Philadelphia Water Department
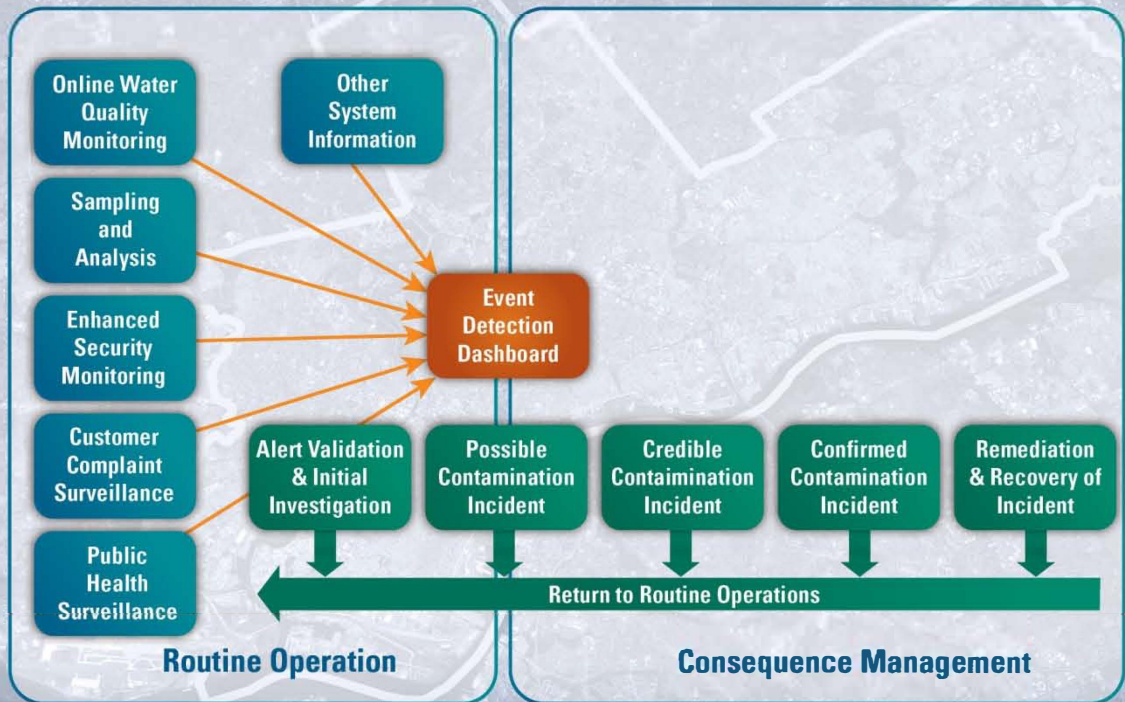*Contamination Warning System Demonstration Pilot Project:*

Contamination Warning System Dashboard Development

Online Water Quality Monitoring

Other System Information

Sampling and Analysis

Enhanced Security Monitoring

Customer Complaint Surveillance

Public Health Surveillance

Event Detection Dashboard

Alert Validation & Initial Investigation

Possible Contamination Incident

Credible Contamination Incident

Confirmed Contamination Incident

Remediation & Recovery of Incident

Return to Routine Operations

Routine Operation

Consequence Management

WBG012313172402PHL

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EPA Disclaimer

Although the information in this document has been funded wholly or in part by the United States Environmental Protection Agency under the Water Security Initiative program, it may not necessarily reflect the views of the agency and no official endorsement should be inferred.

Acknowledgments

The Philadelphia Water Department would like to recognize the following individuals and organizations for their assistance and contributions in this effort:

Abstract

The Philadelphia Water Department (PWD) developed a comprehensive contamination warning system (CWS) for its drinking water system under a Water Security (WS) initiative grant from the U.S. Environmental Protection Agency (EPA). The integration of multiple information streams is a core element of a CWS. The object of the system engineering and data integration component is to combine five surveillance components—online water quality monitoring, consumer complaint surveillance, sampling and analysis, enhanced security monitoring, and public health surveillance—into a centralized platform that can be used to determine whether a water contamination event has occurred and to facilitate appropriate response and consequence management actions.

The CWS Dashboard serves as a centralized CWS event data management, incident investigation, and issue resolution platform for the CWS project. The CWS Dashboard provides automatic event detection, opportunity for preliminary cross-component data analysis and map display for quick response and coordination among a large group of users, including PWD, Philadelphia Department of Public Health (PDPH), and other agencies. This paper discusses the CWS Dashboard development process and architecture that supports these functions.

The CWS Dashboard development process used for the PWD Pilot Project consisted of five steps:

1. Define business processes.
2. Define user requirements.
3. Define use cases.
4. Design the software.
5. Develop a solution.

To create the centralized CWS Dashboard, data streams from the five surveillance components were linked via real-time integration, and the data from this real-time feed was transformed into actionable information using data analytics. The business intelligence architecture provided the framework to make this critical conversion of the raw data streams and the flexibility and scalability needed to address current and future application needs. An intensive 12-month CWS Dashboard software design and implementation effort resulted in the development of a robust Web Geographic Information System (GIS)–based CWS Dashboard to be installed at the core of the CWS information technology and system infrastructure.

Project Background

PWD developed a comprehensive CWS for its drinking water system under a WS initiative grant. The WS initiative is a program developed by the EPA in partnership with drinking water utilities and other key stakeholders in response to Homeland Security Presidential Directive 9. The WS initiative involves designing, deploying, and evaluating a model CWS for drinking water security. A CWS is a systematic approach to collecting information from various sources, including monitoring and surveillance programs, to detect contamination in drinking water early enough to reduce public health or economic consequences. The WS initiative goal is to develop water security CWS guidance that can be applied by drinking water utilities nationwide.

The project has six major components:

1. Online water quality monitoring(OWQM)
2. Sampling and analysis (S&A)
3. Enhanced security monitoring (ESM)
4. Customer complaint surveillance (CCS)
5. Public health surveillance (PHS)
6. Consequence management (CM)

The integration of multiple information streams is a core element in designing a CWS. Taken separately, each component provides its own set of event triggers that have value for event detection. However, contamination events not indicated by any individual system component may be detected through signal integration as multivariate response triggers and other relevant analysis tools have different characteristics and thresholds than individual component triggers. The objective of system engineering (SE) and data integration is to combine the five surveillance components—OWQM, CCS, S&A, ESM, and PHS—into a centralized platform that can be used to determine whether a water contamination event has occurred and to facilitate appropriate response and consequence management actions.

Dashboard Development Process

The CWS Dashboard development process used for the PWD Demonstration Pilot Project consisted of five steps (Figure 1):

1. Define business processes.
2. Define user requirements.
3. Define use cases.
4. Design the software.
5. Develop a solution.

The process started during the operational strategy discussions that defined the core business processes and initial information flow. Two important component-specific documents necessary for the Dashboard development process were the output of the operational strategy: a high level information flow diagram and a business process definition. Using the information flow diagrams, the system engineering team then verified the sources of information for the given component and detailed the systems of record for the data (that is, the application or database housing the data for the component).

FIGURE 1
Software Development Flow
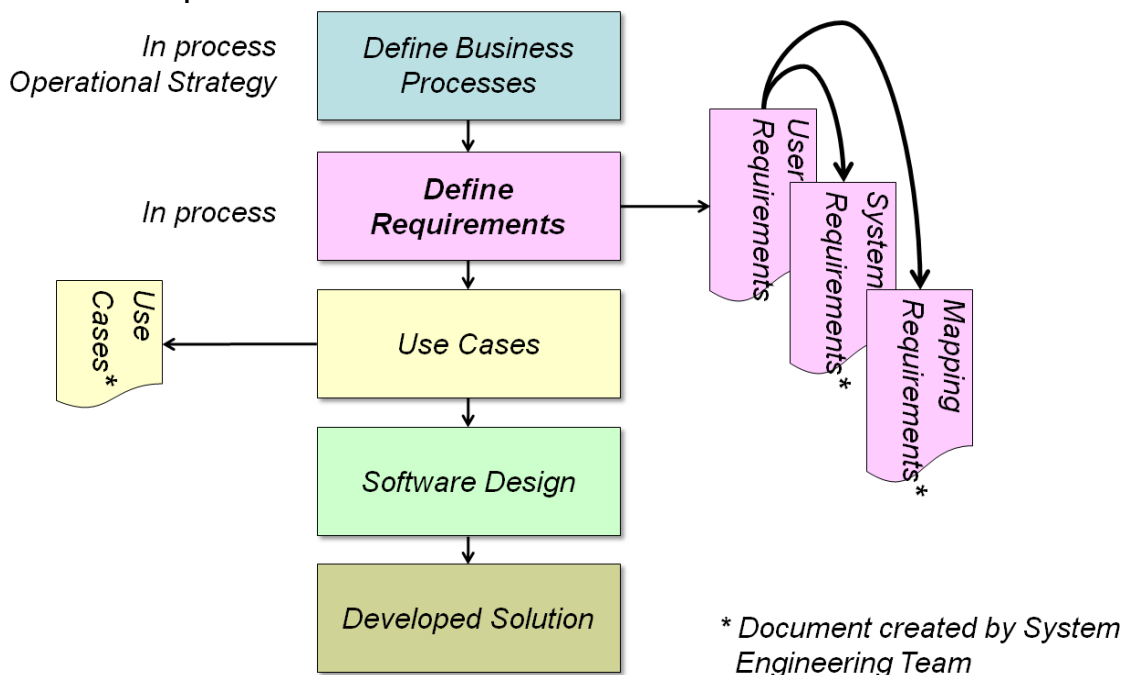
Once the business processes and information flows were defined, the SE team defined the user requirements. The process followed to create the requirements that embodied the requested functionality from PWD staff had four steps:

1. Educate PWD staff on the process development through chartering workshops.

2. Conduct requirement definition workshops with key staff from each component.

3. Review and prioritize the requests and apply technology constraints.

4. Develop the software design documents.

The SE team conducted a series of dashboard requirement workshops with component leads and primary CWS Dashboard users from each component to determine the end-user requirements from a component-specific perspective. The requirements were documented in a tracking spreadsheet for management and analysis. Each requirement was then categorized and prioritized by component leads and users. Common requirements across all components were identified through this process. Each requirement was assigned a priority rating based on its scope and criticality and an assessment of dual-use daily operational needs and CWS project operational strategy needs.

Once the requirements were reviewed and prioritized, all requirements categorized as high and medium were analyzed further to convert them into meaningful use cases to aid in software development. A use case is a list of steps typically defining interactions between a user and a system to achieve a goal. Software design documents (tables or figures) were prepared to document the conversion of user requirements to use cases and provide overall guidance on the architecture of the CWS Dashboard.

More information on the development of the user requirements and use cases can be found in the PWD white paper titled "Development of User Requirements and Use Cases for a CWS Dashboard."

CWS Dashboard Architecture

PWD envisioned a web-based dashboard application to serve as a centralized CWS event data management, incident investigation, and issue resolution platform for the CWS project. To create the centralized CWS Dashboard, data streams from the OWQM, S&A, ESM, CCS and PHS components needed to be extracted from their source systems, transformed into a common data model, and loaded into the dashboard database. The business intelligence architecture (BIA) provides the framework to manage this critical conversion of the raw data streams. In general, a BIA is a framework for organizing data and information management and technology components to build the business intelligence, or in this case, the CWS Dashboard. The underlying BIA and supporting integration plays an important role in efforts that fuse data from multiple streams to provide operational insight. The BIA also provides the flexibility and scalability to address current and future application needs through plug-in analytical modules that allow new functionality without having to recreate integration components.

PWD's Business Intelligence Architecture

Each component within the CWS has a system of record that houses and manages the source data for the component, and PWD plans to continue to use these systems as the long-term data repository for each component. The systems of record for each of the surveillance components, the method of conveyance, and frequency of data collection were identified to be:

- CCS: Azteca Cityworks Computerized Maintenance Management System (CMMS); direct database pull every 2 minutes.

- OWQM: ClearSCADA Historian and Kisters WISKI; direct synchronization with OWQM station repository every 2 minutes.

- PHS: Maven; aggregate data and event detection system (EDS) results once a day.

- S&A: Legacy database (migrating to QSI WinLIMS); direct database pull once a day.

- ESM: Panasonic Network Video Recorders; direct network integration (link to Panasonic system enabled through Internet Explorer ActiveX component).

The transformation of data into actionable information was completed by integrating the component systems of record to feed the data into a short-term Operational Data Store (ODS), perform analytics (such as event detection), and convert it to actionable information. The ODS allows each component's data to be visualized and analyzed for the end users. The ODS created for the CWS Dashboard follows a standard BIA flow that extracts data from the system of record, transforms it into a structure that can be more readily consumed by the CWS Dashboard, and loads it into the ODS. These steps are referred to as an extract transform load (ETL) process. It should be noted that data are also subjected to quality control reviews before they are transformed into a hierarchy that can be readily applied by the CWS Dashboard. From the ODS, analytical algorithms are run on the data, and the results are then made available to the CWS Dashboard where they are united with the GIS data to provide geospatial context. The end output from the BIA is a customizable, interactive dashboard that provides clear visualization of the information by leveraging the modules in the analytical toolbox. Figure 2 illustrates the BIA process flow. Note that 311 calls are not directly loaded into the data warehouse. They are forwarded to the PWD Call Center and then entered into Cityworks. Figure 3 shows a slightly different, more dashboard-oriented view of PWD's system architecture.

FIGURE 2
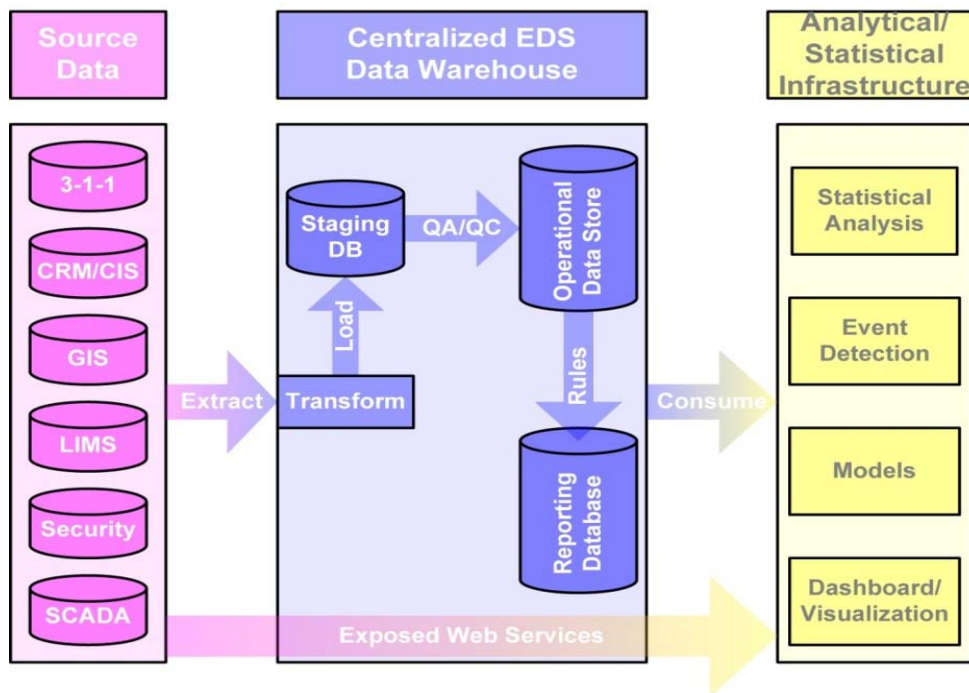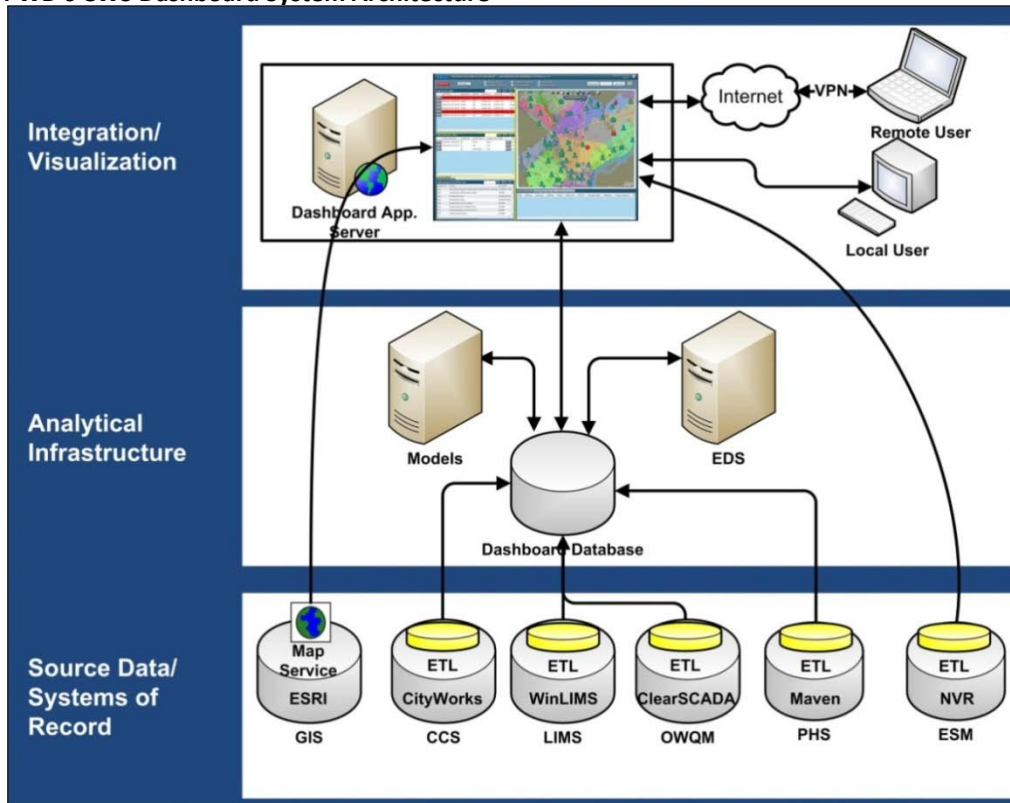**General Business Information Architecture Process Flow**

FIGURE 3
PWD's CWS Dashboard System Architecture

CWS Dashboard Software Design and Implementation

An intensive 12-month CWS Dashboard software design and implementation effort was undertaken to install a robust Web GIS-based CWS Dashboard system at the core of the CWS information technology (IT) and system infrastructure. The CWS Dashboard serves as a centralized platform for CWS event data management, incident investigation, and issue resolution for the CWS project. The system also provides automated event detection and the opportunity for preliminary cross component data analysis while allowing the map display to enable quick response and coordination among a large group of users, including PWD, PDPH, and other agencies. The CWS Dashboard has the following main features and functions:

- **CWS alert table**—Users can view any automated or manual alerts generated by a CWS monitoring and surveillance component indicating an unusual condition. New alerts are displayed chronologically. Users can filter the alerts by component, as well as modify the alert status, resolution, and action taken while investigating an event.

- **Alert detail table**—Users can view specific information relevant to the alert. For example, the alert detail table for CCS provides the service request type, customer name, address, telephone number, time generated, service request status, and associated pressure district and water treatment plant. A direct link to Cityworks is available.

- **CWS incident table**—Users can view any validated alerts generated by a CWS monitoring and surveillance component. Users have the ability to combine related alerts.

- **Activity log**—Users can view and create messages during the different stages of an alert investigation. The activity log automatically keeps track of alerts and incident activity.

- **Chat**—Users can chat with other online CWS Dashboard users by typing a message in the provided space.

- **Map toolbar**—Users have access to several functions that allow them to interact with the map, including zoom, pan, previous and forward extents, and identify. The map toolbar allows access to tools to allow users to view up to 2 days of OWQM data as time series charts or current data as gauges from each OWQM site.

- **Map layers**—Users can turn on and turn off map layers such as pressure districts and component alerts.

- **Documents**—Users can view important CWS documents and forms, including component operational strategies, the Consequence Management Plan, and the Risk Communication Plan.

- **Incident Command System**—The CWS Dashboard provides a live and customized event-driven ICS. The tool enables PWD to develop and populate the ICS based on the type of incident and the availability of designated personnel within the ICS. It also gives PWD the ability to track the actions taken by ICS personnel through the use of activity logs.

Figure 4 shows the CWS Dashboard configuration, while Figures 5 and 6 display screenshots of the CWS Dashboard for the OWQM and CCS components, respectively.

FIGURE 4
PWD's CWS Dashboard Configuration

FIGURE 5
PWD's CWS Dashboard Screenshot of the Online Water Quality Monitoring Component
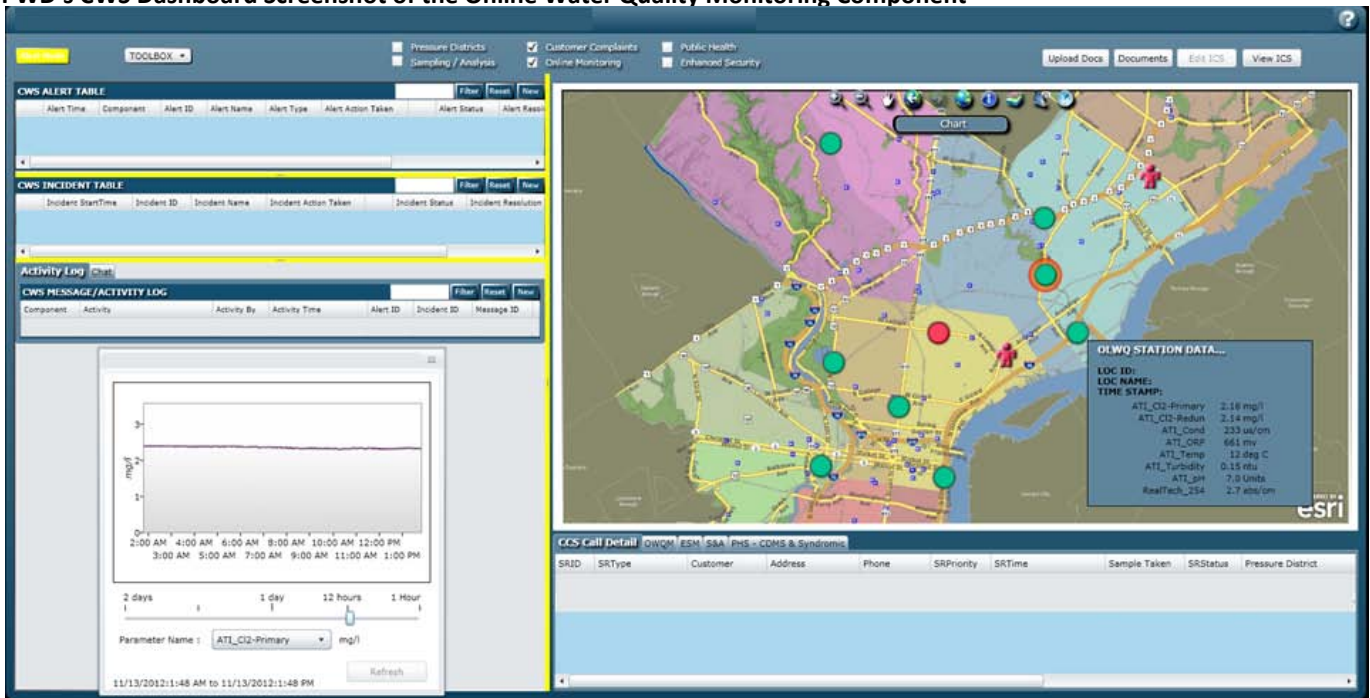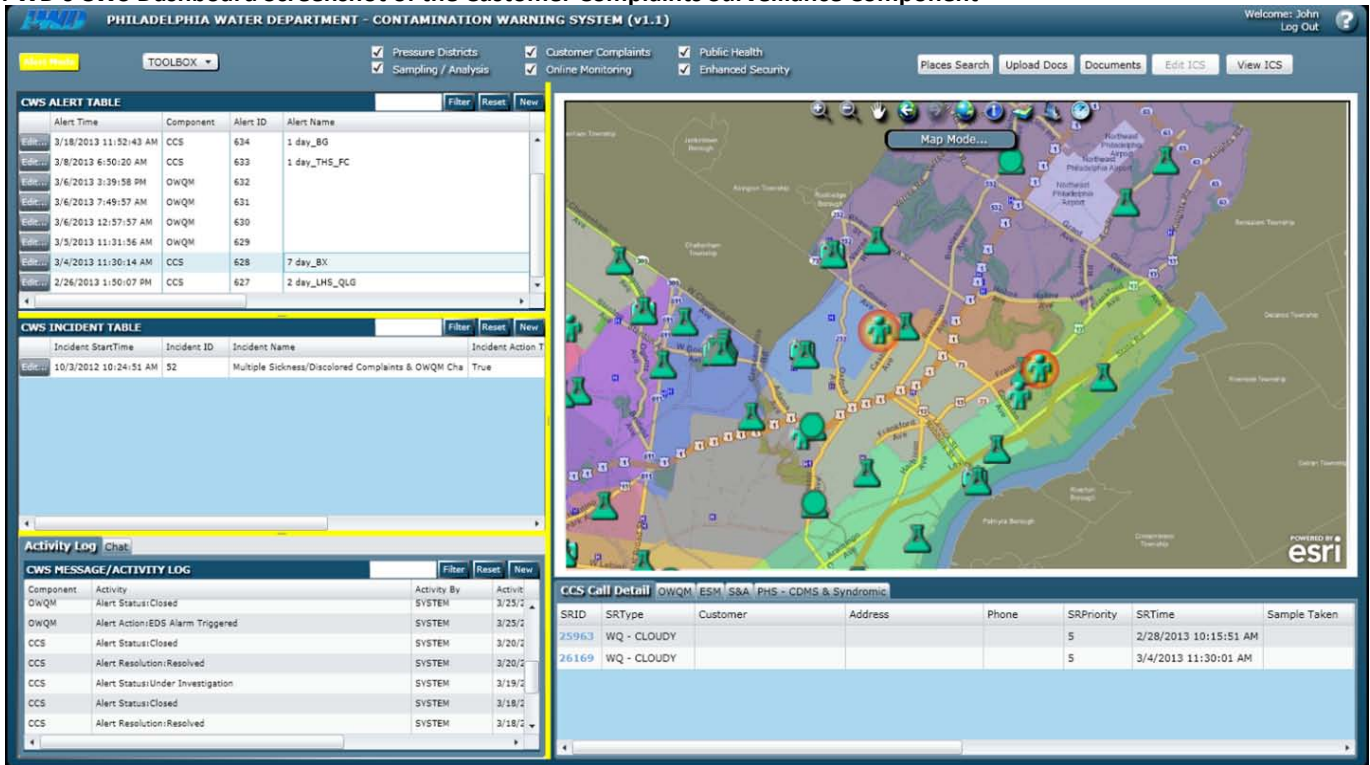

FIGURE 6
PWD's CWS Dashboard Screenshot of the Customer Complaints Surveillance Component

Lessons Learned

The following lessons learned were realized during the development and implementation of the CWS Dashboard:

- **Planning**—Development of a final CWS Dashboard and implementation plan requires the consideration of many details. The required level of effort must be adequately anticipated. Having input from all stakeholders and end users is key and requires a fair bit of coordination to minimize the impact on already busy schedules.

- **Network connectivity**—It is important to know the connectivity and network load requirements, both internally and externally, when building and provisioning the application. Because the Dashboard is pulling data from multiple sources in real-time, impact on the network must be reviewed to ensure high availability with relatively fast response times.

- **Operations and Maintenance**—The underlying integration of systems relies on a *contract* between applications/databases and programming interfaces. If applications are upgraded or replaced, care must be taken to ensure that the contracts are not broken (which would in turn break the integration). Documentation of all processes is critical for long-term maintenance.

- **Development**—Joint software code development between the utility and consultant is beneficial to engage each one's expertise, familiarity with systems, and access to infrastructure.

- **Training**—The CWS Dashboard should not be used for training until it is fully functional to avoid misunderstandings with regard to the system that may ultimately increase staff resistance.

Benefits

The following benefits were realized with the development and implementation of the CWS Dashboard:

- Increased cooperation and establishment of a formal relationship with internal stakeholders through PWD staff participation in the CWS Dashboard development.

- PWD-implemented tools better optimize the distribution system through the development and execution of the CWS Dashboard.

- Improved response time through the implementation of the CWS Dashboard and training.

- Improved content and presentation of information from multiple components in one location for key decision-makers through the development and implementation of the CWS Dashboard.

- Water industry technology innovations through implementation of the CWS Dashboard and PWD's outreach presentations.

- Greater confidence by regulators in PWD's response to water contamination through the development and implementation of the CWS Dashboard.

Conclusions and Recommendations

The CWS Dashboard was developed to automate event detection and provide an opportunity for preliminary cross-component data analysis and map display to facilitate quick response and coordination among a large group of users, including other agencies. To create a centralized CWS Dashboard, data streams from the OWQM, S&A, ESM, CCS and PHS components were transformed into actionable information through the BIA.

The five-step process used in the CWS Dashboard development process proved to be successful. PWD believes it is important to divide the CWS Dashboard development into self-contained modules with sufficient capabilities to allow users to become familiar with the application and provide feedback to the SE team, rather than to take the user requirements and implement the application in full. These design iterations further enhanced the requirements process by allowing users to interact with and understand in more detail how the application could enable and automate the business processes.

PWD has benefited from integrating the various component data systems into a centralized dashboard application that contains many features and user functions. The CWS Dashboard is a complex application that brings together data from multiple components and facilitates the determination of whether a contamination or operational event has occurred in the water utility system. The CWS Dashboard provides important system information into the hands of key decision-makers 24/7 to support timely and appropriate responses to water quality anomalies.

Abbreviations and Acronyms

BIA   Business Intelligence Architecture
CM   Consequence Management
CMMS   Computerized Maintenance Management System
CWS   Contamination Warning System
CCS   Customer Complaint Surveillance
EDS   Event Detection System
EPA   United States Environmental Protection Agency
ESM   Enhanced Security Monitoring
ETL   Extract Transform Load
GIS   Geographic Information System
ICS   Incident Command Structure
IT   Information technology
LIMS   Laboratory Information Management System
ODS   Operational Data Store
OWQM   Online Water Quality Monitoring
PDPH   Philadelphia Department of Public Health
PHS   Public Health Surveillance
PWD   Philadelphia Water Department
S&A   Sampling and Analysis
SE   System Engineering
SCADA   System Control and Data Acquisition
WS   Water Security