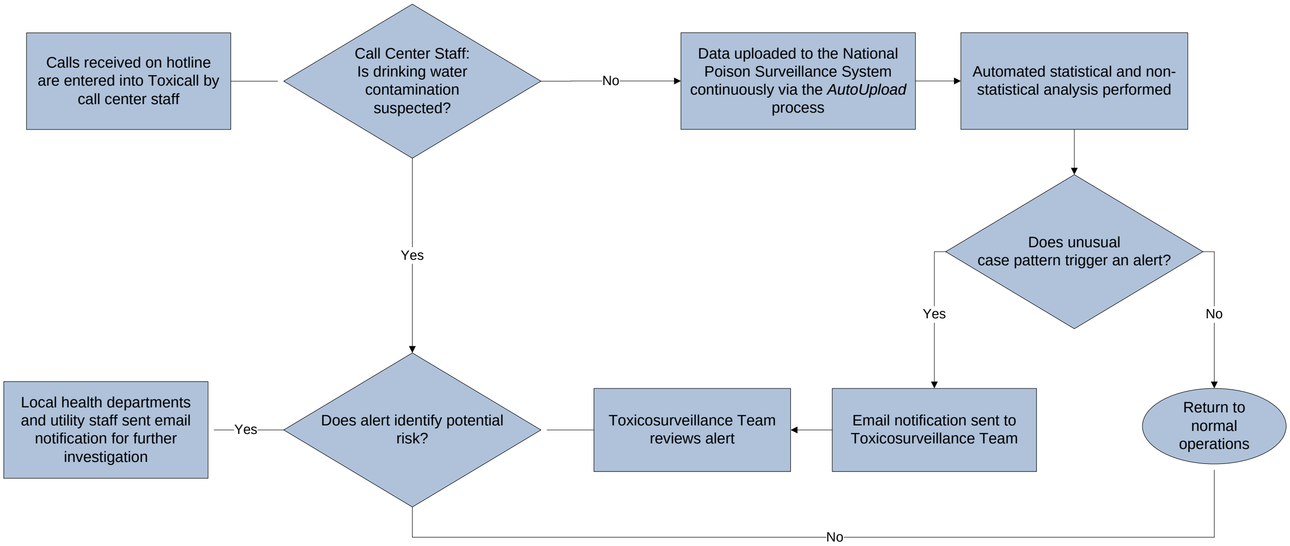

Figure 7-1. DPIC Drinking Water Surveillance Process Flow

Data collected by DPIC in Toxicall® is uploaded into the NPDS on a near real-time basis via an automated process. The American Association of Poison Control Centers operates NPDS to aggregate PCC data from across the nation for purposes of statistical analysis, alert processing and communication of findings. NPDS offers center-centric (i.e., all calls handled by a PCC) as well as geocentric (i.e., all calls occurring within a certain area) surveillance. For example, DPIC covers southwest Ohio as well as an area in northeast Ohio; geocentric surveillance allows DPIC to analyze these areas separately, if desired. Four toxicosurveillance statistical categories can be applied for surveillance, including:

- **Total call volume:** All calls to poison control, including exposure information, substance identification, and general education calls.
- **Human exposure call volume:** Calls pertaining to human exposures only.
- **Clinical effect counts:** Based on symptoms exhibited due to human exposure.
- **Case based:** Case definition specified by poison control using key words and logic.

Because DPIC handles calls from outside the Cincinnati area, a geocentric surveillance approach including all Ohio zip codes in the GCWW service area was utilized for the Cincinnati CWS. Statistical analyses can be performed in NPDS on the total call volume human exposure call volume, and clinical effect count toxicosurveillance definitions. Because total call volume includes calls not pertinent to possible water contamination exposure (e.g., substance identification calls), focus was placed instead on statistical analysis of human exposure call volume and clinical effect count definitions. Aberrations that are greater than three times the standard deviation from the baseline and involve at least two cases for either of these definitions trigger an email, which is sent to the toxicosurveillance team (on call 24/7/365) for further investigation.

The case based definition in NPDS's Syndromic Definition Module was leveraged for non-statistical surveillance of possible water contamination cases. The toxicosurveillance team developed a customized search through this module that incorporates specific substance and symptom keywords thought to be most likely related to an incident involving a specific class of contaminants (e.g., metals) 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 DPIC relies on human surveillance. The human surveillance method for the Cincinnati CWS relies on expertise from certified staff members and physician toxicologists, along with the open call center environment that facilitates ongoing discussion and consultation among staff members, in order to identify anything "out of the ordinary" in the observed calls. In addition, DPIC established a "Water Safety Hotline" that is dedicated for water contamination queries. Health care and public health providers as well as 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. During the evaluation period, approximately two alerts per month were identified through human surveillance, comprising 3.7% of all DPIC alerts.

Similar to the EpiCenter surveillance tool, the DPIC surveillance tool was not significantly altered for the Cincinnati CWS because it was a previously established public health entity. One enhancement to the surveillance of PCC data was the inclusion of a water-based syndrome definition, and increased awareness of the possibility of water contamination incidents by DPIC staff. Evaluation of the DPIC surveillance tool focuses on its ability to identify public health incidents, including water contamination. In the context of the CWS, a DPIC valid alert is any alert tied to an intentional or unintentional public health incident, including water contamination. Classification of an alert as valid is at the discretion of the DPIC investigator.

7.2 Design Objective: Spatial Coverage

The spatial coverage is the cumulative area where DPIC has the ability to detect a public health incident, including water contamination, in the GCWW distribution system based on spatial data provided in the alerts. The zip codes listed in DPIC alerts represent caller location; although location was not regularly recorded in DPIC alert investigations by protocol, this information was sometimes provided. Because DPIC also provides toxicology advice to ED physicians, in some instances this location represents the place of treatment for a person (i.e., a hospital) rather than the location of exposure. This affects the interpretation of spatial analysis results. The three metrics used to evaluate how well DPIC surveillance achieves this design objective were area and population coverage, and spatial extent of an alert. The following subsections define each metric, describe how it was evaluated, and present the results.

7.2.1 Area and Population Coverage

Definition: Area coverage describes how alerts are distributed geographically, while population coverage describes the geographic area covered by the DPIC surveillance tool.

Analysis Methodology: Analysis of empirical data including a statistical analysis of alerts per zip code, as well as analysis of zip codes per alert, was performed using alert data from the combined DPIC surveillance strategies (statistical, non-statistical and human surveillance).

Results: Since DPIC covers the entire Southwest Ohio area, the DPIC surveillance tool covers 100% of the GCWW retail service area. Fifty-two out of 486 (11%) total DPIC alerts contained zip code information. A low percentage of zip codes were recorded because the standard protocol used by DPIC does not require the location to be recorded, as described above. However, these 52 alerts encompassed 70% of all zip codes in Hamilton County; only 19 county zip codes were not included in any alerts. Even with a low percentage of alerts reporting zip codes, DPIC alerts occurred throughout the county, indicating the comprehensive area coverage for this surveillance tool. There does not appear to be any clear pattern in the geographical distribution of DPIC alerts within Hamilton County.

Descriptive statistics demonstrating the number of alerts per zip code are provided in **Table 7-1**. The histogram in **Figure 7-2** depicts the frequency of alerts per zip code.

Table 7-1. Statistics of Alerts per Zip Code

Parameter	Alerts per Zip Code
Average	4.98
Median	3
Minimum	1
Maximum	39

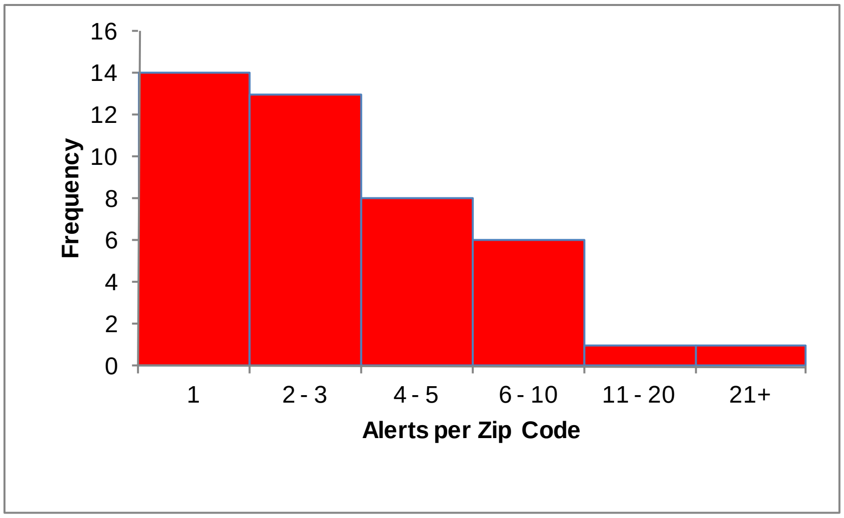

Figure 7-2. Histogram of Alerts per Zip Code

7.2.2 Spatial Extent of an Alert

Definition: Spatial extent of an alert describes the geographic area (size) of each DPIC alert.

Analysis Methodology: Statistical analyses of the average, minimum, and maximum number of caller zip codes in DPIC alerts was performed for the entire evaluation period using the combined surveillance strategies (statistical, non-statistical, and human surveillance).

Results: As mentioned in Section 7.2.1, zip code information was available for only 11% of DPIC alerts. The average, median, and range of zip codes per alert are presented in **Table 7-2**. The statistics in this table represent the number of distinct zip codes per alert. For example, if two callers from 45219 were listed in the same alert, that alert contains one zip code. Most alerts had between three and seven zip codes implicated, as shown in the histogram in **Figure 7-3**. No alert encompassed more than 11 zip codes.

Table 7-2. Statistics of Zip Codes per Alert

Parameter	Zip Codes per Alert
Average	4.96
Median	5
Minimum	1
Maximum	11

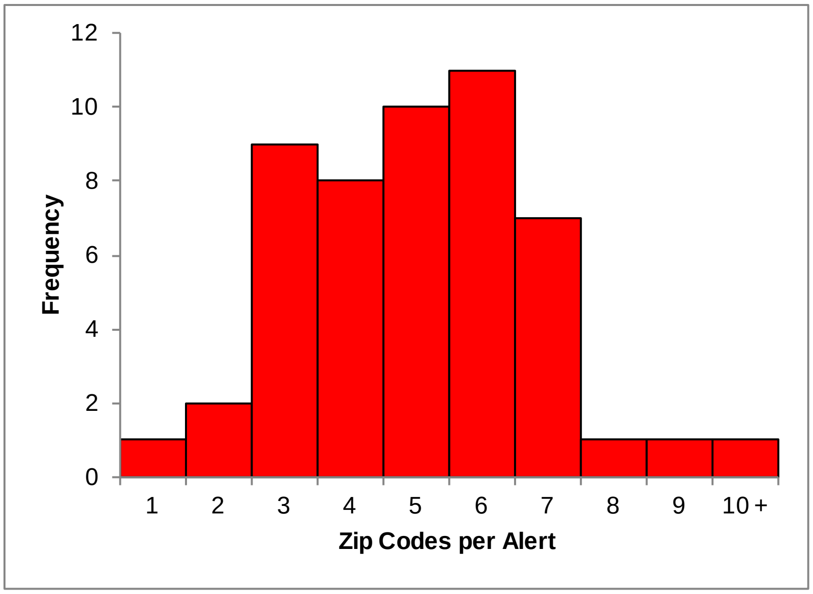

Figure 7-3. Histogram of Zip Codes per Alert

Alert zip codes were also analyzed to determine whether the locations were clustered or random. A "cluster" was defined as more than one call being from the same zip code (i.e., two calls from the 45013 zip code constitutes a "cluster"). Often, the location of zip codes in any one alert appeared random, although in 14 instances a cluster of calls was observed. This happened most frequently with the 45219 zip code, which was involved in half of the cluster incidences. Zip code 45219 was implicated more often because that zip code contains a plurality of the hospitals in Hamilton County; calls to DPIC from ED physicians in this area were recorded as 45219 calls. Two other zip codes with a hospital, 45014 and 45229, also contained a cluster. The remaining clusters were randomly distributed around Hamilton County. A listing of these cluster frequencies can be found in **Table 7-3**.

Table 7-3. Cluster Frequency per Zip Code

Zip Code	Cluster Frequency
45013	1
45014*	1
45067	1
45219*	7
45226	1
45229*	1
45241	1
45247	1

*Contains at least one hospital

7.2.3 Summary

Zip code information was only available for 52 of the 486 listed alerts, which limits the statistical relevance of the data sample to the broader population. In addition, identifying caller location as opposed to exposure location leads to many alerts reported in zip codes with a concentration of hospitals, and makes interpretation of the results difficult; for example, alert clusters appear to be affected by hospital location within Hamilton County, but no other patterns are readily apparent. However, alerts that did contain zip code information covered around 80% of the county population, demonstrating acceptable area coverage.

7.3 Design Objective: Contaminant Coverage

The DPIC surveillance tool monitors calls from persons which may signal a public health incident, including water contamination or calls from healthcare providers who are treating exposed persons. For DPIC calls, contaminant coverage is dependent on the health-seeking behaviors following symptom presentation, as described in Section 3.3. Simulation study results from the simulated Astute Clinician monitoring (via patients being treated by primary care physicians or ED physicians) are also presented in this section. In order to evaluate how well the DPIC surveillance tool and Astute Clinician monitoring met this design objective, contamination scenario coverage was evaluated. The following subsection defines the metric, describes how it was evaluated, and presents the results.

7.3.1 Contamination Scenario Coverage

Definition: Contamination scenario coverage is defined as the ratio of contamination incidents that are actually detected to those that are theoretically detectable based on the design of the DPIC surveillance tool. Detectable contamination scenarios included those which originated at distribution system attack nodes rather than facility attack nodes, and those that were assumed to result in calls to DPIC (i.e., rapid symptom onset, unusual symptoms). No calls to DPIC were assumed for individuals exposed to the Toxic Chemical 8, Biological Agent 3, 4, 5, 6 and 7. For the Astute Clinician monitoring, all contamination scenarios that originated at distribution system attack nodes were theoretically detectable.

Analysis Methodology: Since no water contamination incidents occurred during the evaluation period, simulation study results were utilized to quantify this metric. The ratio of scenarios actually detected to those that were theoretically detectable (based on the assumptions regarding health-seeking behavior that were parameterized in the model) was calculated for each contaminant. Additionally, the average and median number of cases at the time of detection was calculated for each contaminant. Certain contamination scenarios that were not theoretically detectable were screened out of the analysis including those that originated at facility attack nodes (which were detected by the ESM component) and those which involved the nuisance chemicals.

Results: The DPIC surveillance tool (which was modeled based on DPIC's volume-based clinical effects algorithm, and DPIC's active human surveillance) detected 85% (717 scenarios) of the theoretically detectable scenarios (846 scenarios). **Table 7-4** below shows the detection statistics for the DPIC surveillance tool for each contaminant.

Table 7-4. DPIC Detection Statistics

Contaminant	Scenarios Detected	Scenarios Not Detected	Percent Detected	Average # Cases at Time of Detection	Median # Cases at Time of Detection
Toxic Chemical 1	94	0	100%	247	136
Toxic Chemical 2	16	78	17%	431	322
Toxic Chemical 3	58	36	62%	516	421
Toxic Chemical 4	94	0	100%	728	480
Toxic Chemical 5	94	0	100%	519	265
Toxic Chemical 6	90	4	96%	5,332	4,028
Toxic Chemical 7	94	0	100%	848	478
Toxic Chemical 8	Not detectable	-	-	-	-
Biological Agent 1	94	0	100%	308	156
Biological Agent 2	83	11	88%	126	91
Biological Agent 3	Not detectable	-	-	-	-

Contaminant	Scenarios Detected	Scenarios Not Detected	Percent Detected	Average # Cases at Time of Detection	Median # Cases at Time of Detection
Biological Agent 4	Not detectable	-	-	-	-
Biological Agent 5	Not detectable	-	-	-	-
Biological Agent 6	Not detectable	-	-	-	-
Biological Agent 7	Not detectable	-	-	-	-

The DPIC surveillance tool generally had a high detection rate across almost all contaminants, with 100% detection for five of the eleven contaminants and another two contaminants at 88% and 96%. There was a noticeably lower detection rate for Toxic Chemical 2 (17%) and Toxic Chemical 3 (62%), which is the result of the rapid symptom progression that occurs following exposure to these contaminants. Exposed individuals proceed quickly to the severe symptom level, at which time urgent treatment is pursued (i.e., call 911 to request EMS transport to the ED, or self-transport to the ED). Accordingly, only a small percentage of cases call DPIC at the lower symptom level before proceeding to moderate and severe symptoms, which results in lower detection rates for these contaminants.

Additionally, for most contaminants, only several hundred cases had occurred on average at the time of detection which demonstrates the limited number of calls to DPIC required to produce an alert (i.e., the scenarios did not progress for a long time prior to detection).

The Astute Clinician monitoring (which was conducted via monitoring the number of cases seen by primary care physicians or ED physicians) detected 99.5% (1,395 scenarios) of the theoretically detectable scenarios (1,402 scenarios). **Table 7-5** below shows the detection statistics for the Astute Clinician monitoring for each contaminant.

Table 7-5. Astute Clinician Detection Statistics

Contaminant	Scenarios Detected	Scenarios Not Detected	Percent Detected	Average # Cases at Time of Detection	Median # Cases at Time of Detection
Toxic Chemical 1	93	1	99%	429	344
Toxic Chemical 2	94	0	100%	246	142
Toxic Chemical 3	94	0	100%	276	119
Toxic Chemical 4	94	0	100%	770	480
Toxic Chemical 5	94	0	100%	534	265
Toxic Chemical 6	94	0	100%	3,760	2,322
Toxic Chemical 7	94	0	100%	1,001	625
Toxic Chemical 8	94	0	100%	2,121	1,706
Biological Agent 1	94	0	100%	332	167
Biological Agent 2	94	0	100%	115	88
Biological Agent 3	94	0	100%	21,213	1,647
Biological Agent 4	94	0	100%	284	247
Biological Agent 5	94	0	100%	435	208
Biological Agent 6	85	3	97%	18	17
Biological Agent 7	89	3	97%	38	33

The Astute Clinician surveillance tool had a high detection rate, at or above 97% for all contaminants. For all contaminants, the CWS model was parameterized such that it does not take many cases for identification of a contaminant by an astute clinician. The contaminants included in the model produce very unusual symptoms (and in the case of the toxic chemicals, rapid symptom onset), which allows for a more efficient clinical interpretation by an astute clinician who had familiarity with chemical poisonings and waterborne or infectious diseases. For the few scenarios where detection did not occur for Biological Agents 6 and 7, there were either very few individuals infected or no individuals infected.

7.3.2 Summary

The contamination scenario coverage results from the simulation study demonstrate that the DPIC surveillance tool and Astute Clinician monitoring are able to frequently and quickly detect a broad range of contaminants. While both of these surveillance strategies proved effective through analysis of simulation study results, the monitoring conducted by astute clinicians in real-world situations provides broader and more reliable (sensitive) contaminant coverage, as DPIC detection is limited to contaminants with rapid symptom onset which produce unusual symptoms in a short period of time. Furthermore, detection by DPIC is dependent on calls being placed to the poison control hotline whereas active monitoring by astute clinicians is conducted continually during treatment of patients at doctor's offices and at the ED.

7.4 Design Objective: Alert Occurrence

Alert occurrence addresses how well the DPIC surveillance tool performs by describing the volume of alerts that occurred, and the number of these alerts that were valid (i.e., public health incident, including possible water contamination). It should be noted that no valid alerts occurred during the evaluation period of the DPIC surveillance tool. Analyses conducted and presented for the contamination scenario coverage metric reflect the occurrence of valid alerts in the simulation study (Section 7.3.1). Thus, to characterize this design objective, invalid alerts were evaluated. The following subsection defines the metric, describes how it was evaluated and presents the results.

7.4.1 Invalid Alerts

Definition: Invalid alerts include any alert generated by the DPIC surveillance tool that is determined as not related to a public health incident, including water contamination, following alert investigation.

Analysis Methodology: The total number of invalid alerts is equal to the number of total alerts minus the number of valid alerts. These invalid alerts were quantified by month and analyzed statistically for the entire evaluation period.

Results: A total of 486 invalid alerts occurred, with an average of 16.7 alerts per month. As seen in **Figure 7-4**, the number of invalid alerts fluctuated by month, ranging from 4 to 41 alerts. The high number of alerts in the August 2009 reporting period was due to 19 alerts occurring on August 18, 2009; although this is an unusually high number of alerts in one day, they were not related. There did not appear to be any seasonal patterns.

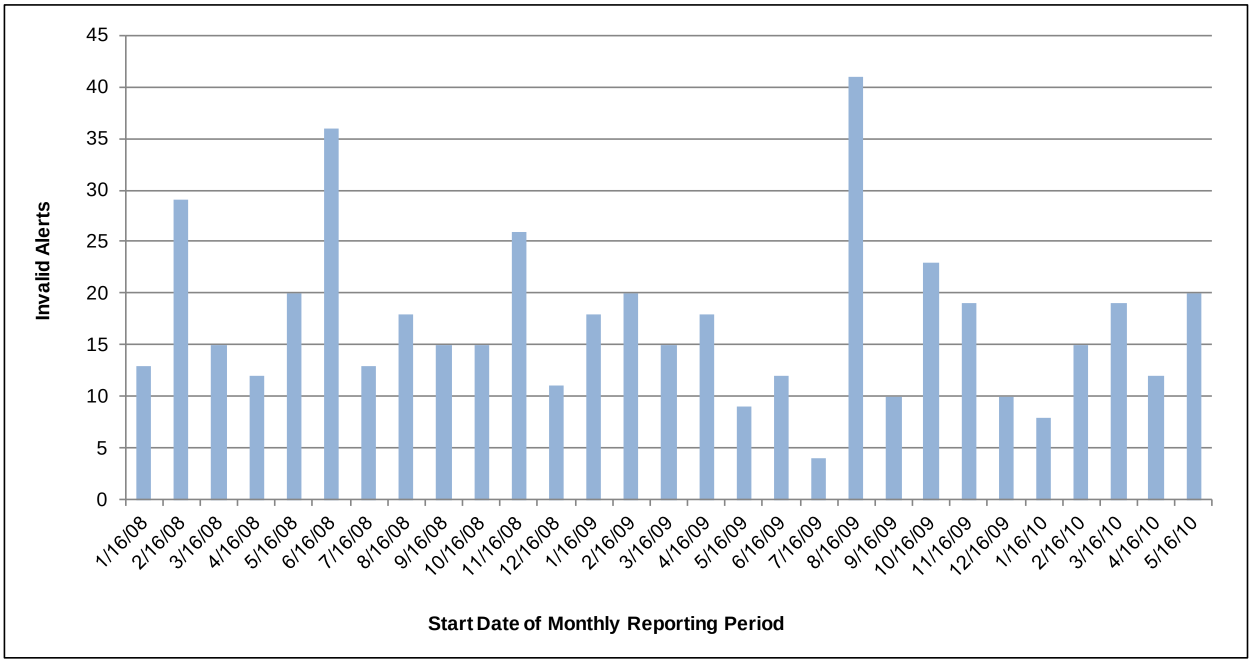

Figure 7-4. DPIC Invalid Alerts per Reporting Period

Table 7-6 includes statistics for DPIC invalid alerts for the evaluation period as a whole.

Table 7-6. Statistics of Alerts per Month

Parameter	Alerts per Month
Average	16.7
Median	15
Minimum	4
Maximum	41

7.4.2 Summary

The number of invalid alerts per month fluctuated, with no discernible seasonal patterns. Between 10 and 20 invalid alerts occurred during most months, and, on average, 16.7 invalid alerts were received per month.

7.5 Design Objective: Timeliness of Detection

Timeliness of detection refers to the time it takes for a potential public health incident, including water contamination, to be detected by the DPIC surveillance tool; the timeline begins with initial transmission of DPIC call data and concludes with completion of the alert investigation. Post-exposure factors that would affect the overall timeliness of detection, such as time to symptom onset and health-seeking behaviors, are discussed in Section 3.3. In order to evaluate how well the DPIC surveillance tool met this design objective, the following four metrics were evaluated: time for data transmission, time for event detection, time to recognize alerts and time to investigate alerts. The following subsections define the metric, describe how it was evaluated and present the results.

7.5.1 Time for Data Transmission

Definition: Time for data transmission measures the amount of time it takes collected call data to be uploaded into the NPDS system, from which point it is available for analysis via algorithms applied to the toxicosurveillance categories.

Analysis Methodology: Time for data transmission was summarized, as reported by NPDS.

Results: NPDS collects data in near real-time (< 1 minute) and no interruptions in actual data transmission were recorded during the evaluation period.

7.5.2 Time for Event Detection

Definition: Time for event detection describes the time required for the DPIC surveillance tool to generate an alert using the statistical, non-statistical and human surveillance analysis methods. This is the time for analysis of data and generation of a result.

Analysis Methodology: Since no documented data on time for event detection was collected, a qualitative characterization of time for event detection was performed based on feedback from DPIC personnel for each of the surveillance tools.

Results: For the human exposure call volume and clinical effect count algorithms, the NPDS analysis module includes a latency period of four hours to allow adequate time for call details to be completely entered into the system. This latency period begins after the defined surveillance window, as set by the user in NPDS. For example, if the definition period was set for 1 to 2 pm, calculations for that period will not be performed until 6 pm. Once calculations begin, they are completed in near real-time. Since the latency period applies to all statistical calculations, the time for event detection is consistent at four hours for the human exposure call volume and clinical effect counts. In contrast, NPDS is programmed to generate alerts immediately for the non-statistical case based definition (no latency period) for any case entered into Toxicall® database that matches the definition criteria. Therefore, the time for event detection using non-statistical surveillance is near real-time.

For the human surveillance method, the time for event detection is approximately 15 minutes for household calls and 45 minutes for physician calls. For household calls, DPIC interacts with the caller for approximately 15 minutes prior to flagging an alert for additional investigation by senior personnel if water contamination is suspected. For calls received from ED physicians, DPIC interacts with the physician for an average of 45 minutes during the investigation. Therefore, the time for event detection for either household or hospital calls during a possible water contamination incident is expected to be less than one hour. An overview of the results is found in **Table 7-7**.

Table 7-7. Time for Event Detection

Surveillance Method	Latency Period?	Time for Event Detection
Statistical (human exposure call volume and clinical effect count algorithms)	Yes	4 hours
Non-statistical (case-based definition)	No	Near real-time
Human	No	15 or 45 minutes

7.5.3 Time for Alert Recognition

Definition: Time for alert recognition quantifies the time for DPIC staff to recognize the email alert and begin the investigation. This portion of the timeline begins when an alert is generated by the NPDS algorithms and notification is sent via email to public health personnel, and ends when public health personnel recognize receipt of the alert.

Analysis Methodology: Statistical analysis (average, median, and range) of time for alert recognition was performed for each month for the combined surveillance tools, as collected from the investigation checklists. Calculations were also performed for the evaluation period as a whole.

Results: The average time for recognition of DPIC alerts was approximately 10 hours during most reporting periods (**Figure 7-5**).

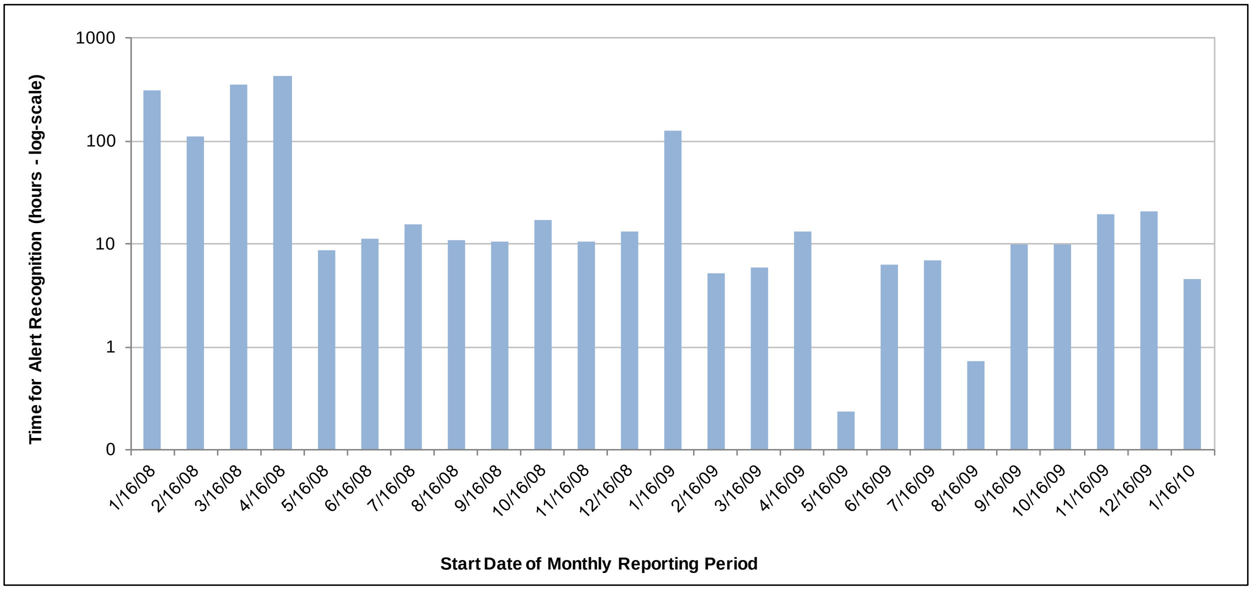

Figure 7-5. Average Time to Recognize DPIC Alert by Month

Overall statistics are presented in **Table 7-8**. The difference between the overall average (54.2 hours) and median (11 hours) values represents a relatively long time for alert recognition during the beginning of the evaluation period. During this time, participants were not expected to investigate alerts in real-time; therefore, investigations may have been delayed until personnel had more time to perform investigations.

Table 7-8. Time to Recognize DPIC Alert (Hours)

Parameter	Time (hours)
Average	54.2
Median	11
Minimum	<1
Maximum	426

7.5.4 Time to Investigate Alerts

Definition: Time to investigate alerts includes the portion of the incident timeline that begins with the recognition of a DPIC alert, and ends with a determination regarding whether or not contamination is possible. The time to investigate alerts, as captured in the investigation checklists, is based on the nature of the alert details and the investigation procedures that must be implemented before concluding that the alert is not indicative of a possible contamination incident. For PHS drills and the simulation study, this data represents the timeline from the contaminant injection to the time that contamination is deemed possible. As noted in Section 3.3, no time delay for alert recognition was parameterized in the CWS model as it was assumed that alert investigations occurred immediately upon receipt of alerts based on the nature of the underlying case data (i.e., similar symptom categories and case clustering).

Analysis Methodology: Analysis of invalid alerts recorded during the evaluation period was performed to calculate the overall time, as well as average, median and range of times as listed in the investigation checklists for the combined DPIC surveillance tools. Information on investigation time from PHS drills was used to describe time to investigate simulated DPIC alerts that were ultimately determined to be possible contamination incidents.

Timeline data gathered from investigation of DPIC alerts during PHS drills was used to parameterize the investigation time for DPIC alerts in the simulation study. Simulation study results from the simulated DPIC case based statistical surveillance and Astute Clinician monitoring (via patients being treated by primary care physicians or ED physicians) are also presented in this section. Simulation study timeline data (which, as noted above, started at the time of contaminant injection) was evaluated to illustrate the timeliness of detection overall and for scenarios initiated at periods of high or low demand. Percentile values were calculated to examine the distribution of data, and are presented in a box-and-whisker plot. Average detection times were calculated for individual contaminants, as well as for scenarios initiated at high or low demand periods for individual contaminants.

Results: The results presented below are arranged in order of empirical data, drill data, and simulation study data.

Empirical Data

Figure 7-6 shows the average invalid alert investigation time for each monthly reporting period. Some long investigation times were recorded during the development and testing phase (early in the evaluation period) when investigators were not expected to respond immediately to alerts.

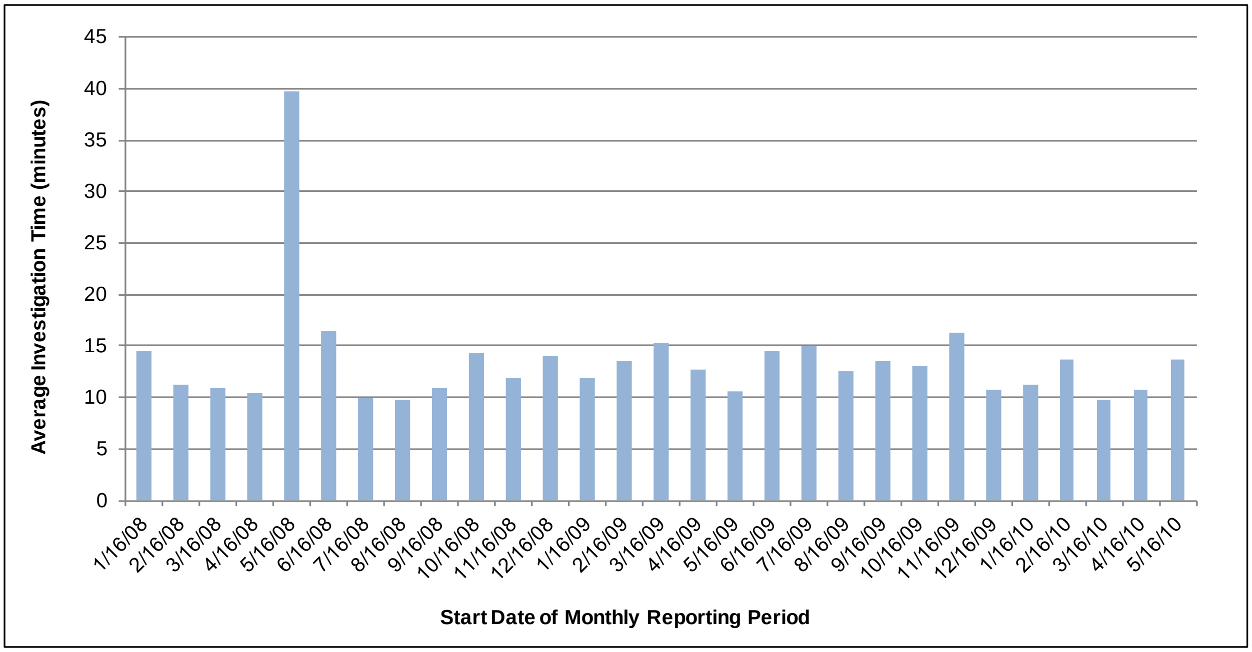

Figure 7-6. DPIC Average Invalid Alert Investigation Time (n=486, empirical data)

Time for alert investigation decreased considerably after the first six months of alert investigation. The decrease is most likely due to a transition from a development and testing phase to a "go live" phase after the first six months. It may also be due to staff becoming more aware and comfortable with the investigation process, and hence executing alerts in a more expedient manner.

Statistics for time for alert investigation over the entire evaluation period are shown in **Table 7-9**.

Table 7-9. DPIC Invalid Alert Investigation Time (minutes, empirical data)

Parameter	Time (minutes)
Average	14
Median	15
Minimum	2
Maximum	180

Drill Data

The investigation of a simulated DPIC alert was characterized by performing drills and exercises. During the PHS Drill 2 (July 28, 2009), a call to DPIC from a daycare facility was used to report symptoms caused by water contamination with a toxic chemical. This investigation also involved a simulated alert generated from the 911 surveillance tool. In this instance, a Possible contamination determination was reached after approximately 1.5 hours. While this is a reasonable estimate for how long it might take to investigate valid alerts, the actual investigation time during a "live" incident may vary depending on other factors (e.g., personnel availability). The timeline for the July 2009 PHS drill is presented below in **Figure 7-7**, which displays some of the key points of the investigation following receipt of a simulated DPIC alert.

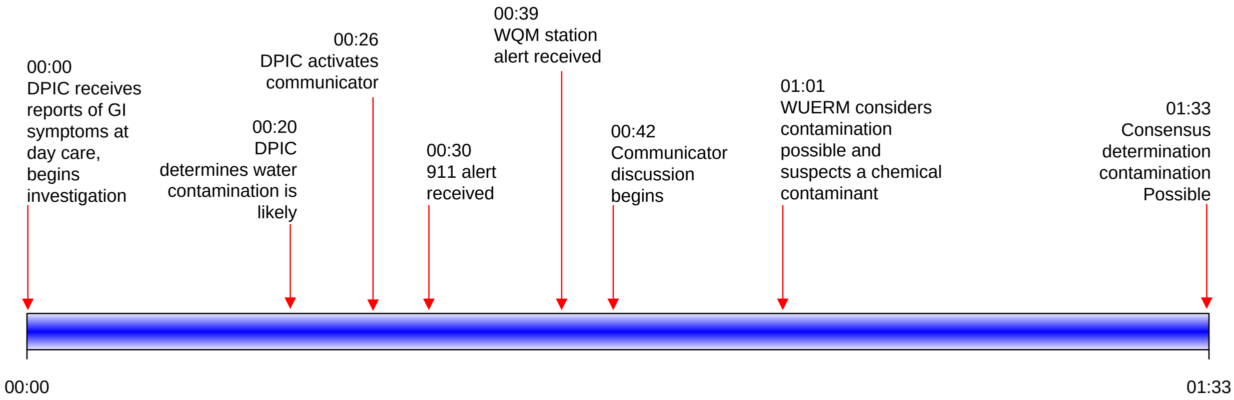

Figure 7-7. PHS Drill 2 Timeline (DPIC Alert)

Simulation Study Data

Figure 7-8 demonstrates the overall timeliness of detection statistics for the DPIC surveillance tool and for scenarios initiated at low and high demand periods, using percentile values to illustrate the distribution of data in a box-and-whisker plot. The impact of the time delay for exposures between scenarios initiated and period of high and low demand are noticeable, with an approximate 6 hour difference in average detection times. For scenarios started at a low demand periods, exposures do not occur until seven hours after the injection time (12:00 am), unlike the scenarios initiated at high demand (9:00 am), which could have resulted in exposure soon thereafter at the 9:30 am or 12:00 pm exposure events.

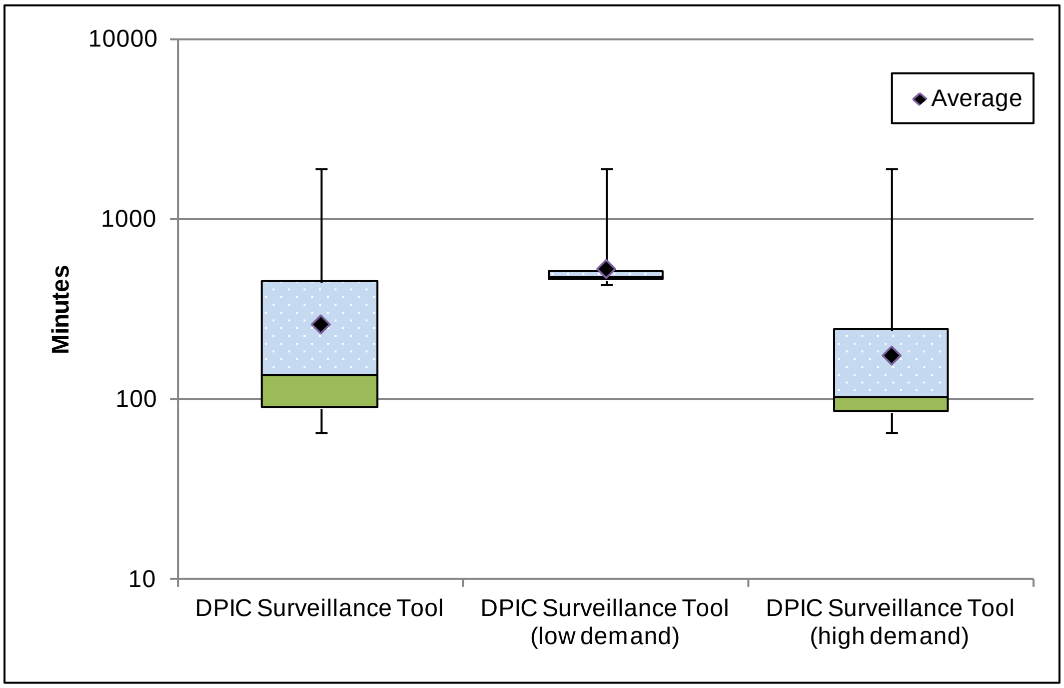

Figure 7-8. DPIC Surveillance Tool Timeliness of Detection (simulation study data)

There were a total of 717 scenarios (85%) detected by the DPIC data stream with an average detection time of 263 minutes (**Table 7-10**). Low demand scenarios were detected on average 535 minutes after the time of contaminant injection, whereas high demand scenarios were detected on average 177 minutes following contaminant injection.

Table 7-10. DPIC Data Stream Timeliness of Detection (simulation study data)

Scenarios	Count	Average	Median
Total	717	263	137
Low Demand	173	535	479
High Demand	544	177	102

The low and high demand scenarios are further compared, in **Figure 7-9** below, where contaminants are arranged in increasing order of timeliness of detection by the total set of detected scenarios. No data is presented for the average detection time for low demand scenarios for Toxic Chemical 2, as the DPIC surveillance tool did not detect the one theoretically detectable scenario, or there were no low demand scenarios included in the model runs, such as with Biological Agent 2.

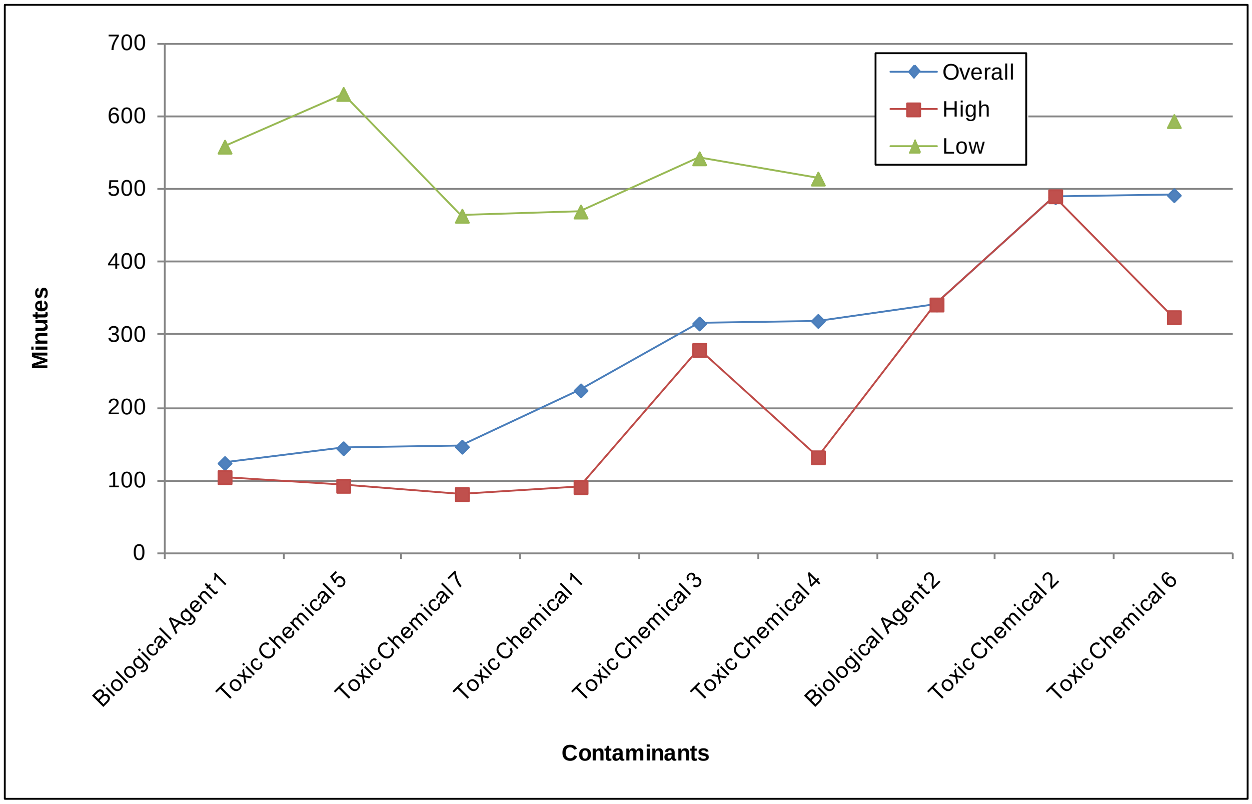

Figure 7-9. DPIC Surveillance Tool Timeliness of Detection (simulation study data)

The differences in timeliness of detection by the DPIC surveillance tool (a range from ~100 minutes to ~500 minutes was observed, as shown in Figure 7-9) are likely due to a variety of factors, including the dose required to produce symptoms, symptom onset time, the number of cases required to exceed the DPIC statistical or human surveillance thresholds, and the number of high or low demand scenarios modeled for each contaminant (which affects time delays to exposure).

Figure 7-10 demonstrates the overall timeliness of detection statistics for Astute Clinician monitoring and for scenarios initiated at low and high demand periods, using percentile values to illustrate the distribution of data in a box-and-whisker plot. As with all of the previous surveillance tools, the Astute Clinician had a longer detection time for the low demand scenarios (~39 hours) than the high demand scenarios (11 hours), accounted for by the increased amount of time between injection of the contaminant and exposures.

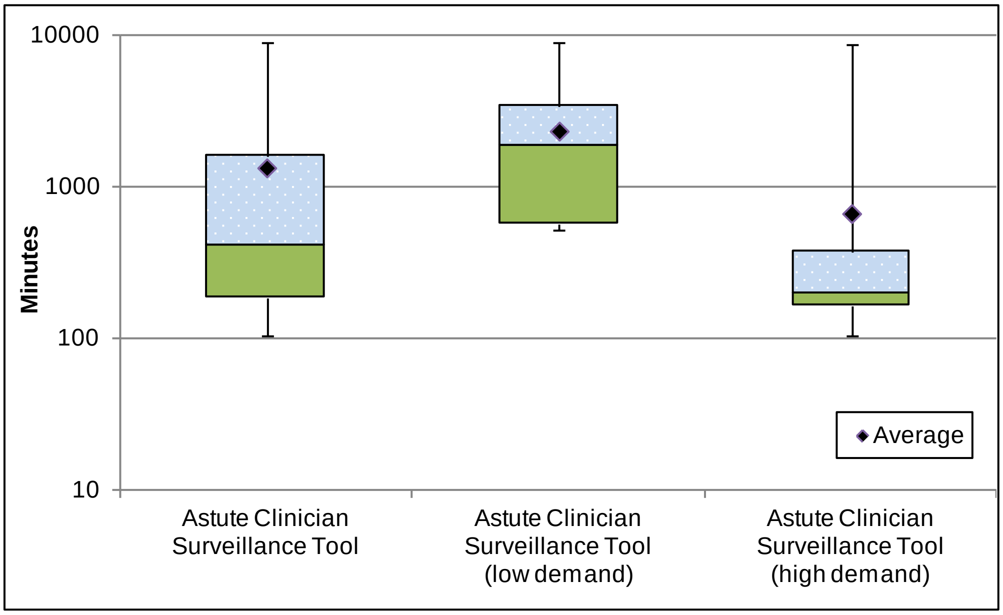

Figure 7-10. Astute Clinician Data Stream Timeliness of Detection (simulation study data)

There were a total of 1,395 scenarios (99.5%) detected by Astute Clinician monitoring with an average detection time of 1,340 minutes (**Table 7-11**). Low demand scenarios were detected on average 2,341 minutes after the time of contaminant injection, whereas high demand scenarios were detected on average 669 minutes following contaminant injection.

Table 7-11. Astute Clinician Data Stream Timeliness of Detection (simulation study data)

Scenarios	Count	Average	Median
Total	1395	1,340	405
Low Demand	506	2,341	1,870
High Demand	835	669	195

The low and high demand scenarios were further compared to observe differences between the toxic chemicals and biological agents. For most biological agents, detection required much longer time, as seen in **Figure 7-11** below, where contaminants are arranged in increasing order of timeliness of detection by the total set of component scenarios. The averages for low or high demand scenarios are not presented where no data was available. This figure demonstrates the impact of the symptom onset timing on timeliness of detection. Contaminants with a slower symptom onset result in a longer time delay prior to detection (days to weeks). Furthermore, a greater number of cases are required for detection by an astute clinician for some biological agents which result in non-specific systems following exposure compared to the toxic chemicals. This translates to a longer delay prior to detection. The model was parameterized in this manner based on input from toxicological subject matter experts from DPIC.

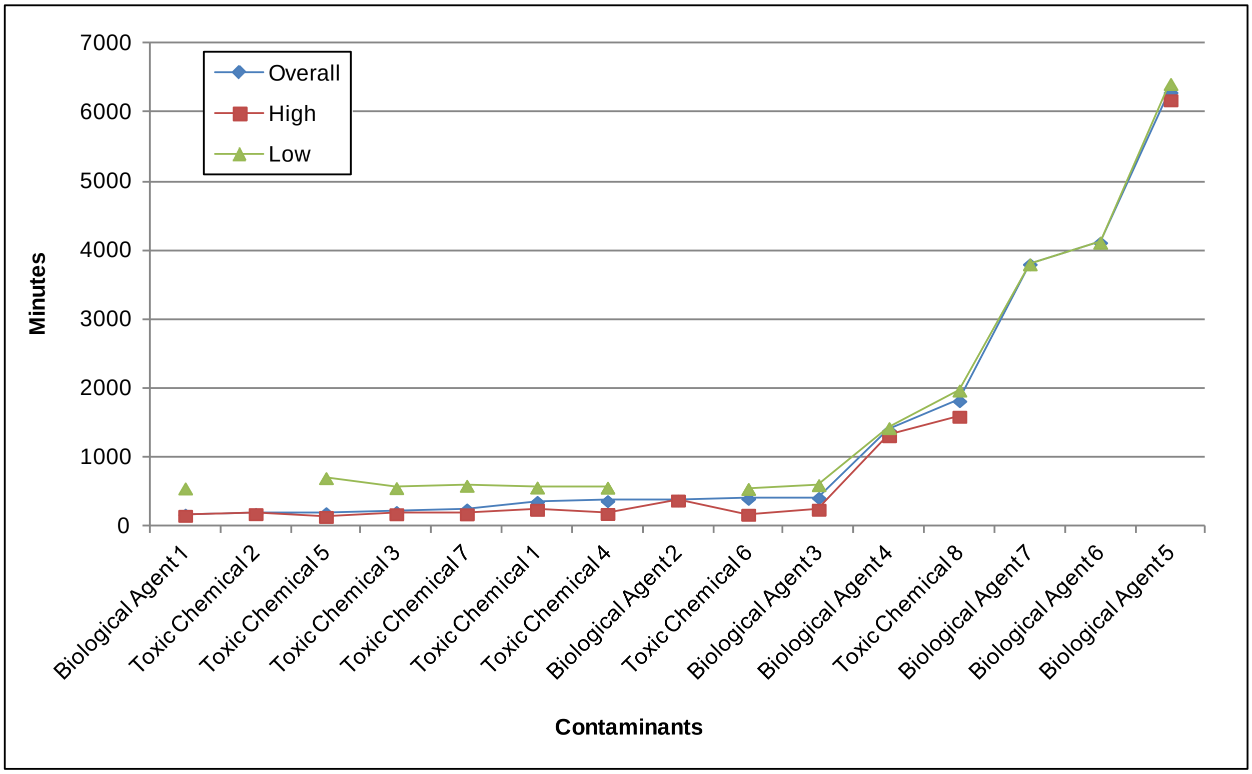

Figure 7-11. Astute Clinician Data Stream Timeliness of Detection (simulation study data)

7.5.5 Summary

The timeliness of detection for the DPIC surveillance tool was fairly consistent. DPIC data collection and transmission occurs in near real-time (<1 minute) for statistical, non-statistical, and human surveillance. Time for event detection was approximately 4 hours for statistical surveillance (due to latency period built into NPDS), near real-time for non-statistical surveillance, and 15 or 45 for human surveillance (depending on source of phone call). After the first six months of the evaluation period, time for alert recognition stabilized at around 11 hours per alert, with most alerts recognized within 24 hours. The majority of invalid alert investigations took approximately 15 minutes to complete; valid alerts may took longer to investigate (~1.5 hours) based on observations during drills and exercises.

Simulation study data analysis showed that for chemical contamination scenarios, case counts exceeded the detection thresholds for the DPIC surveillance tool and Astute Clinician monitoring within hours (for the high demand scenarios). Days to weeks elapsed before detection of some biological agents and toxic chemicals.

7.6 Design Objective: Operational Reliability

Analysis of the operational reliability of the DPIC surveillance tool addresses functional aspects of the tool and quantifies the percent of time that the DPIC surveillance tool was working as designed. In order to evaluate how well the DPIC surveillance tool met this design objective, the availability metric was evaluated. The following subsection defines the metric, describes how it was evaluated and presents the results.

7.6.1 Availability

Definition: Availability is the amount of time the DPIC surveillance tool is functional and accessible, expressed in terms of the percent of usable data hours per reporting period. In order for usable data to be generated for the DPIC surveillance tool, data must be successfully entered into the NPDS system; analyzed using statistical, non-statistical, or human surveillance; and any alert information made available to DPIC personnel.

Analysis Methodology: The percent availability was calculated based on total hours available for each of the various DPIC surveillance strategies. Instances of downtime were reported by DPIC personnel and categorized by detection methodology (statistical, non-statistical, or human surveillance). Because downtime was not reported by month, statistics are presented for the entire evaluation period only.

Results: A back-up generator at DPIC ensures that data systems are available at all times, and are not affected by power outages. Therefore, instances of unavailability (for statistical and non-statistical surveillance) generally occur only when NPDS is unavailable, such as during predictable quarterly outages when the NPDS system is being updated. These system upgrades caused temporary unavailability for all of the surveillance categories (statistical, non-statistical, and human surveillance). Upgrades take approximately 12 hours to execute, and thus amount to 48 hours of downtime per year.

Following one system upgrade, the case based surveillance tool (i.e., non-statistical surveillance), was inactive for three weeks in addition to the quarterly updates, amounting to 3.2% of the total evaluation period. Since human surveillance can occur even in the absence of the NPDS, it was always available. The percent of availability by surveillance category can be seen in **Table 7-12**.

Table 7-12. DPIC Availability

Surveillance Method	Downtime (weeks)	Total Weeks	Percent Availability	Percent Unavailable
Statistical Surveillance	0.64	115	99.4%	0.6%
Non-statistical Surveillance	3.64	115	96.8%	3.2%
Human Surveillance	0	115	100.0%	0.0%

7.6.2 Summary

The DPIC surveillance tool achieved a high percentage of availability during the evaluation period. Only one significant downtime event resulted in three weeks of data downtime for the non-statistical surveillance tool. Although system upgrades of the NPDS caused temporary data incompleteness, their effects were minimal.

Section 8.0: Performance of the Integrated Component

8.1 Description of the Integrated PHS Component

The integrated PHS component consists of five surveillance strategies (i.e., automated statistical surveillance and human surveillance conducted by astute clinicians) working together in order to detect public health incidents, including water contamination. The PHS component relies on the integration of available data sources and professional expertise within stakeholder agencies to accomplish this goal. Data sources include CFD (911 calls and EMS runs), hospital EDs and calls to DPIC. During a public health incident, including water contamination, it is expected that persons experiencing symptoms will exhibit certain health-seeking behaviors that feed into the various data streams (Section 3.3). The time for symptom onset and health-seeking behaviors following contaminant exposure affects the data type collected as well as the timeliness of data receipt.

This section focuses on the performance of the integrated PHS component. Since the effectiveness of the various surveillance tools working together is not simply additive, the discussion focuses on a holistic view of component performance. In addition, a discussion of the overall component costs and benefits, along with utility and public health partner compliance with component protocols is included.

8.1.1 Surveillance Tools Overview

The PHS component required numerous surveillance tools to function together as one cohesive unit. These surveillance tools were selected to provide a timely method of surveillance for symptoms indicative of possible water contamination, and to provide sufficient spatial coverage of the GCWW service area. Each surveillance tool contains appropriate algorithms to provide spatial and temporal analysis of data trends; these analyses and data can be accessed by appropriate personnel through computer interfaces (see Table 2-1).

Data collection and analysis within the PHS component is designed such that the various PHS tools are complementary. For example, although 911 call data had the quickest transfer rate to public health partners (Section 8.4), the alerts do not offer as much case record detail as EMS alerts. Utilizing these data streams in tandem allows for broader coverage of the design objectives by having one surveillance tool “cover” in places where another surveillance tool is lacking. Analysis of the PHS surveillance tools coupled with professional and institutional knowledge from investigative personnel provides for a holistic view of the population and improved situational awareness to detect public health anomalies.

Each of the surveillance tools within the PHS component deal with symptoms or health-related complaints from the public. These symptoms are often distilled into categories, or syndromes, for easier classification and analysis. In the case of the 911 data stream, symptoms as described to the dispatch operator are matched to incident codes using the Computer Aided Dispatch system. A cross-walk of the syndromes from the various surveillance tools can be found in **Table 8-1**. It should be noted that syndromes are not mutually exclusive, and one symptom can be classified under more than one syndrome. The DPIC surveillance tool is not included in this table as DPIC’s approach to statistical surveillance does not rely upon syndrome categories.

Table 8-1. Comparison of Syndromes from PHS Surveillance Tools

911 (Incident Codes)	EMS Syndrome	EpiCenter Syndrome
Eye problem[1] Possible stroke	Neurological	Botulinic
Headache Abdominal pain Sick	N/A	Constitutional
Abdominal pain	Gastrointestinal	Gastrointestinal
Hemorrhage	N/A	Hemorrhagic
Fainting Headache Possible stroke	Neurological Psychological	Neurological
Burn/blister[2]	N/A	Rash
Allergies Asthma Breathing problem Chest pain Inhalation[1]	Upper Respiratory	Respiratory
Chest pain Sick Unconscious Person down[1] Fainting Heart problem	Cardiac	N/A
Abdominal pain Seizure Convulsions	Water	N/A

[1] These incident codes were filtered for analysis during the first portion of the evaluation period. Upon conducting an exercise with CFD dispatch operators, they were later removed from the analysis as they were determined not to be relevant to possible water contamination.

[2] These incident codes were added to the group of codes being filtered for analysis during the latter portion of the evaluation period. The exercise conducted with CFD dispatch operators demonstrated their relevance to possible water contamination.

The PHS component differs from other components in that all of the surveillance tools are not managed or monitored by a single agency. PCC call data, for example, is collected and investigated solely by DPIC; results from this surveillance tool are then communicated to other public health partners. Because of this design, effective communication between personnel involved with each of the surveillance tools is crucial to the functional component, and communication protocols were continuously improved throughout the evaluation period. This included development of the “communicator” protocol and regular User’s Group meetings.

8.1.2 Analysis Methodology

The PHS component consists of multiple surveillance tools and personnel in numerous locations. In some instances, separate agencies are responsible for investigation of different surveillance tools. In addition, no two data streams share the same data transmission methods or event detection systems. Therefore, a detailed performance evaluation was performed on each metric for each surveillance tool as presented in Sections 4.0 – 7.0. However, because the PHS surveillance tools were designed to work synergistically, evaluation of the integrated component in this section allows for discussion and analysis of overall PHS component performance.

For the integrated PHS component, the analysis methodology considers the collective performance of the various surveillance tools functioning as a whole. Included in this evaluation are the design objectives used at the surveillance tool level as they apply to the comprehensive component. Quantitative measures derived from empirical data in the surveillance tool evaluations are included to demonstrate how the various parts of the component work together as one cohesive unit. In addition to empirical data and observations gleaned from during the evaluation period, simulation study data was analyzed to understand component performance by challenging the CWS model with an ensemble containing thousands of contamination scenarios.

Evaluation of the integrated component utilizes quantitative measurements from the surveillance tool evaluations to develop a qualitative view of how the PHS component operates to identify public health incidents, including water contamination. The integrated evaluation uses results from empirical data analysis, PHS drills, PHS forums and the simulation study to characterize the performance of the integrated PHS component.

8.2 Integrated Design Objective: Spatial Coverage

Spatial coverage is the cumulative area of the distribution system covered by the PHS component, as dictated by the spatial coverage of the surveillance tools. Adequate spatial coverage ensures that the PHS component is useful for detecting possible contamination affecting any size area in the entire GCWW service area. Metrics used to evaluate how well the PHS component met this design objective include area and population coverage, and the spatial extent of an alert. Available location data was analyzed statistically and spatially for each of the PHS surveillance tools and these results were compiled to ascertain how they work as an integrated system. An overview of results is presented in **Table 8-2**.

Table 8-2. Evaluation of Spatial Coverage Metrics

	PHS Surveillance Tool				Integrated Component
	911	EMS	EpiCenter	DPIC	
Theoretical Spatial Coverage	Covers 22% of GCWW service area	Covers 22% of GCWW service area	Covers 95% of the GCWW service area	Covers 100% of the GCWW service area	Entire utility service area covered by PHS surveillance tools
Metric #1: Area and Population Coverage	Alerts concentrated in areas with higher population densities	Alerts concentrated in areas with higher population densities	Alerts, by nature, indicate a county-wide rise in a certain syndrome category	Alerts occurred in 70% of Hamilton County zip codes, distributed throughout the county	Alert locations covered the majority of GCWW service area; location and frequency affected by population density
Metric #2: Spatial Extent of an Alert	Most alerts encompass 10 kilometers or less	Zip codes with >1 EMS run per alert were concentrated in downtown Cincinnati	Empirical data not available	Alert "clusters" affected by hospital location	Breadth of alerts affected by underlying factors such as population density and hospital location

Spatial coverage for PHS is adequate, granted that investigators have some underlying understanding of weaknesses in the data. The spatial distribution and spatial extent of alerts are both affected by underlying factors, such as population density and hospital location, for some but not all of the surveillance tools. Alerts for 911, EMS, and DPIC's statistical surveillance are generated according to algorithms that do not take population density into account. Therefore, according to business rules, an alert can be issued for the same number of cases regardless of whether they are located in a densely or sparsely populated neighborhood. Investigators need to rely on institutional knowledge of the population to determine if the distribution and extent of alerts suggests possible water contamination, and can also consider other alert details (i.e., syndrome categories) to predict the likelihood of contamination.

Granularity in the available spatial information also affects the interpretation of location and extent of alerts. For the statistical surveillance tools, with the exception of 911 alerts (which identify clusters based on latitude and longitude), the smallest geospatial unit utilized for alerts is zip code. While a standard location categorization, zip codes consist of varying sizes and can encompass large areas. Depending on where EMS runs occurred, they could be in close proximity but not register an alert because they were in separate zip codes. For the human surveillance capability provided by DPIC, the smallest data unit for an alert may be a single call from a household or ED physician. Again, having numerous surveillance streams functioning as an integrated component improves spatial coverage. Cross-referencing alerts from the PHS data streams can provide a more complete spatial picture.

There is evidence that the integrated component provides sufficient spatial coverage for identification of possible contamination as alerts observed during the evaluation period from the various PHS surveillance tools occurred throughout the GCWW service area. Furthermore, one of the enhancements introduced for the 911 and EMS alerts included a Google Earth mapping feature to pinpoint the location of 911 calls and EMS runs which contributed to alerts. This capability, which allows visualization of the overall spatial picture, was identified as a useful feature by the public health partners. During drills and exercises, public health personnel were quick to identify alert clustering and apply knowledge of the area affected during their discussions. For example, during a drill conducted in August 2009, it was quickly noted that a DPIC alert was in close proximity to a 911 alert with similar symptoms. In addition, spatial clustering (or lack thereof), was consistently used during investigations to rule out possible water contamination. This suggests that investigators were able to utilize the tools effectively to make decisions based on spatial considerations.

8.3 Integrated Design Objective: Contaminant Coverage

Performance for this integrated design objective depends on the detection capabilities of each of the surveillance tools used within the PHS component. The ability of these tools to detect possible water contaminants depends on a variety of elements including the type of contaminant, the nature and timing of symptoms produced by the contaminant, and the health-seeking behavior of exposed individuals, as summarized in Section 3.3. Although empirical data was not available to characterize the detection capabilities of the PHS surveillance tools, simulation study results allowed for an analysis of contamination scenario coverage overall and for each surveillance tool. As a whole, the PHS component detected 99.5% of theoretically detectable contamination scenarios. **Table 8-3** presents the detection rates for each of the PHS surveillance tools for the respective sets of theoretically detectable contamination scenarios.

Table 8-3. Evaluation of Contaminant Coverage

	PHS Surveillance Tool					Integrated Component
	911	**EMS**	**EpiCenter**	**DPIC**	**Astute Clinician**	
Metric #1: Contamination Scenario Coverage	80% detection	69% detection	71% detection	85% detection	99.5% detection	Detected 99.5% of theoretically detectable contamination scenario in the simulation study, which included toxic chemicals and biological agents
Number of Theoretically Detectable Contamination Scenarios	702 contamination scenarios	702 contamination scenarios	1,402 contamination scenarios	846 contamination scenarios	1,402 contamination scenarios	

The collective surveillance capabilities of the surveillance tools allowed for successful detection of a variety of chemical and biological contamination scenarios throughout the GCWW service area, based on integrated component design. The detection rates across the surveillance tools demonstrate that each tool was able to detect at least 70% of the scenarios that were theoretically detectable. While the detection capabilities cannot be compared across all of the tools, as there were a different set of theoretically detectable scenarios for each tool (based on the spatial coverage), some comparisons can be made between the 911 and EMS surveillance tools (which shared the same set of theoretically detectable scenarios within the city of Cincinnati limits).

The EMS detection percentage (70%) was somewhat lower when compared to the 911 surveillance tool detection percentage (80%). This is likely the result of some patients deciding on self-transport after calling 911 if an EMS unit had not arrived after a certain amount of time. This resulted in fewer EMS cases being logged and available for statistical analysis, whereas a case record was always recorded for all individuals who called 911. Secondly, following exposure to some of the contaminants, it is likely that some individuals called 911 to request medical assistant and then died prior to the time that an EMS unit arrived. This pattern likely resulted in fewer EMS cases being logged in comparison to 911, and therefore lower detection rates.

8.4 Integrated Design Objective: Alert Occurrence

Alert occurrence addresses component performance by describing the volume of alerts that occurred, and the number of these alerts that were invalid or valid (public health incident, including water contamination). In this way, the design objective describes how well the PHS surveillance tools acting as an integrated component discriminated between valid alerts and normal variability in the data. In order to evaluate how well the PHS component met this design objective, invalid and valid alerts were evaluated using empirical data and simulation study data.

Table 8-4. Evaluation of Alert Occurrence

	PHS Surveillance Tool				Integrated Component
	911	EMS	EpiCenter	DPIC	
Metric #1: Invalid Alerts	Application of new business rules in May 2009 dramatically reduced the number of invalid alerts; now expect ~ 4 false alerts per year	Application of new business rules in May 2009 dramatically reduced the number of invalid alerts; now expect ~ 6 false alerts per year	3 or fewer invalid alerts during most monthly reporting periods; alerts affected by data reporting issues	10 – 20 invalid alerts during most monthly reporting periods	Adjustments to business rules reduced invalid alerts to manageable levels for the 911 and EMS surveillance tools
Metric #2: Valid Alerts	Empirical data not available	Successfully detected H1N1 outbreak, heat related public incident event, and an increase in allergies	Capable of detecting public health incidents, in particular the H1N1 outbreak	Empirical data not available	Despite the fact that no water contamination incidents occurred, two of the surveillance tools demonstrated the ability to detect public health incidents during the evaluation period

The surveillance tools are designed to operate cooperatively for increased overall detection capability by the PHS component. Potential insufficiencies in one surveillance tool can be offset by the integrated system's ability to detect possible health incidents and issue an alert. For example, while the DPIC surveillance tool is well suited for identifying instances where individuals experience highly unusual symptoms with a rapid onset time, it is unlikely to detect a rise in illnesses which onset slowly over a longer period of time. Therefore, the detection capability offered by the EpiCenter surveillance tool can compensate for the inability of the DPIC surveillance tool to detect illnesses with a slow onset time.

Historical analysis of surveillance tool alerting trends is useful in observing overall performance of the integrated system, such as the number of alerts expected per month as well as the co-occurrence of alerts during real public health incidents. A chart of surveillance tool alerts per month can be seen in **Figure 8-1** for the integrated component. The vast majority of these alerts were invalid, and the overall number of 911 and EMS alerts dropped noticeably after the modification to alerting thresholds was implemented in the May 2009 reporting period. The EpiCenter alerts were categorized and depicted separately as either valid or invalid to demonstrate the noticeable uptick in valid alerts during the influenza outbreak between August and October of 2009.

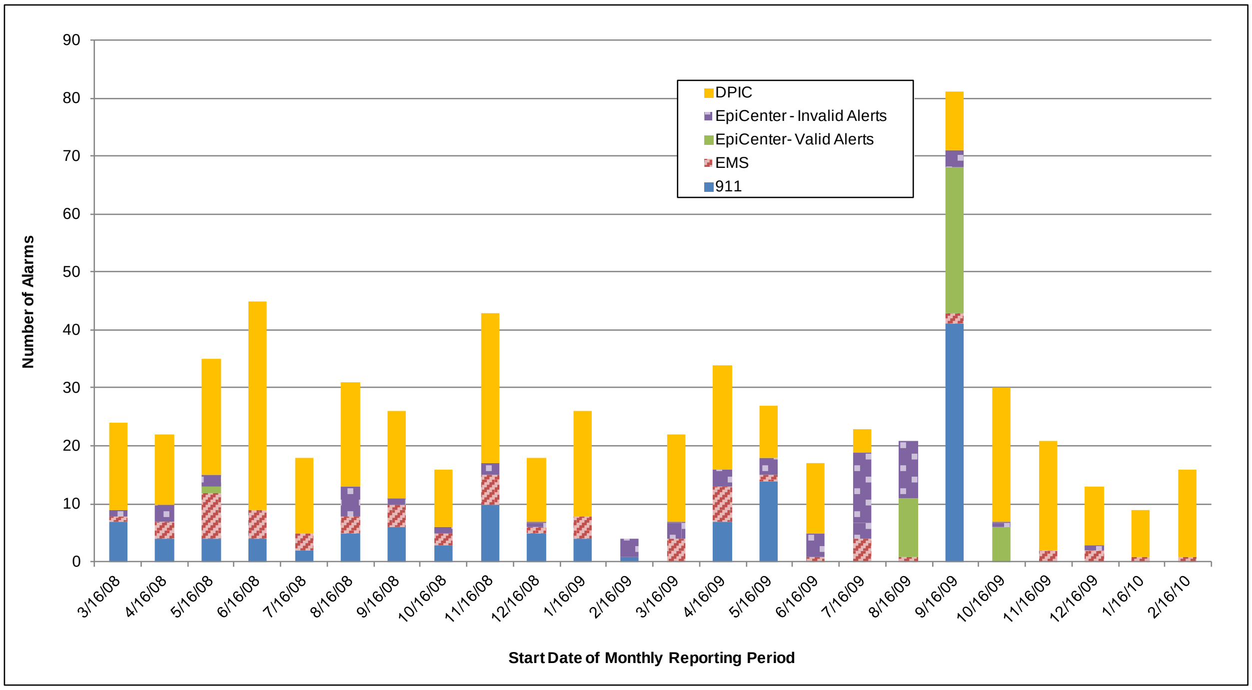

Figure 8-1. Alerts per Month for the Integrated PHS Component

Co-occurrence of valid EMS and EpiCenter alerts during the August and September 2009 reporting periods demonstrates the ability of more than one PHS surveillance tool to indicate a potential public health incident. Following receipt of the alerts, the actions that were taken by investigators responsible for interpreting alert data emphasize their ability to identify valid alerts based on the case details. These concurrent alerts are summarized in **Table 8-5**.

Table 8-5. Concurrent PHS Alerts (empirical data)

	Concurrent Alerts	EMS Date/Time	EpiCenter Date/Time	Resolution
1	EMS/EMS/EpiCenter	8/9/09 2:12 AM	Email from ODH 8/9/2009 8/10/09 11:03 AM (constitutional)	Following communicator activation, was resolved as heat related alert
2	EMS/EpiCenter	10/14/09 3:14 AM	10/14/09 5:03 PM 10/15/09 9:09 AM (both respiratory)	EpiCenter and EMS alerts due to respiratory symptoms; resolved as due to H1N1 activity

Example 1 consisted of two EMS alerts, which prompted activation of the communicator protocol. Included in the communicator discussion was an e-mail received from ODH indicating a high number of elderly persons reporting weakness; this was consistent with data in the EMS alerts. Because of recent high temperatures, the alerts were resolved as heat related. A few hours later, EpiCenter issued a constitutional alert, which encompassed the chief complaints within the EMS alerts. Example 2 depicts the PHS system identifying a documented health outbreak through concurrent alerts. In this case, EMS chief complaints and EpiCenter syndromes were consistent with recent H1N1 activity.

Co-occurrence of alerts was also characterized using simulation study data to identify the percentage of contamination scenarios that generated valid alert clusters by the automated PHS surveillance tools (i.e., 911, EMS, and EpiCenter). Alert clusters were evaluated to understand the sequence of alerts as well as the time that elapsed between concurrent alerts. For this analysis, the contaminants considered to be theoretically detectable by the PHS component were grouped into four categories: contaminants with rapid symptom onset (minutes to several hours), contaminants with moderate symptom onset (> 8 hours to ~1 day), and contaminants with slow symptom onset separated by gastrointestinal or respiratory exposure (~1 day or longer). The results of the analysis are presented below in **Table 8-6**.

This table shows the order and frequency of detection for the 911, EMS, and EpiCenter surveillance tools. In most instances, the 911 surveillance tool was the first to detect and in only one scenario was EMS the first surveillance tool to detect contamination when multiple PHS surveillance tools produced an alert. For a majority of these scenarios, all three surveillance tools alerted.

For most scenarios involving chemical contaminants and biological agents, the order of alerts was: (1) 911, (2) EpiCenter and (3) EMS. If there was not such a significant time lag for EMS data uploads to occur, the EMS alerts would have likely followed soon after the 911 alerts, and the EMS alerts would have occurred prior to EpiCenter alerts. For these scenarios, there was an approximate time lag between the first two alerts of 15 to 24 hours, and an even greater time lag between the second and third alerts (greater than 24 hours).

The order of alerts for Biological Agents 4, 5, 6 and 7 was: (1) EpiCenter, (2) 911, and (3) EMS. In these scenarios, the average time between EpiCenter and 911 alerts was 44.7 hours (with a range of 2.5 to199.5 hours) and the average time between 911 and EMS alerts was 36.2 hours (with a range of 9.0 to 86.0 hours). The order of alerts for these biological agents is in-line with assumptions integrated into the CWS model regarding human behavior. The symptom onset progression is more gradual for the biological agents, and individuals do not pursue extremely urgent health-seeking behavior in large percentages until symptoms reach the severe level. Therefore, it is more likely that case counts would gradually increase at the ED and contribute to EpiCenter alerts prior to the time that thresholds for 911 or EMS would be exceeded.

Table 8-6. Concurrent PHS Alerts (simulation study data)

Contaminants	Order of Alerts	Instances of Alert Order	Minutes Between First and Second Alert			Minutes Between Second and Third Alert		
			Average	Minimum	Maximum	Average	Minimum	Maximum
Contaminants with rapid symptom onset • Toxic Chemicals (1-7) • Biological Agent 1	911/EMS	59	1,578	1,199	2,759			
	911/EpiCenter	45	1,406	749	4,049			
	EMS/911	1	121	121	121			
	EpiCenter/EMS	3	30	30	30			
	911/EMS/EpiCenter	20	1,454	1,199	2,759	3,426	1,410	5,730
	911/EpiCenter/EMS	211	1,337	989	2,729	794	30	1,470
Contaminants with moderate symptom onset • Toxic Chemical 8 • Biological Agent 2 • Biological Agent 3	911/EMS	1	1,319	1,319	1,319			
	911/EpiCenter	9	1,316	1,109	1,469			
	EpiCenter/EMS	5	1,470	1,470	1,470			
	911/EpiCenter/EMS	64	932	29	1,469	1,560	30	4,350
	EpiCenter/911/EMS	40	117	91	271	2,722	1,319	4,259
Contaminants with slow symptom onset (gastrointestinal exposure) • Biological Agent 4 • Biological Agent 5	911/EpiCenter	1	89	89	89			
	EpiCenter/911	17	2,276	91	11,971			
	EpiCenter/EMS	11	7,492	4,350	10,110			
	911/EpiCenter/EMS	5	497	89	749	2,046	1,470	4,350
	EpiCenter/911/EMS	60	2,683	151	11,971	2,171	539	5,159
	EpiCenter/EMS/911	1	5,790	5,790	5,790	61	61	61
Contaminants with slow symptom onset (respiratory exposure) • Biological Agent 6 • Biological Agent 7	911/EMS	3	1,079	599	1,859			

8.5 Integrated Design Objective: Timeliness of Detection

Timeliness of detection as it relates to the PHS component encompasses the time from initial data transmission to completion of an alert investigation. Post-exposure factors can affect timeliness, and include items such as time to symptom onset and health-seeking behaviors, are discussed in Section 3.3. These time delays occur prior to the time for data transmission. Metrics used to evaluate how well the component met this design objective include time for data transmission, time for event detection, time for alert recognition and time to investigate alerts. Analysis of invalid alerts recorded during the evaluation period was performed to present summary-level timeliness data for each metric (**Table 8-7**).

Table 8-7. Evaluation of Timeliness

	PHS Surveillance Tool				**Integrated Component**
	911	**EMS**	**DPIC**	**EpiCenter**	
Metric#1: Time for Data Transmission	Typically between 45 – 100 minutes; some long delays during network outages	Average of 13.2 hours from time of EMS run to data upload	Uploads to NPDS occur in near-real-time (< 1 minute)	Uploaded in batches every 10 minutes[1]	Most data transmitted in 1 hour or less (EMS is the exception)
Metric #2: Time for Event Detection	Generally less than 10 seconds	Usually between 12 – 16 minutes	4 hours after specified timeframe (for statistical analyses)	Generally about 1 hour	The majority of event detection takes less than 1 hour
Metric# 3: Time for Alert Recognition	Median time: 13 hours	Median time: 10.5 hours	Median time:10.7 hours	No data available	Median times indicate a lag in alert recognition (~10 – 13 hours)
Metric #4: Time to Investigate Alerts	Usually between 5 – 15 minutes per alert	Between 10 – 100 minutes per alert	90% of investigations took 20 minutes or less	Approximately 15 minutes per alert	Most investigations took 20 minutes or less

[1] While data is electronically uploaded every 10 minutes, data is routinely delayed as paper records are often not entered into the electronic system until the following morning.

Empirical data show overall efficient operation of data transmission and event detection. While vulnerable to network outages and other instances of system downtime, these events did not appear to impede the consistent operation of the integrated system. Some time delay was observed for the time it takes public health investigators to acknowledge alerts and begin investigation; the median time period observed was between 10 to 13 hours. Part of this delay is due to alerts that were produced after normal business hours, which were not recognized by investigators until the next workday. For example, personnel responsible for investigation of 911 and EMS alerts were unable to access the User Interface remotely, which contains data pertinent to the alert investigations. The public health partners recognized the need for off-site, 24/7 access to the User Interface, and suggested this component modification during a lessons learned workshop. Once investigations were started, resolution usually occurred within 20 minutes.

A major strength of the PHS component is that it provides a balance of data that is both timely and informed. While the 911 surveillance tool is the fastest to collect and analyze data, it is “coarse” compared to more detailed patient data available in EMS, EpiCenter, and DPIC alerts. For example, the EpiCenter surveillance tool requires a longer time to produce alerts, but is the richest in detail and medical validity. During investigations, data that is captured more quickly can be checked against other data sources with more descriptive data to help determine causation. For example, following an EMS alert for respiratory symptoms, a review of hospital data may reveal that instances of respiratory complaints in the ED have been increasing for the past few weeks due to a recently confirmed influenza outbreak, even though the volume may not have been substantial enough to produce an alert.

Simulation study timeline data (which started at the time of contaminant injection) was evaluated to illustrate the timeliness of detection overall for the PHS component and for scenarios initiated at periods of high or low demand (**Figure 8-2**). Percentile values were calculated to examine the distribution of data in a box-and-whisker plot.

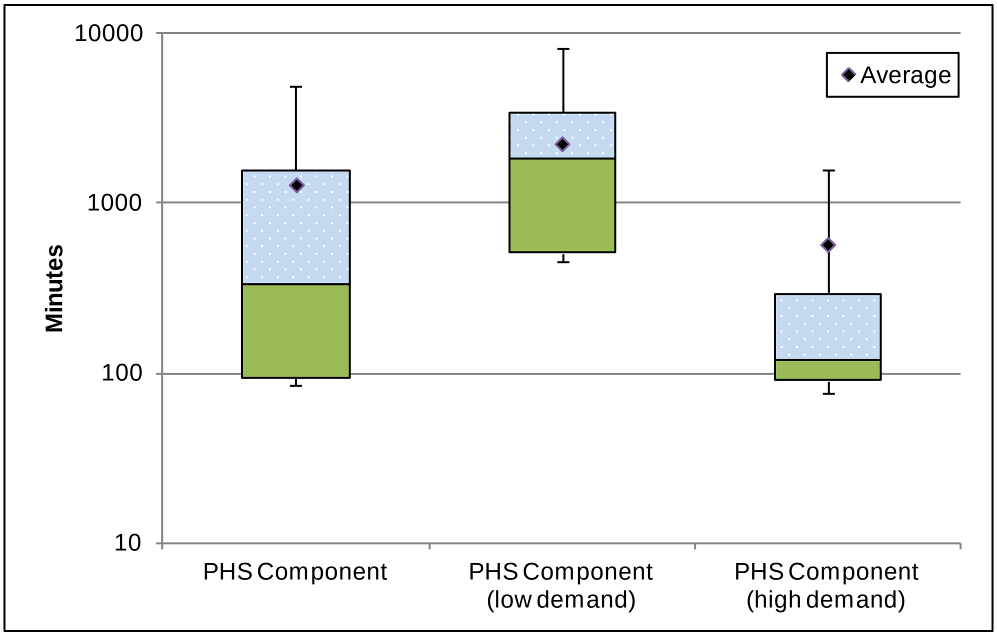

Figure 8-2. PHS Component Timeliness of Detection

The overall average time of detection for the PHS component was 1,377 minutes (approximately one day). As was discussed for each of the surveillance tools, timeliness of detection was slower for the set of contamination scenarios that were initiated during periods of low demand (12:00 am) due to the time delay for the first exposures to occur seven hours later (7:00 am), unlike the scenarios initiated at high demand (9:00 am), which could have resulted in exposure soon thereafter at the 9:30 am or 12:00 pm exposure events.

The timeliness of detection by the PHS component was calculated per contaminant for all scenarios detected (**Figure 8-3**). As was observed for each individual surveillance tool, the detection timeline was generally more rapid for the toxic chemicals (within hours) in comparison to certain biological agents (within days to weeks), predominantly due to the longer symptom onset time following exposure for certain biological agents. The time delay for low symptom onset is displayed in this figure (see red asterisks) for each contaminant to illustrate the average detection time in relation to symptom onset. Note that symptom onset occurs only after an individual has become exposed to a contaminant (which occurs some time after the contaminant injection); therefore, the data in this figure should not be interpreted chronologically. Figure 8-3 indicates that symptom onset time is closely related to the time of detection for a given contaminant.

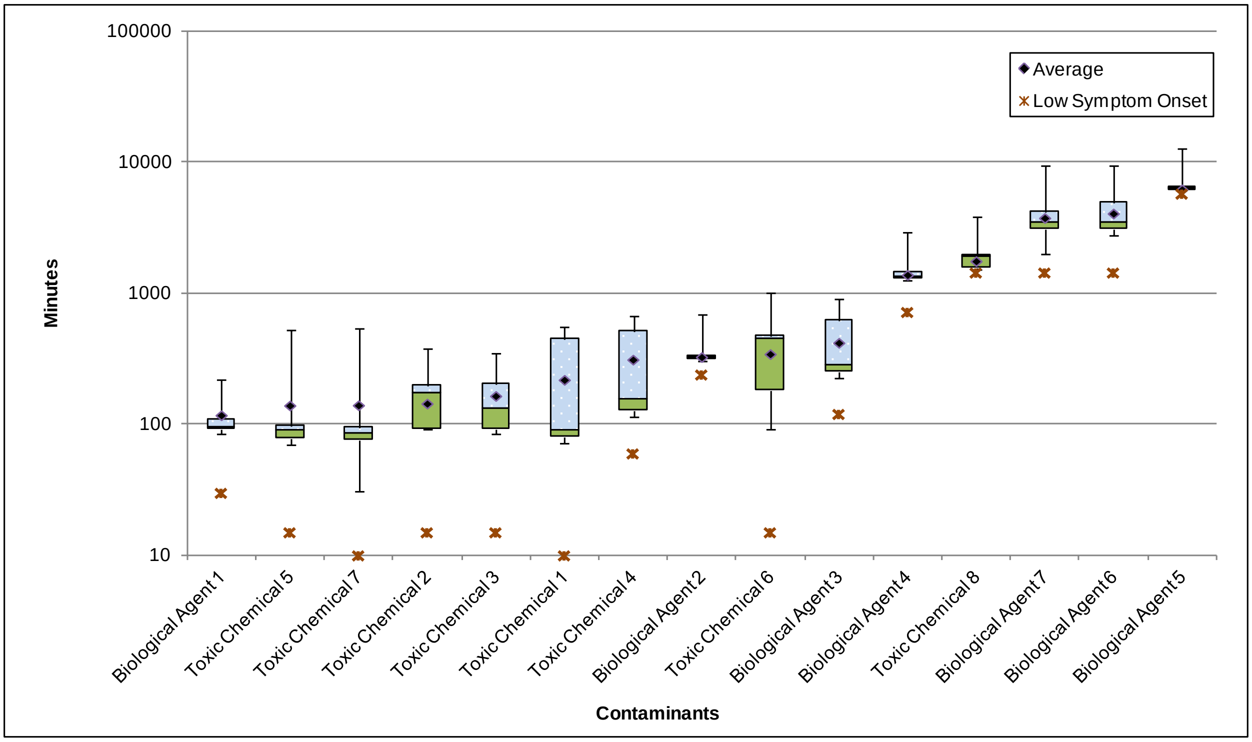

Figure 8-3. PHS Component Timeliness of Detection and Low Symptom Onset

8.6 Integrated Design Objective: Operational Reliability

Component reliability considers the physical operation of the integrated PHS component. Operational reliability comprises the metrics of availability and data completeness, which quantify the percent of time that the integrated PHS component is working as designed. A summary of the operational reliability metrics can be found in **Table 8-8**.

Table 8-8. Evaluation of Operational Reliability

	PHS Surveillance Tool				Integrated Component
	911	EMS	DPIC	EpiCenter	
Metric#1: Availability	92% availability overall; most downtime due to network instability causing a delay in data collection	95% availability overall; most downtime due to network instability causing delay in data transmission	100% availability overall due to human surveillance	100% availability overall; no recorded downtime	Excellent availability; at least a portion of the PHS component was available 100% of the time
Metric #2: Data Completeness	92% data completeness overall; data incompleteness caused by network instability	≥ 90% data completeness overall for most reporting periods	98.8% data completeness overall; data incompleteness due to NPDS upgrades	≥92% data completeness overall; some data incompleteness due to hospital going offline	Excellent data completeness; overall data completeness was 96%

The PHS component experienced excellent operational reliability during the evaluation period. There was a high percent of availability and data completeness for the integrated component; in particular, at least one of the PHS surveillance tools was available 100% of the time (see **Figure 8-4**). In addition, the percent of data completeness was also high, at 96%. One potential weakness in this area is that the 911 and EMS data streams rely on the same network to function; instability or outages in this network would reduce component data completeness by 50% until operation was repaired. Despite this potential weakness, there is no reason to expect that a high level of operational reliability would not continue based on historical data.

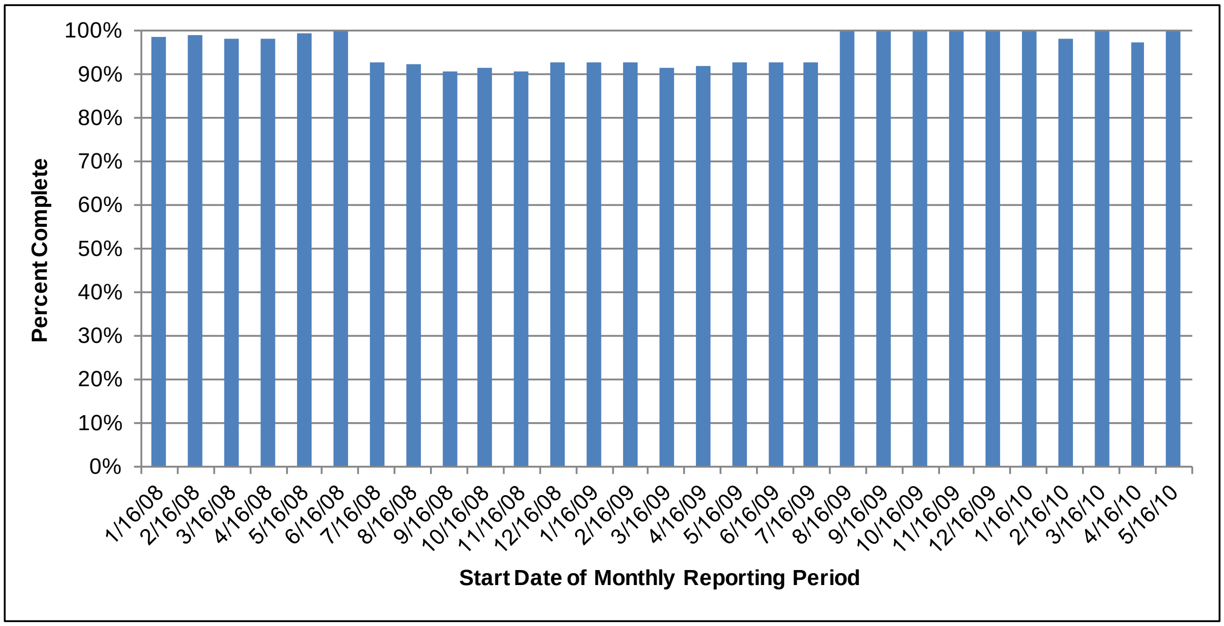

Figure 8-4. PHS Component Data Completeness (based on 911, EMS and EpiCenter data streams)
Note: The dates for the DPIC data incompleteness are unknown, therefore, the data was not included in this figure but the effects would be negligible.

8.7 Integrated Design Objective: Sustainability

Sustainability is a key objective in the design of a CWS and each of its components, which for the purpose of this evaluation is defined in terms of the cost-benefit trade-off. Costs are estimated over the 20-year lifecycle of the CWS and include the capital cost to implement the CWS and the cost to operate and maintain the CWS. The benefits derived from the CWS are defined in terms of primary and dual-use benefits. The primary benefit of a CWS is the potential reduction in consequences in the event of a contamination incident; however, such a benefit may be rarely, if ever, realized. Thus, dual-use benefits that provide value to routine utility operations are an important driver for sustainability. Ultimately, sustainability can be demonstrated through utility and partner compliance with the protocols and procedures necessary to operate and maintain the CWS. The three metrics that were evaluated to assess how well the Cincinnati CWS met the design objective of sustainability are: costs, benefits, and compliance. The following subsections define each metric, describe how it was evaluated, and present the results.

8.7.1 Costs

Definition: Costs are evaluated over the 20-year lifecycle of the Cincinnati CWS, and comprise costs incurred to design, deploy, operate, and maintain the PHS component since its inception.

Analysis Methodology: Parameters used to quantify the implementation cost of the PHS component were extracted from the *Water Security Initiative: Cincinnati Pilot Post-Implementation System Status* (USEPA, 2008b). The cost of modifications to the PHS component made after the completion of implementation activities were tracked as they were incurred. O&M costs were tracked on a monthly basis over the duration of the evaluation period. Renewal and replacement costs, along with the salvage value at the end of the Cincinnati CWS lifecycle were estimated using vendor supplied data, field experience and expert judgment. Note that all costs reported in this section are rounded to the nearest dollar. Section 3.5 provides additional details regarding the methodology used to estimate each of these cost elements.

Results: The methodology described in Section 3.5, was applied to determine the value of the major cost elements used to calculate the total lifecycle cost of the PHS component, which are presented in **Table 8-9**. It is important to note that the Cincinnati CWS was a research effort, and as such incurred higher costs than would be expected for a typical large utility installation. A similar PHS component implementation at another utility should be less expensive as it could benefit from lessons learned and would not incur research-related costs.

Table 8-9. Cost Elements used in the Calculation of Lifecycle Cost

Parameter	Value
Implementation Costs	$1,305,966
Annual O&M Costs	$17,871
Renewal and Replacement Costs	$241,351
Salvage Value	-

Table 8-10 presents the implementation cost for each PHS design element, with labor costs presented separately from the cost of equipment, supplies and purchased services.

Table 8-10. Implementation Costs

Design Element	Labor	Equipment, Supplies, Purchased Services	Component Modifications	Total Implementation Costs
Project Management[1]	$102,749	-	-	$102,749
Public Health Surveillance Tools	$491,312	$71,073	$31,163	$593,548
Communication and Coordination	$172,197	-	-	$172,197
Procedures	$76,409	-	-	$76,409
Shared IT Systems	$283,923	$77,140	-	$361,063
TOTAL:	**$1,126,590**	**$148,213**	**$31,163**	**$1,305,966**

[1] Project management costs incurred during implementation were distributed evenly among the CWS components.

Project management includes all overhead activities necessary to design and implement the component. The cost for PHS tools includes designing and implementing automated event detection systems for monitoring 911 calls and EMS runs. Communication and coordination includes the cost of establishing a Public Health User's Group and developing automated alert notification emails. The procedures costs included developing procedures that guide the routine operation of the component and alert investigations, along with training.

Finally, shared IT systems, includes the procurement, set-up, and configuration of application and database servers that host the PHS event detection algorithms. As this system is utilized by both PHS and CCS, the associated cost was split evenly between these two components.

Overall, the PHS tools design element had the highest implementation costs (45%). The technical implementation of the new event detection systems for 911 calls and EMS runs involved an analysis to identify the appropriate statistical tools for each data source, transfer of data from CFD to GCWW servers, programming and testing to implement the statistical algorithms, construction of a user interface to allow access to underlying case data and development of an alert notification email. For DPIC, the technical implementation of the event detection system for PCC calls involved development of a new business process to identify possible water contamination when receiving hotline calls, as well as development of call volume and case based definition algorithms to detect possible water contamination. The total implementation cost for shared IT systems and communication and coordination were lower at 28% and 13%, respectively. Implementation costs for project management and for development of the procedures for routine operation and training on those procedures were significantly lower at 8% and 6%, respectively.

The component modification costs represent the labor, equipment, supplies and purchased services associated with enhancements to the PHS component after completion of major implementation activities in December 2007. The additional expenses were incurred to modify the 911 and EMS event detection systems, including the addition of more underlying case data (such as geospatial data and incident identifier codes), as well as adjustment of the alerting thresholds for both data streams to reduce the number of alerts. The annual labor hours and costs of operating and maintaining the PHS component, broken out by design element, are shown in **Table 8-11**.

Table 8-11. Annual O&M Costs

Design Element[1]	Total Labor (hours/year)	Total Labor Cost ($/year)	Supplies and Purchased Services ($/year)	Total O&M Cost ($/year)
Public Health Surveillance Tools	138	$7,223	-	$7,223
Communication and Coordination	56	$2,307	-	$2,307
Procedures	134	$8,342	-	$8,342
TOTAL:	**348**	**$17,871**	**-**	**$17,871**

[1] Overarching project management costs were only incurred during implementation of the PHS component and are not applicable for annual O&M costs.

O&M for the PHS tools requires routine monitoring and troubleshooting of the IT infrastructure. The communication and coordination design element involves regular Public Health User's Group meetings which are scheduled four times per year. Most of the O&M labor hours reported under procedures are attributable to the routine investigation of PHS alerts.

Two of the major cost elements presented in Table 8-9, the renewal and replacement costs and salvage value, were based on costs associated with two major pieces of equipment installed for the PHS component. The useful life of these items was estimated at 5 years and 10 years, respectively, based on manufacturer-provided data and input from subject matter experts. It was assumed that the item with a useful life of 5 years would need to be replaced three times during the 20-year lifecycle of the CWS, and the item with a useful life of 10 years was assumed to be replaced once. Because the useful life of the final installment of all equipment items will expire at the end of the 20-year lifecycle, there is no salvage value for this component, as reported in Table 8-9. The cost of these items is presented in **Table 8-12**.

Table 8-12. Equipment Costs

Equipment Item	Useful Life (years)	Unit Capital Costs	Quantity (# of Units)	Total Cost
Wireless CISCO Devices and Routers	10	$382	26	$9,932
Shared IT Systems (Application and Database Servers)[1]	5	$77,140	1	$77,140
			TOTAL:	**$87,072**

[1] Equipment utilized by CCS and PHS; costs evenly split between two components.

To calculate the total lifecycle cost of the PHS component, all costs and monetized benefits were adjusted to 2007 dollars using the change in the Consumer Price Index (CPI) between 2007 and the year that the cost or benefit was realized. Subsequently, the implementation costs renewal and replacement costs, and annual O&M costs were combined to determine the total lifecycle cost:

PHS Total Lifecycle Cost: **$1,788,073**

Note that in this calculation, the implementation costs were treated as a one-time balance adjustment, the O&M costs recurred annually, and the renewal and replacement costs for major equipment items were incurred at regular intervals based on the useful life of each item.

8.7.2 Benefits

Definition: The benefits of CWS deployment can be considered in two broad categories: primary and dual-use. Primary benefits relate to the application of the CWS to detect contamination incidents, and can be quantified in terms of a reduction in consequences. Primary benefits are evaluated at the system-level and are thus discussed in the report titled *Water Security Initiative: Evaluation of the Cincinnati Contamination Warning System Pilot* (USEPA, 2013). Dual-use benefits are derived through application of the CWS to any purpose other than detection of intentional and unintentional drinking water contamination incidents. Unintentional contamination incidents may result from various sources, such as a depressurization event or a backflow event resulting from failure in a cross connection control program.

Analysis Methodology: Information collected from forums, such as data review meetings, lessons learned workshops, and interviews were used to identify dual-use applications of the WQM component of the CWS.

Results: Operation of the PHS component of the CWS has resulted in benefits beyond the detection of intentional and unintentional contamination incidents. These key dual-use benefits and examples identified by the utility include:

1. Relationships formed and knowledge base discovered as part of a PHS component which can be employed in other areas of participant agencies:
    - The communication and team decision-making practiced during drills and exercises for the Cincinnati CWS can be applied to consequence management activities for any number of public health emergencies (e.g., natural disasters, pandemic influenza, non-water related terrorist attacks, etc.). Even if water is not directly related to or impacted by the incident, the drinking water supply is almost always a key resource in response and recovery.
2. Improved knowledge of partner agency’s abilities and organizational structure:
    - This familiarity may manifest itself in ways as simple as knowing the correct person to contact and when to contact that individual during an incident. Being more familiar with partners’ capabilities helps to improve trust and collective decision-making abilities.

- An example from the Cincinnati CWS is demonstrated by the relationship formed between DPIC and HCPH. Epidemiologists at HCPH recognized that the expertise of DPIC could be employed to augment research on unintentional overdoses as part of their Injury Surveillance System. A representative from HCPH was able to utilize roundtable discussions at DPIC as a forum to present injury data and gather feedback on the most effective method to display data analyses. In return, DPIC was able to utilize Hamilton County injury data summaries and epidemiological expertise. Leveraging these relationships for purposes beyond the initial CWS goal of identifying and responding to possible water contamination incidents serves to justify the time expended on the CWS as a means of improvement of the function of an agency as a whole.

3. Use of 911 and EMS data for other applications:
    - An example of this is the utilization of this data for public health issues that do not necessitate an immediate response, such as injury surveillance and retrospective analysis of disease outbreaks. Essentially, data can be used for research purposes to provide a more complete picture of the public health status of a community. As discussed earlier, data can also be used in a more real-time fashion to improve situational awareness during public health outbreaks or events (e.g., EMS alerts during H1N1 outbreak).
4. Improved communication and coordination:
    - A conscious effort from the User's Group members to attend and create productive meetings resulted in not only a measurably improved means by which to convey information with one another, but also bolstered confidence between member agencies. This benefits the CWS and any other applications which require interagency communication.
    - The "communicator" protocol was implemented to allow expedient communication among all members of the User's Group when a PHS alert occurs that requires in-depth investigation and analysis. The communicator is an auto-dialer system operated by CFD, which can be utilized to issue an urgent message to all members of the User's Group. It can be used to notify personnel via phone and email of a possible water contamination incident or other developing public health situation.
    - Communications between local public health and DPIC officials during drills and exercises yielded a reasonable hypothesis of the causative agent in most drill scenarios. The expertise of the DPIC toxicologists, in particular, was invaluable during the process of narrowing down possible contaminants. For example, during a full-scale exercise conducted in October 2008, the DPIC participants were able to surmise that two contaminants were involved based on limited information provided during the exercise. Although drills and exercises rely on hypothetical contamination scenarios, it can be expected these discussions would occur during investigation of a possible water contamination incident. The combination of DPIC toxicological expertise and public health partner input proved a valuable asset for contaminant identification.

8.7.3 Compliance

Definition: Compliance captures the acceptability of the PHS component by measuring the willingness of persons and organizations to monitor, maintain and actively participate in the CWS. The use of PHS surveillance tools and communication procedures during routine operations as well as during drills and exercises is tracked to represent the acceptability of the CWS.

Analysis Methodology: This metric was measured by determining the percent completeness of PHS investigation checklists. Another method used to evaluate compliance was an assessment of the willingness of local public health partners and utility personnel to participate in training, drills and exercises, which evaluate the actions of participants during the process of investigating simulated PHS alerts.

Results: The percent of investigation checklists completed by at least one participant health department can be seen in **Figure 8-5**. The percent completed was generally good with more than 75% completeness for most months. Investigation checklists were not always completed during the investigations due to personnel utilizing other means of documentation; however, it was indicated during group discussions that the alerts were still noted and investigated. In total, 83% of investigation checklists were completed during the evaluation period.

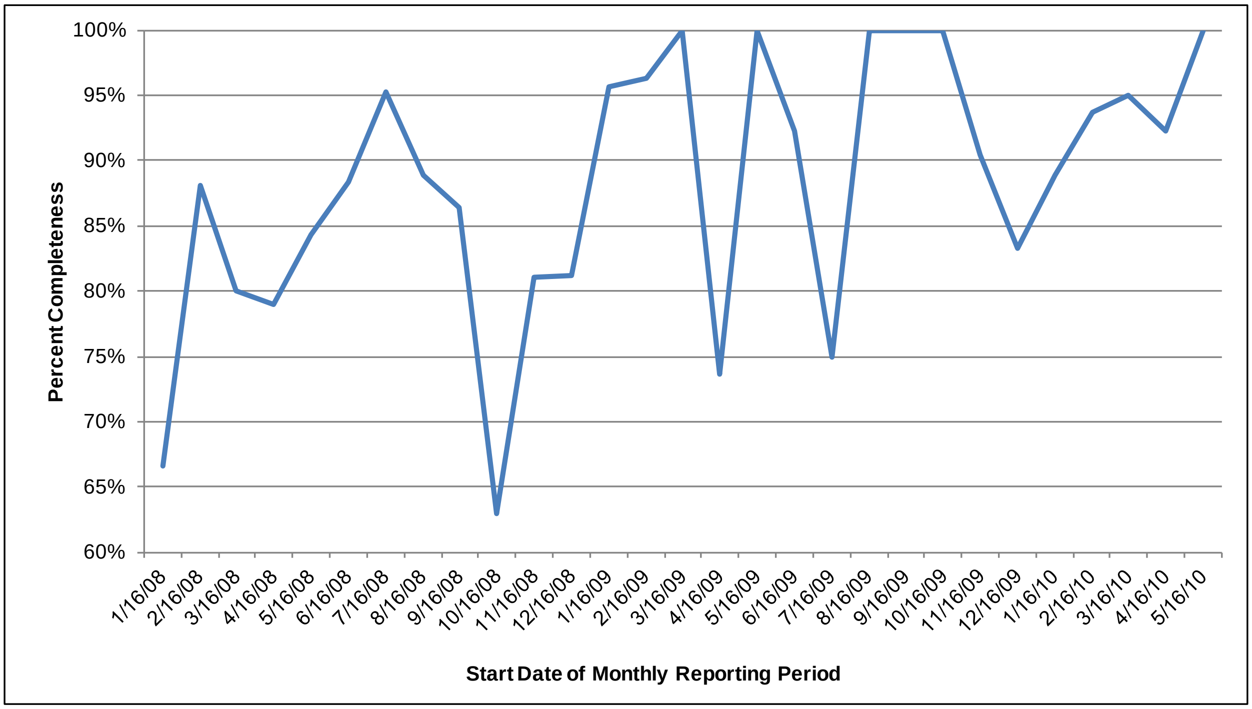

Figure 8-5. Percent Investigation Checklists Completed per Month

Attendance was recorded at all User's Group meetings, drills, and exercises to ensure that core participants (CHD, HCPH, DPIC, FBI and GCWW) were present during meeting discussions and decision-making. Since the beginning of 2009, 100% attendance and participation was documented at most drills, meetings, and exercises, as evidenced from attendance sheets and discussions between all partners during these events. All core members also participated in the communicator call, activated in August 2009. As previously mentioned, stakeholders intend to continue the User's Group meetings and found value in drills and exercises, further bolstering the proof of acceptability for communication procedures, meetings, drills, and exercises.

8.8 Summary of the Integrated Component

The PHS component implemented for the Cincinnati CWS has demonstrated the ability to successfully detect events of public health significance and has achieved acceptability with its users. Strengths of this component include the ability to reliably detect true public health incidents through various surveillance tools and providing expanded situational awareness during such incidents. In addition, effective communication practices enhanced the acceptability of the system to its users. The communicator protocol, in particular, was a sizable improvement, as proven through drills and exercises. Improvements to the system could be made in the timeliness of participants to recognize alerts, which could occur via increased off-site access to the User Interface. Going forward, outside funds for the design of drills and exercises may be necessary in order for these to be feasible; one way to mitigate this could be to approach surveillance in the PHS component using an “all hazards” approach. Overall, the empirical data and simulation study data demonstrate that the PHS component functionality successfully meets the design objectives described above, and serves a valuable role in the overall CWS.

Section 9.0: Summary and Conclusions

The evaluation of the PHS component of the CWS involved analysis of empirical data, data from drills and exercises, results from the simulation study, qualitative observations gleaned from participants during forums, and cost and benefit analysis from the benefit-cost analysis. System design objectives were evaluated through metrics analysis for each of the surveillance tools as well as for the integrated component. Highlights, limitations, and considerations for interpretation of this analysis are presented in this section.

9.1 Highlights of Analysis

Evaluation of the PHS component revealed numerous areas of special interest. First, the system did achieve the functionality conceived during the design phase, as observed through concurrent alerts and the successful detection of public health incidents. In addition, improvements to the communication strategies were particularly successful at increasing efficiency of alert investigations.

As designed, the PHS component was expected to successfully detect possible water contamination by observing changes in the health status of the community as monitored by various surveillance tools. It was expected that during an actual public health incident, including water contamination, multiple surveillance tools would trigger alerts in the same timeframe. This would be supported by some degree of “patient continuity,” or observing patient volume from the start to the end of their health-seeking behavior. An example of PHS successfully identifying a public health incident occurred during the H1N1 outbreak during the fall of 2009, when both EMS and EpiCenter alerts were attributed to influenza activity. Together, these observations highlight the ability of PHS to register multiple alerts and fulfill one design objective. Moreover, simulation study results demonstrated the ability of the PHS surveillance tools to identify the majority of contamination scenarios involving a variety of chemical and biological contaminants.

During the evaluation phase, some observations of data trends led to component modifications to improve the overall functionality and sustainability of the system. Frequent invalid alerts produced by the 911 and EMS surveillance tools precipitated an adjustment of thresholds and alerting criteria to reduce the number of invalid alerts; since this time, far fewer alerts have occurred.

Other examples of the PHS component achieving design objectives occur in its ability to consistently provide data that is both timely and informative. As discussed in Section 8.6, the integrated component achieved excellent data availability and completeness throughout the evaluation period. Data was both timely and informative, via the utilization of data that could be collected quickly (e.g., 911 calls) and also data that contained medically validated information (e.g., EpiCenter).

Improvements to communication strategies and participation in User’s Group meetings were particularly useful for increasing efficiency of investigations and bolstering acceptability. Development of the communicator protocol allowed for the first-hand presentation of data to all investigation participants, resulting in faster analysis and discussions that led to reasonable hypotheses of causative agents. The pledge to continue participation in the User’s Group meetings confirms its usefulness for stakeholder agencies. Finally, the identification of numerous benefits (Section 8.7.2) augments member acceptability and encourages future participation in PHS surveillance activities.

9.2 Limitations of the Analysis

Some limitations identified during the analysis of the PHS component included missing documentation for some alert investigations, limited data granularity, and a lack of empirical data for certain metrics. While most alert investigations were documented, some were occasionally recorded by other means at local health departments; this data was not available for analysis. Likewise, the DPIC protocol did not require that location be noted during alert investigations, which limited the ability to conduct spatial analysis of alerts produced by this surveillance tool. Spatial analysis was also inhibited by the level of data granularity available; for EMS, EpiCenter, and DPIC, the smallest geospatial unit recorded was the zip code level. Because zip codes can be rather large, this may not be the best spatial representation of alerts.

The largest limitation to the PHS analysis was a lack of empirical data for various metrics due to the absence of water contamination incidents during the evaluation period. These gaps were filled through analysis of simulation study results; however, simulated results may differ from real-life experience.

9.3 Potential Applications of the PHS Component

The PHS component of the Cincinnati CWS was tailored to the agencies and data available within the GCWW service area; therefore, the evaluation of this component is specific to Cincinnati, and interpretation should be treated as such. For example, the GCWW service area encompasses multiple public health jurisdictions and partners, which presented certain communication challenges. These challenges were partially addressed through implementation of the communicator protocol. In addition, the data volume and quality in Cincinnati may differ from other cities. However, the Cincinnati CWS revealed numerous applications and lessons that can be applicable to other CWS installations.

Because the Cincinnati CWS was a pilot project, a certain degree of trial and error was necessary to produce a viable, functioning system. As discussed in Section 2.0, NRDM data was originally included in the PHS design; however, due to unforeseen instability in reporting and unavailability of data for research purposes, the use of this surveillance tool was not included in the final component. In addition, the start-up costs for the Cincinnati CWS were mainly due to purchases related to improving the timeliness of data collection (e.g., wireless routers, servers, etc.). Based on the results here and capabilities in other cities, it may be determined these start-up costs can be reduced based on the design of other systems. Furthermore, integrating data surveillance methods described here with an “all hazards” approach to PHS (i.e., incorporating surveillance of food safety, pandemic influenza and/or injury surveillance) creates an even more sustainable CWS.

Improved communication strategies, as developed in the Cincinnati CWS, are widely applicable and can be implemented anywhere. Regardless of the number of stakeholders involved in expansion projects, effective communication will be necessary to perform efficient investigations into possible contamination incidents. Face-to-face meetings, such as the User’s Group meetings, are important for improving stakeholder relationships and refining communication strategies. As mentioned previously, the User’s Group meetings were identified as one of the most valuable aspects of the CWS. Given that improved communication protocols are relatively inexpensive to implement, the lessons learned through the Cincinnati CWS should be considered for implementation at all expansion utilities.

The overarching goal of the PHS component is to improve situational awareness such that consideration of the possibility for water contamination is raised while performing surveillance activities. The astute observations of public health personnel allow for detection of changes of the health status of their community, given that they understand their populations. Indeed, the overall success of the PHS component of a CWS depends not only on reliable data, but also requires public health professionals who are aware of their service population and the possible causes of changes in observed health trends. The evaluation presented here should aid other PHS projects in improving the existing capabilities of public health personnel in order to participate in an effective CWS.

Section 10.0: References

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Section 11.0: Abbreviations

The list below includes acronyms approved for use in the PHS component evaluation. Acronyms are defined at first use in the document.

Cardiaccat	Cardiac Syndromic Surveillance Category
CCS	Customer Complaint Surveillance
CDC	Centers for Disease Control and Prevention
CFD	Cincinnati Fire Department
CHD	Cincinnati Health Department
CMP	Consequence Management Plan
CUSUM	Cumulative Sum
CWS	Contamination Warning System
DPIC	Drug and Poison Information Center
EARS	Early Aberration Reporting System
ED	Emergency Department
EMA	Exponential Moving Average
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
ESM	Enhanced Security Monitoring
FBI	Federal Bureau of Investigation
GCWW	Greater Cincinnati Water Works
Gicat	Gastrointestinal Syndromic Surveillance Category
HCPH	Hamilton County Public Health
HI/HB	Health Impacts and Human Behavior
HIPAA	Health Insurance Portability and Accountability Act
HMS	Health Monitoring Systems
ICS	Incident Command System
Neurons	Neurological Syndromic Surveillance Category
NPDS	National Poison Data System
NRDM	National Retail Data Monitor
O&M	Operation and Maintenance
ODH	Ohio Department of Health
OTC	Over-the-Counter (Sales of Pharmaceuticals)
PCC	Poison Control Center
PHS	Public Health Surveillance
Poison	Poisoning Syndromic Surveillance Category
Psychcat	Psychological Syndromic Surveillance Category
RLS	Recursive Least Squares
RODS	Real-time Outbreak and Disease Surveillance
S&A	Sampling and Analysis
SQL	Structured Query Language

Upperresp	Upper Respiratory Syndromic Surveillance Category
USEPA	United States Environmental Protection Agency
WQM	Water Quality Monitoring
WSI	Water Security Initiative
WUERM	Water Utility Emergency Response Manager

Section 12.0: Glossary

Alert. Information from a monitoring and surveillance component indicating an anomaly in the system, which warrants further investigation to determine if the alert is valid.

Alert Investigation. A systematic process, documented in a standard operating procedure, for determining whether or not an alert is valid, and identifying the cause of the alert. If an alert cause cannot be identified, contamination is possible.

Anomaly. Deviations from an established baseline. For example, a water quality anomaly is a deviation from typical water quality patterns observed over an extended period.

Baseline. Normal conditions that result from typical system operation. The baseline includes predictable fluctuations in measured parameters that result from known changes to the system. For example, a water quality baseline includes the effects of draining and filling tanks, pump operation and seasonal changes in water demand, all of which may alter water quality in a somewhat predictable fashion.

Benefit. An outcome associated with the implementation and operation of a contamination warning system that promotes the welfare of the utility and the community it serves. Benefits are classified as either primary or dual-use.

Benefit-cost analysis. An evaluation of the benefits and costs of a project or program, such as a contamination warning system, to assess whether the investment is justifiable considering both financial and qualitative factors.

Biological Agents. These contaminants of biological origin include pathogens and toxins that pose a risk to public health at relatively low concentrations.

Box-and-whisker plot. A graphical representation of nonparametric statistics for a dataset. The bottom and top whiskers represent the minimum and maximum values, respectively. The bottom and top of the box represent the 25th and 75th percentiles of the ranked data, respectively. The line inside the box represents the 50th percentile, or medial of the ranked data. Note that some data sets may have the same values for the percentiles presented in box-and-whisker plots, in which case not all lines will be visible.

Component response procedures. Documentation of roles and responsibilities, process flows, and procedural activities for a specified component of the contamination warning system, including the investigation of alerts from the component. Standard operating procedures for each monitoring and surveillance component are integrated into an operational strategy for the contamination warning system.

Confirmed. In the context of the threat level determination process, contamination is Confirmed when the analysis of all available information from the contamination warning system has provided definitive, or nearly definitive, evidence of the presence of a specific contaminant or class of contaminant in the distribution system. While positive results from laboratory analysis of a sample collected from the distribution system can be a basis for confirming contamination, a preponderance of evidence, without the benefit of laboratory results, can lead to this same determination.

Consequence management. Actions taken to plan for and respond to possible contamination incidents. This includes the threat level determination process, which uses information from all monitoring and surveillance components as well as sampling and analysis to determine if contamination is Credible or

Confirmed. Response actions, including operational changes, public notification, and public health response, are implemented to minimize public health and economic impacts, and ultimately return the utility to normal operations.

Consequence management plan. Documentation that provides a decision-making framework to guide investigative and response activities implemented in response to a possible contamination incident.

Contamination incident. The introduction of a contaminant in the distribution system with the potential to cause harm to the utility or the community served by the utility. A contamination incident may be intentional or accidental.

Contamination scenario. Within the context of the simulation study, parameters that define a specific contamination incident, including: injection location, injection rate, injection duration, time the injection is initiated, and the contaminant that is injected.

Contamination warning system. An integrated system of monitoring and surveillance components designed to detect contamination in a drinking water distribution system. The system relies on integration of information from these monitoring and surveillance activities along with timely investigative and response actions during consequence management to minimize the consequences of a contamination incident.

Costs, implementation. Installed cost of equipment, IT components, and subsystems necessary to deploy an operational system. Implementation costs include labor and other expenditures (equipment, supplies and purchased services).

Cost, life cycle. The total cost of a system, component, or equipment over its useful or practical life. Life cycle cost includes the cost of implementation, operation & maintenance, and renewal & replacement.

Costs, operation & maintenance. Expenses incurred to sustain operation of a system at an acceptable level of performance. Operational and maintenance costs are reported on an annual basis, and include labor and other expenditures (supplies and purchased services).

Costs, renewal & replacement. Costs associated with refurbishing or replacing major pieces of equipment (e.g., water quality sensors, laboratory instruments, IT hardware, etc.) that reach the end of their useful life before the end of the contamination warning system lifecycle.

Coverage, contaminant. Specific contaminants that can potentially be detected by each monitoring and surveillance component, including sampling & analysis of a contamination warning system.

Coverage, spatial. The areas within the distribution system that are monitored by, or protected by, each monitoring and surveillance component of a contamination warning system.

Credible. In the context of the threat level determination process, a water contamination threat is characterized as Credible if information collected during the investigation of possible contamination corroborates information from the validated contamination warning system alert.

Data completeness. The amount of data that can be used to support system or component operations, expressed as a percentage of all data generated by the system or component. Data may be lost due to QC failures, data transmission errors, and faulty equipment among other causes.

Distribution system model. A mathematical representation of a drinking water distribution system, including pipes, junctions, valves, pumps, tanks, reservoirs, etc. The model characterizes flow and pressure of water through the system. Distribution system models may include a water quality model that can predict the fate and transport of a material throughout the distribution system.

Dual-use benefit. A positive application of a piece of equipment, procedure, or capability that was deployed as part of the contamination warning system, in the normal operations of the utility.

Ensemble. The comprehensive set of contamination scenarios evaluated during the simulation study.

Event detection system. A system designed specifically to detect anomalies from the various monitoring and surveillance components of a contamination warning system. An event detection system may take a variety of forms, ranging from a complex set of computer algorithms to a simple set of heuristics that are manually implemented.

Evaluation period. The period from January 16, 2008 to June 15, 2010 when data was actively collected for the evaluation of the Cincinnati contamination warning system pilot. For the PHS component, the evaluation period was from January 2008 to June 2010 for the 911, EMS, and DPIC surveillance tools. For the EpiCenter surveillance tool, the evaluation period was from March 2008 to March 2010.

Exposure. In the simulation model, any person who ingests, inhales or detects contaminated water.

Hydraulic connectivity. Points or areas within a distribution system that are on a common flow path.

Incident Commander. In the Incident Command System, the individual responsible for all aspects of an emergency response; including quickly developing incident objectives, managing incident operations and allocating resources.

Incident timeline. The cumulative time from the beginning of a contamination incident until response actions are effectively implemented. Elements of the incident timeline include: time for detection, time for alert validation, time for threat level determination and time to implement response actions.

Injection location. The specific node in the distribution system model where the bulk contaminant is injected into the distribution system for a given scenario within the simulation study.

Invalid alert. An alert from a monitoring and surveillance component that is not due to an anomaly and is not associated with an incident or condition of interest to the utility.

Job function. A description of the duties and responsibilities of a specific job within an organization.

Metric. A standard or statistic for measuring or quantifying an attribute of the contamination warning system or its components.

Model. A mathematical representation of a physical system.

Model parameters. Fixed values in a model that define important aspects of the physical system.

Module. A sub-component of a model that typically represents a specific function of the real-world system being modeled.

Monetizable. A cost or benefit whose monetary value can be reliably estimated from the available information.

Monitoring & surveillance component. Element of a contamination warning system used to detect unusual water quality conditions, potentially including contamination incidents. The four monitoring & surveillance components of a contamination warning system include: 1) online water quality monitoring, 2) enhanced security monitoring, 3) customer complaint surveillance and 4) public health surveillance.

Node. A mathematical representation of a junction between two or more distribution system pipes, or a terminal point in a pipe in a water distribution system model. Water may be withdrawn from the system at nodes, representing a portion of the system demand.

Nuisance chemicals. Chemical contaminants with a relatively low toxicity, which thus generally do not pose an immediate threat to public health. However, contamination with these chemicals can make the drinking water supply unusable.

Operational strategy. Documentation that integrates the standard operating procedures that guide routine operation of the monitoring and surveillance components of a drinking water contamination warning system. The operational strategy establishes specific roles and responsibilities for the component and procedures for investigating alerts.

Optimization phase. Period in the contamination warning system deployment timeline between the completion of system installation and real-time monitoring. During this phase the system is operational, but not expected to produce actionable alerts. Instead, this phase provides an opportunity to learn the system and optimize performance (e.g., fix or replace malfunctioning equipment, eliminate software bugs, test procedures, and reduce occurrence of invalid alerts).

Possible. In the context of the threat level determination process, a water contamination threat is characterized as Possible if the cause of a validated contamination warning system alert is unknown.

Primary benefits. Benefits that are derived from the reduction in consequences associated with a contamination incident due to deployment of a contamination warning system.

Priority contaminant. A contaminant that has been identified by the EPA for monitoring under the Water Security Initiative. Priority contaminants may be initially detected through one of the monitoring and surveillance components and confirmed through laboratory analysis of samples collected during the investigation of a possible contamination incident.

Process flow. The central element of a standard operating procedure that guides routine monitoring and surveillance activities in a contamination warning system. The process flow is represented in a flow diagram that shows the step-by-step process for investigation alerts, identifying the potential cause of the alert and determining whether contamination is possible.

Public health incident. An occurrence of disease, illness or injury within a population that is a deviation from the disease baseline in the population.

Public health response. Actions taken by public health agencies and their partners to mitigate the adverse effects of a public health incident, regardless of the cause of the incident. Potential response actions include: administering prophylaxis, mobilizing additional healthcare resources, providing treatment guidelines to healthcare providers and providing information to the public.

Real-time monitoring phase. Period in the contamination warning system deployment timeline following the optimization phase. During this phase, the system is fully operational and is producing actionable alerts. Utility staff and partners now respond to alerts in real-time and in full accordance with standard operating procedures documented in the operational strategy. Optimization of the system still occurs as part of a continuous improvement process, however the system is no longer considered to be developmental.

Routine operation. The day-to-day monitoring and surveillance activities of the contamination warning system that are guided by the operational strategy. To the extent possible, routine operation of the contamination warning system is integrated into the routine operations of the drinking water utility.

Salvage value. Estimated value of assets at the end of the useful life of the system.

Simulation study. A study designed to systematically characterize the detection capabilities of the Cincinnati drinking water contamination warning system. In this study, a computer model of the contamination warning system is challenged with an ensemble of 2,023 simulated contamination scenarios. The output from these simulations provides estimates of the consequences resulting from each contamination scenario, including fatalities, illnesses, and extent of distribution system contamination. Consequences are estimated under two cases, with and without the contamination warning system in operation. The difference provides an estimate of the reduction in consequences.

Threat level. The results of the threat level determination process, indicating whether contamination is Possible, Credible or Confirmed.

Threat level determination process. A systematic process in which all available and relevant information available from a contamination warning system is evaluated to determine whether the threat level is Possible, Credible, or Confirmed. This is an iterative process in which the threat level is revised as additional information becomes available. The conclusions from the threat evaluation process are considered during consequence management when making response decisions.

Time for Confirmed determination. A portion of the incident timeline that begins with the determination that contamination is Credible and ends with contamination either being Confirmed or ruled out. This includes the time required to perform lab analyses, collect additional information, and analyze the collective information to determine if the preponderance of evidence confirms the incident.

Time for contaminant detection. A portion of the incident timeline that begins with the start of contamination injection and ends with the generation and recognition of an alert. The time for contaminant detection may be subdivided for specific components to capture important elements of this portion of the incident timeline (e.g., sample processing time, data transmission time, event detection time, etc.).

Time for Credible determination. A portion of the incident timeline that begins with the recognition of a possible contamination incident and ends with a determination regarding whether contamination is Credible. This includes the time required to perform multi-component investigation and data integration, implement field investigations (such as site characterization and sampling) and collect additional information to support the investigation.

Time for initial alert validation. A portion of the incident timeline that begins with the recognition of an alert and ends with a determination regarding whether or not contamination is possible.

Toxic chemicals. Highly toxic chemicals that pose an acute risk to public health at relatively low concentrations.

Valid Alert. Alerts due to public health incidents, including water contamination.

Water Utility Emergency Response Manager. A role within the Cincinnati contamination warning system filled by a mid-level manager from the drinking water utility. Responsibilities of this position include: receiving notification of validated alerts, verifying that a valid alert indicates Possible contamination, coordinating the threat level determination process, integrating information across the different monitoring and surveillance components, and activating the consequence management plan. In the early stages of responding to Possible contamination, the Water Utility Emergency Response Manager may serve as Incident Commander.