United States
Environmental Protection
Agency

Water Quality Surveillance and Response System Primer

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Introduction

This document provides an overview of Water Quality Surveillance and Response Systems (SRS) as applied to drinking water distribution systems. It provides basic information about the design and objectives of an SRS, and describes how these systems can provide a framework for detecting and responding to water quality incidents occurring in a drinking water distribution system. This primer covers the following five topics:

- **Topic 1**: What is an SRS?
- **Topic 2**: What are the components of an SRS?
- **Topic 3**: What are common design goals for an SRS?
- **Topic 4**: What are common performance objectives for an SRS?
- **Topic 5**: What is the process for implementing an SRS?

Topic 1: What is an SRS?

Drinking water utilities are responsible for managing water quality from source to tap and thus are implementing systems to improve water quality monitoring throughout their system. An SRS provides a systematic framework for enhancing distribution system monitoring activities and using the collected information to better manage the system.

One application of an SRS is monitoring for natural, accidental or intentional contamination incidents, such as:

- Source water contamination, including chemical spills and algal blooms
- Backflow through service connections, hydrants and other access points
- Contamination at storage tanks and reservoirs
- Cross-connections with non-potable water
- Infiltration of contaminated water into the distribution system during low pressure events

Incidents that impact distributed water quality, such as those listed above, are unpredictable and may occur with greater frequency than might be assumed. An SRS can improve a utility's ability to detect and respond to these incidents in time to reduce adverse public health and economic impacts.

An SRS also provides substantial benefit to routine operations and water quality management. The real-time data generated by an SRS provides a means of identifying emerging water quality incidents, such as low chlorine residual levels, nitrification, rusty water, and taste and odor episodes. Early identification of these incidents can provide sufficient time to respond and implement corrective action.

Topic 2: What are the components of an SRS?

Figure 1 shows the components of an SRS grouped into two operational phases, surveillance and response. The surveillance components are designed to provide timely detection of water quality incidents in drinking water distribution systems and include: Online Water Quality Monitoring, Enhanced Security Monitoring, Customer Complaint Surveillance, and Public Health Surveillance. The response components include Consequence Management and Sampling & Analysis, which support timely response actions that minimize the consequences of a contamination incident.

> **DID YOU KNOW?**
>
> Most drinking water utilities have existing capabilities and resources that provide the foundation for implementing an SRS.

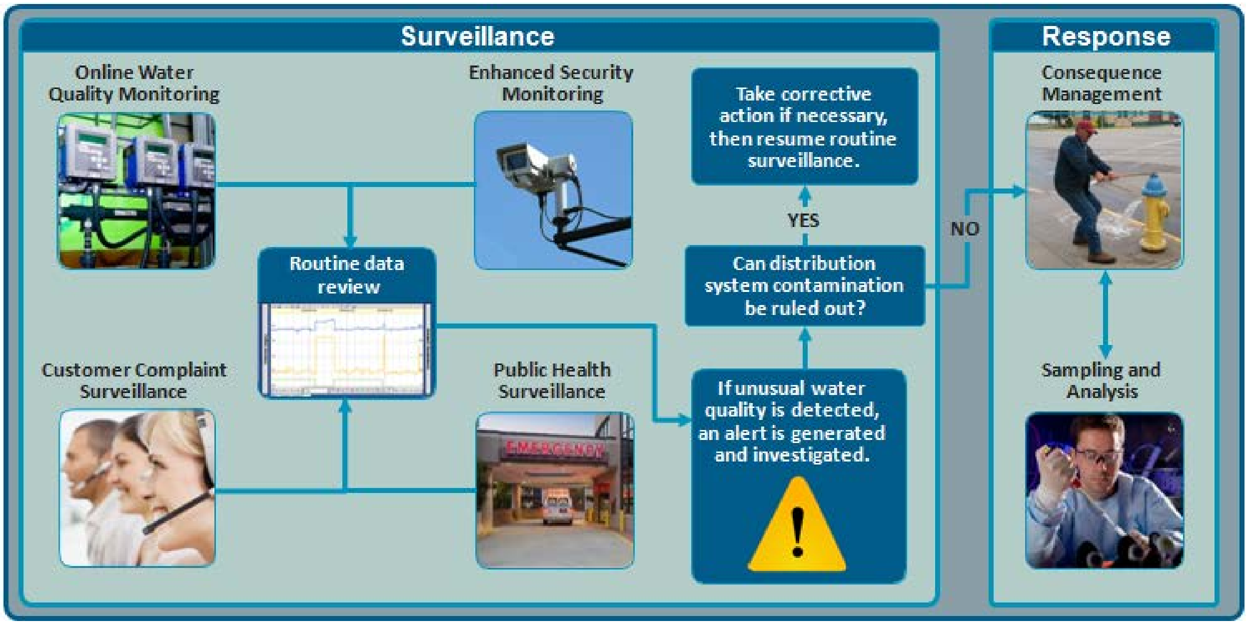


Figure 1. Surveillance and Response System Components

The components of an SRS are based on information, systems and procedures that likely exist in some form at many drinking water utilities and local partner organizations. These existing capabilities can be leveraged to implement a cost-effective SRS. Each of the SRS components is described in more detail in the following subsections.

Online Water Quality Monitoring

Definition: Online Water Quality Monitoring involves continuous monitoring of water quality parameters at strategic locations in the distribution system. Data from these monitoring stations is automatically transmitted to a central information management system and analyzed to detect water quality anomalies. Monitoring stations measure water quality parameters such as:

- Chlorine residual
- Total organic carbon
- UV-Visible spectral absorbance
- Turbidity
- Conductivity
- pH

Data from monitoring stations is analyzed using techniques ranging from visual inspection to automated statistical analysis in order to identify periods where the data generated by these sensors deviates from typical patterns.

Role in an SRS: Online Water Quality Monitoring has the potential to detect a broad range of water quality changes resulting from incidents such as cross-connections or backflow, nitrification, treatment process upsets and the introduction of contaminants into the distribution system. This component can provide good spatial representation of the distribution system, depending on the number and placement of monitoring stations. The real-time water quality data obtained from locations throughout the distribution system provides information that can be used to improve daily system operations and water quality management. For more information, see the *Online Water Quality Monitoring Primer* (USEPA, 2015a).

Enhanced Security Monitoring

Definition: Enhanced Security Monitoring involves the use of equipment and procedures to detect and respond to security breaches at distribution system facilities that are vulnerable to contamination. It is operated in collaboration with local law enforcement to ensure timely response to alerts from security systems such as:

- Intrusion detection systems, such as door or hatch alarms and motion sensors
- Video monitoring systems such as Internet Protocol cameras, infrared cameras, event-based network video recorders, and video analytics to detect unusual activity in captured images

Alert and video data from security equipment is typically sent to a central location, such as a utility control center, for viewing and monitoring. Video displayed on a graphical user interface can provide useful information to quickly determine whether or not activity at a site is authorized.

Role in an SRS: Unlike traditional physical security improvements such as installation of fencing or locks, Enhanced Security Monitoring provides real-time notification of intrusion incidents using equipment such as contact switches and video cameras. Rapid detection and assessment of an intrusion can drastically reduce the time it takes to respond to a security breach. While the Enhanced Security Monitoring component has limited spatial coverage, protecting only individual sites in the distribution system, it has the potential to provide an alert in sufficient time to prevent the intentional contamination of a distribution system facility. Enhanced Security Monitoring can also detect acts of vandalism or theft. For more information, see the *Enhanced Security Monitoring Primer* (USEPA, 2015b).

Customer Complaint Surveillance

Definition: Customer Complaint Surveillance monitors water quality complaint data in call or work management systems and identifies abnormally high volumes and spatial clustering of complaints that may be indicative of deteriorating water quality. Datastreams commonly monitored include:

- Interactive Voice Response systems that include an option for reporting water quality concerns
- Email and social media that may provide a mechanism for customer feedback
- Work management systems that track the investigation of and response to customer complaints

Role in an SRS: Customer Complaint Surveillance can only detect contaminants that impart a discernible taste, odor or appearance to drinking water, thereby limiting the contaminant coverage provided by this component. However, Customer Complaint Surveillance provides nearly complete spatial coverage of a distribution system, and spatial clustering of complaints can focus the investigation on a specific area of the distribution system. Customer complaints are timely and serve as an early indicator of a potential degradation in drinking water aesthetics. For more information, see the *Customer Complaint Surveillance Primer* (USEPA, 2015c).

Public Health Surveillance

Definition: Public Health Surveillance analyzes public health data to identify disease clusters that may be caused by contaminated drinking water. It is operated in collaboration with local public health partners to ensure timely detection of possible drinking water contamination incidents. Datastreams commonly monitored include:

- Emergency department data
- Poison control center calls
- Emergency medical services runs
- 911 calls
- School absenteeism
- Medication sales

Role in an SRS: Public Health Surveillance differs from the other surveillance components in that it is generally monitored by local public health partners, whereas other surveillance components are monitored by water utility personnel. The utility's role in this component is to establish effective communication protocols with public health agencies to ensure that the utility is notified when a public health agency receives an alert or suspects that an outbreak may be related to drinking water exposures. In many cases, public health agencies already monitor some of the datastreams listed above, and these existing systems may be readily incorporated into an SRS with minimal effort. Depending on the surveillance tools in use, the Public Health Surveillance component has the potential to detect a wide range of chemical and biological contaminants. For more information, see the *Public Health Surveillance Primer* (USEPA, 2015d).

Consequence Management

Definition: Consequence Management consists of planning and procedures for responding to possible drinking water contamination incidents. It is operated in collaboration with a variety of local and state response partners, including law enforcement, public health and emergency response agencies. The primary functions of this component are to:

- Establish the credibility of a possible contamination incident
- Minimize public health and economic consequences
- Guide the remediation and recovery effort

Planning for Consequence Management requires integration of common elements of existing utility plans, such as emergency response and communication plans, while also coordinating with local, state and federal partners using the Incident Command System. Planning and coordination are necessary to reduce the time for implementation of response actions (for example, isolation, flushing, public notification), which in turn directly affects the degree to which public health and economic consequences can be mitigated.

Role in an SRS: While Consequence Management does not play a role in day-to-day utility operations, this component does provide the framework that guides the systematic investigation of, and response to, possible contamination incidents detected through the SRS surveillance components. Integrated information from these components, along with results from Sampling and Analysis, provides information to make informed decisions during consequence management. This component also promotes stronger interagency relationships and prepares a utility to respond to a wide range of emergencies. For more information, see the *Consequence Management Primer* (USEPA, 2015e).

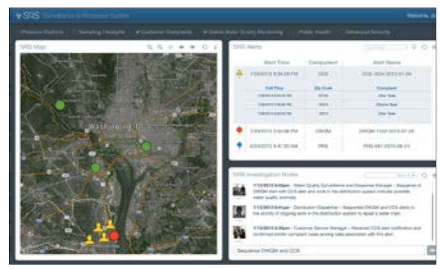
Sampling and Analysis

Definition: Sampling and Analysis involves the collection and analysis of water samples from a distribution system. Sampling activities are activated through Consequence Management to further investigate possible contamination incidents. Analyses are conducted for chemicals, radionuclides, pathogens and biotoxins at utility labs and through pre-arranged laboratory partnerships or contracts. The primary functions of this component are to:

- Perform field testing and sample collection
- Analyze samples for contaminants of concern
- Characterize the extent of contamination

Role in an SRS: Sampling and Analysis provides critical information used to make decisions during Consequence Management such as the results from laboratory analyses for a wide variety of contaminants. This information is used to confirm or rule out possible water contamination. For more information, see the *Sampling and Analysis Primer* (USEPA, 2015f).

System Engineering



Successful implementation of the surveillance and response components described above requires coordination of managerial, technical and training activities across the entire utility and with partner organizations. These system engineering efforts are necessary given the potential complexity of a multi-component SRS and the multi-disciplinary approach to system design. Application of system engineering principles to the design of an SRS can reduce costs through more effective utilization of existing and planned resources. **Table 1** describes four main areas in which system engineering supports SRS implementation.

Table 1. Role of System Engineering in SRS Implementation

Area	Activities
Comprehensive project management	Establish an overarching project management structure to guide implementation, establish priorities and ensure that project objectives are met
Integrated information management	Develop requirements for access to and display of information during alert investigations and consequence management Identify information management solutions that facilitate integration of information across multiple components
Integrated operational strategy	Assign roles and responsibilities for routine operation and maintenance of the SRS Develop procedures and checklists for investigating alerts generated by the surveillance components
Training and exercise program	Develop a multi-year SRS training and exercise program for utility and response partner personnel that includes classroom training as well as field-level drills and tabletop exercises

Topic 3: What are common design goals of an SRS?

Design goals define the specific benefits that a utility would like to realize through implementation and operation of an SRS, and thus inform the design of the system. A number of benefits can be realized from an SRS, all of which derive from increased knowledge about variable water quality in a distribution system and implementation of procedures to respond to water quality problems in a timely and effective manner. General benefits derived from an SRS include the ability to detect and respond to contamination incidents as well as improve day-to-day management of distribution system water quality.

Several example design goals are described in **Table 2**. While all of these design goals can be achieved through implementation of a multi-component SRS, it is a good idea to prioritize those that are most important to a utility's broader objectives. Establishing utility-specific design goals helps to ensure that the resulting SRS will be focused on those benefits deemed most important.

Table 2. Examples of SRS Design Goals

Example Design Goal	Description
Detect and respond to contamination incidents	Provide timely detection of possible contamination incidents and a framework to guide response actions, which can minimize public health and economic consequences
Improve water quality in the distribution system	Provide timely information about water quality changes in the distribution system to allow for faster treatment or operational changes in order to maintain water quality targets
Increase level of customer confidence and service	Provide timely and effective response to customer complaints and thorough responses to customer water quality concerns
Enhance physical security	Ensure the integrity of water distribution facilities and deter acts of tampering, theft and vandalism
Demonstrate the safety of the drinking water supply	Integrate public health information to quickly identify waterborne illnesses, or to demonstrate that the majority of community outbreaks are not waterborne
Improve ability to detect water quality anomalies	Provide real-time surveillance of water quality, and related datastreams, which can be used to detect unusual water quality conditions and verify the underlying cause
Prevent infrastructure damage	Identify water quality conditions that could potentially damage infrastructure and implement corrective action
Strengthen interagency relationships	Work collaboratively with laboratories, public health partners and emergency response partners in areas of common interest and to improve public health protection
Strengthen Incident Command Structure	Develop a robust utility Incident Command Structure that is compatible with response partner command structures to provide a foundation for a coordinated response to any emergency or hazard

Topic 4: What are common performance objectives for an SRS?

Performance objectives for an SRS gauge how well the surveillance and response components, either individually or as a whole, achieve the design goals established for the system. USEPA identified the following performance objectives for an SRS:

- **Incident coverage**: The number and type of incidents that can be detected by the SRS, including those resulting from natural, accidental or intentional contamination.
- **Spatial coverage**: The percent of a utility's distribution system monitored by the SRS.
- **Timeliness of detection and response**: The amount of time between the start of a water quality incident and detection by an SRS component, and the amount of time between detection and implementation of response actions to minimize the consequences of the incident.
- **Operational reliability**: The percentage of time that the SRS is functioning at a level that achieves the other performance objectives.
- **Alert occurrence**: The frequency of detection of true water quality incidents, the frequency of incidents that go undetected, and the frequency of invalid alerts.
- **Sustainability**: The degree to which the benefits derived from the SRS justify the cost to implement and maintain the system.

Additional information about each performance objective and how each relates to the design of SRS components is presented below. Note that the degree to which some of the performance objectives are achieved may depend on the number of surveillance components deployed. For example, greater incident coverage, spatial coverage and timeliness of detection can be expected when multiple surveillance components are implemented.

Incident Coverage

An SRS can be designed to rapidly detect a variety of water quality incidents, as illustrated in **Table 3**.

Table 3. Water Quality Incidents That Can Be Detected By An SRS

Water Quality Incident	Online Water Quality Monitoring	Public Health Surveillance	Customer Complaint Surveillance
Distribution system contamination	✓	✓	✓
Cross-connections	✓	✓	✓
Turbidity spikes due to main breaks or hydrant flushing	✓	**n/a**	✓
Rusty or dirty water	✓	**n/a**	✓
Excessive chlorine feed	✓	**n/a**	✓
Excessive fluoride feed	✓	✓	**n/a**
Loss of chlorine residual	✓	**n/a**	**n/a**
Nitrification	✓	**n/a**	**n/a**
Excessive, localized corrosion	✓	**n/a**	**n/a**

Detection of distribution system contamination incidents is based on grouping contaminants into detection classes based on similarities in the ability of the SRS surveillance components to detect them. **Table 4** lists 11 detection classes, along with example contaminants, and indicates the potential for Online Water Quality Monitoring, Public Health Surveillance, and Customer Complaint Surveillance to detect contaminants in a given detection class at the smallest concentrations that could cause serious harm to public health or distribution system infrastructure. The table shows that a combination of these three SRS components would provide complete coverage of all 11 detection classes.

Table 4. Example Contaminant Detection Classes Used in SRS Design[1]

Detection Class	Example Contaminant[2]	Online Water Quality Monitoring	Public Health Surveillance	Customer Complaint Surveillance
Toxic Industrial Chemical	Cyanide	✓	✓	✓
Toxic Inorganics	Arsenite	✓	✓	✓
Pesticides	Oxamyl	✓	✓	✓
Odorless Pesticides	Aldicarb	✓	✓	**n/a**
Chemical Warfare Agents	VX	**n/a**	✓	**n/a**
Radionuclides	Alpha, Beta and Gamma emitters	**n/a**	✓	**n/a**
Bacterial Toxins[3]	Botulinum toxins	✓	✓	**n/a**
Plant Toxins	Ricin	✓	✓	**n/a**
Waterborne Pathogens[3]	*Vibrio cholerae*, *Salmonella typhi*	✓	✓	**n/a**
Bioterrorism Agents[3]	*Bacillus anthracis*	✓	✓	**n/a**
Hydrocarbons	Gasoline	✓	**n/a**	✓

[1] Enhanced Security Monitoring is not included in this table because the component detects intrusions at facilities vulnerable to contamination independent of contaminant class.
[2] These contaminant classes represent the most serious threats of intentional distribution system contamination. Other contaminant classes could be defined to align with utility-specific design goals.
[3] Many of the contaminants in these detection classes are detectable by Online Water Quality Monitoring due to the presence of co-contaminants that alter common water quality parameters.

Spatial Coverage

Two of the surveillance components, Online Water Quality Monitoring and Enhanced Security Monitoring, have intrinsic spatial coverage limitations because they are installed at a finite number of fixed locations. On the other hand, Customer Complaint Surveillance and Public Health Surveillance rely on human observations and behavior, and thus may provide robust spatial coverage throughout a distribution system. **Table 5** shows how integration of the four surveillance components can provide comprehensive and overlapping spatial coverage throughout a distribution system.

Table 5. Spatial Coverage Provided by Each of the SRS Surveillance Components

Component	Spatial Coverage
Online Water Quality Monitoring	Limited number of monitoring stations placed at strategically chosen locations to provide optimal coverage of distribution system water quality
Enhanced Security Monitoring	Monitoring infrastructure such as tanks, reservoirs and pump stations that supply finished water to large areas of the distribution system
Customer Complaint Surveillance	Coverage of the entire utility service area in which customer complaints are captured
Public Health Surveillance	Coverage of portions of the service area within public health jurisdictions that conduct surveillance activities in coordination with the utility

Additionally, well-planned Sampling and Analysis response procedures can provide information from field testing and laboratory analysis of samples collected from anywhere in a distribution system.

Timeliness of Detection and Response

SRS components can be designed to provide timely information about changing water quality in a distribution system. Early discovery of emerging water quality issues in a distribution system allows for prompt corrective actions that prevent isolated incidents from escalating into widespread problems. Timely information provided by the SRS helps operators and water quality managers to ensure that water quality is maintained from the treatment plant to the customer's tap.

Figure 2 shows the time for various SRS components to detect contamination relative to the time of initial onset of symptoms for different contaminant types. The figure illustrates how the multi-component design of an SRS has the potential to detect contamination incidents within the timeframe that public health consequences would occur, specifically:

- Online Water Quality Monitoring can detect a wide range of contamination incidents within a few hours to a few days depending upon where the monitoring stations are located relative to the location of contaminant introduction.
- Customer Complaint Surveillance and some forms of Public Health Surveillance, such as monitoring calls to poison control centers or 911, have the potential to detect chemical contamination within a few hours.
- Field and laboratory results from Sampling and Analysis may be available within a few hours to a few days depending on the analytical methods employed.
- Enhanced Security Monitoring may detect an intentional contamination incident in progress, and therefore could help to prevent contamination of, or limit contaminant spread within, the distribution system at the earliest stage of an incident.

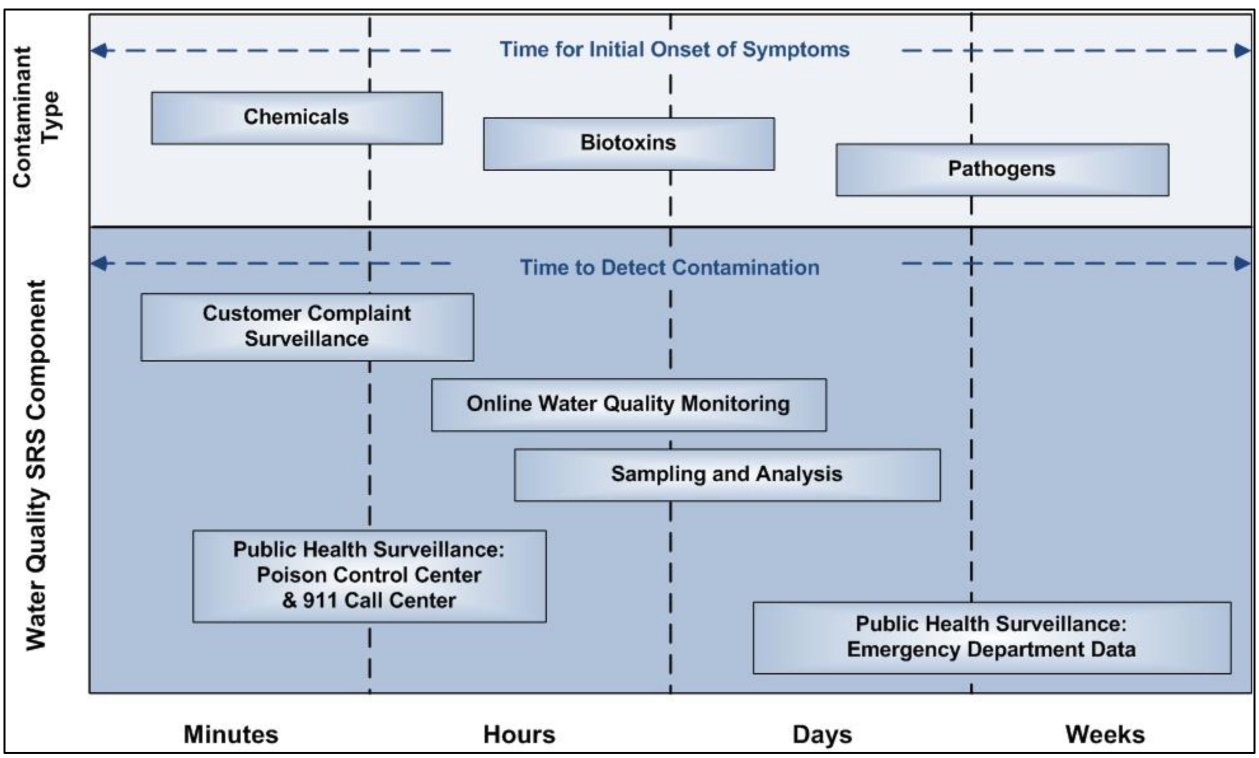


Figure 2. Relative Timing of Public Health Consequences and Detection by SRS Components

Operational Reliability

In order for an SRS to maintain the ability to detect water quality incidents in sufficient time to implement an effective response, the components should be available and producing accurate data 24/7. This degree of operational reliability can be accomplished by building redundancy into the SRS at several levels. At the system level, the SRS surveillance components have significant overlap with respect to both contaminant coverage and spatial coverage. Thus, if one component is temporarily unavailable, other components can provide at least partial contaminant and spatial coverage. At the component level, multiple datastreams provide redundancy such that if one datastream is temporarily unavailable, the component is still capable of detecting contamination incidents using the remaining datastreams. For example, chlorine residual and oxidation-reduction potential provide similar water quality information; if both parameters are measured at a water quality monitoring station, there would be a backup should one of the instruments malfunction. A third level of redundancy can be achieved through use of ancillary systems that support each component such as uninterruptable power supplies and failover IT systems.

Alert Occurrence

The SRS should be designed to minimize the occurrence of invalid alerts without compromising the ability of the system to detect water quality incidents. An excessive rate of invalid alerts can reduce a utility's confidence in the system and needlessly expend staff resources on the investigation of nuisance alerts. **Table 6** describes common causes of invalid alerts and indicates how they can be minimized.

Table 6. Strategies for Reducing the Occurrence of Invalid Alerts

Cause of Invalid Alerts	Description	Mitigation Strategy
Equipment problems	These invalid alerts are due to equipment faults and failures. Examples include malfunctioning water quality sensors and security monitoring equipment.	Perform regular equipment checks and implement a robust maintenance program. Implement remote diagnostics.
Procedural errors	These invalid alerts are attributed to personnel deviating from standard operating procedures.	Ensure proper training for utility personnel and response partners. Conduct exercises on a regular basis to reinforce these procedures.
Background variability	These invalid alerts are due to normal variations in the monitored datastream, such as daily utility operations and changes in the health of the community, which can occasionally cause alerts.	Configure data analysis systems to identify and ignore typical patterns in background variability.
Other	These invalid alerts are due to a cause other than those listed above. For example, a rise in customer complaints after long holiday weekends during which a call center is closed may cause an alert.	Adapt surveillance component alert thresholds as needed, and train utility staff to recognize rare, yet benign causes of invalid alerts.

In a multi-component SRS, valid alerts indicative of possible contamination can be identified through spatial and temporal clustering of alerts from different components. Examples of alert patterns representative of contamination incidents are shown in the following two figures.

Figure 3 shows a typical detection pattern for toxic chemicals with a taste or odor. As shown, this type of contaminant would first be detected through Customer Complaint Surveillance. Because many toxic chemicals start producing acute symptoms within minutes of exposure, a Public Health Surveillance alert could follow shortly thereafter. Finally, Online Water Quality Monitoring might detect the contaminant within several hours of the start of the contamination incident.

Figure 3. Typical Alert Pattern for Toxic Chemicals with Taste and Odor

Figure 4 shows a typical detection pattern for biological agents, such as pathogens and biotoxins. Many biological agents are tasteless and odorless, and thus would not be detected by Customer Complaint Surveillance. Furthermore, many biological agents don't produce symptoms until several hours to several days after exposure. Under this scenario, Online Water Quality Monitoring would likely be the first component to detect contamination, followed by Public Health Surveillance hours to days later.

Figure 4. Typical Alert Pattern for Biological Agents with Delayed Symptoms Onset

Sustainability

The sustainability of an SRS is driven by factors that influence the ability of a drinking water utility to operate and maintain the system over an extended period of time and in the face of competing priorities that could siphon resources away from the program.

Keys to sustainability of an SRS include minimizing new resources required to implement and operate the system by leveraging existing capabilities, and by integrating SRS procedures into routine business practices. Examples of strategies to develop a sustainable SRS include:

- Leveraging existing human resources
- Leveraging existing systems and procedures
- Conducting a realistic assessment of potential staffing requirements for operation and maintenance of an SRS
- Providing training on the use and applications of an SRS to utility personnel at all levels of the organization

DID YOU KNOW?

Designing an SRS to provide value during day-to-day utility operations is the key to sustainability.

Topic 5: What is the process for implementing an SRS?

Implementation of an SRS should follow typical project management principles, including assembly of a project management team, development of a schedule and budget, and establishing project goals and constraints. An SRS can be implemented incrementally as staffing and budget constraints dictate. **Table 7** describes six steps for implementation of an SRS.

Table 7. Process for Implementing an SRS

Implementation Stage	Description
1.) Preparation	• Establish a project management team • Establish design goals and performance objectives • Identify project constraints (for example, total capital budget, personnel available to support the project, etc.)
2.) Assessment	• Conduct an inventory of existing resources that could be leveraged for the SRS • Assess existing capabilities with respect to the design goals and performance objectives established for the SRS
3.) Develop a master plan for the SRS	• Review and reconcile preliminary component designs • Evaluate alternative SRS designs and determine the SRS components that will be implemented or enhanced • Develop preliminary information management requirements • Develop an overarching schedule and budget
4.) Design and installation	• Develop detailed workplan and specifications for each component • Implement the design and install equipment • Develop the procedures that govern operation of the SRS • Track progress according to the overall schedule and budget
5.) Preliminary testing	• Train utility and partner personnel on SRS operations and procedures • Operate the SRS for the purpose of collecting data necessary to understand system performance • Troubleshoot and optimize the SRS and its components to meet the established performance objectives • Revise procedures to align with the manner in which the SRS is intended to operate
6.) Routine operation and maintenance	• Operate the SRS to achieve the design goals established for the system • Respond to alerts in real-time • Maintain the SRS to meet the established performance objectives • Implement routine training and exercise activities • Periodically evaluate SRS performance and identify aspects of the system that may benefit from further enhancement

DID YOU KNOW?

The purpose of preliminary testing is to learn how the SRS functions and to optimize performance. Thus, during this stage alerts are typically not investigated in real-time, and only minimal response actions would be considered.

Next Steps

Visit the Water Quality Surveillance and Response Website at http://water.epa.gov/infrastructure/watersecurity/lawsregs/initiative.cfm for more information about SRS practices. The Website contains guidance and tools that will help a utility to enhance surveillance and response capabilities, as well as case studies that share utility experiences with SRS implementation and operation. A utility can use this guidance to implement an SRS that cost-effectively meets their design goals and performance objectives.

References

USEPA. (2015a). *Online Water Quality Monitoring Primer*, 817-B-15-002A.

USEPA. (2015b). *Enhanced Security Monitoring Primer*, 817-B-15-002B.

USEPA. (2015c). *Customer Complaint Surveillance Primer*, 817-B-15-002C.

USEPA. (2015d). *Public Health Surveillance Primer*, 817-B-15-002D.

USEPA. (2015e). *Consequence Management Primer*, 817-B-15-002E.

USEPA. (2015f). *Sampling and Analysis Primer*, 817-B-15-002F.