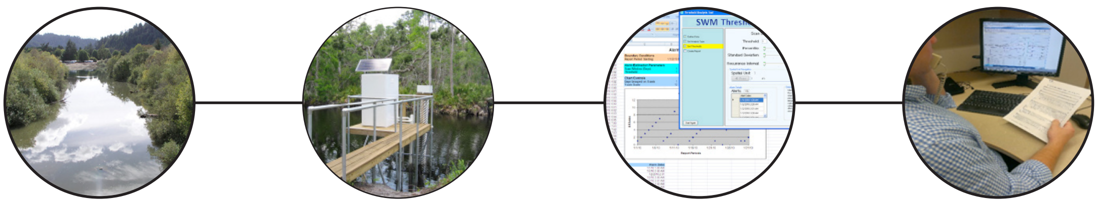
United States
Environmental Protection
Agency

Online Source Water Quality Monitoring

For Water Quality Surveillance and Response Systems



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Abbreviations

ADS	Anomaly Detection System
ANSI	American National Standards Institute
ASME-ITI	American Society of Mechanical Engineers Innovative Technologies Institute
AWWA	American Water Works Association
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CH2M	CH2M Hill, Inc.
CIO	Chief Information Officer
CM	Consequence Management
CREAT	Climate Resilience Evaluation and Awareness Tool
DBP	Disinfection Byproduct
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DWMAPS	Drinking Water Mapping Application to Protect Source Waters
ECHO	Enforcement and Compliance History Online
EPA	United States Environmental Protection Agency
ERP	Emergency Response Plan
EWS	Early Warning System
GAC	Granular Activated Carbon
GIS	Geographic Information System
HAB	Harmful Algal Bloom
HMI	Human Machine Interface
IT	Information Technology
LIMS	Laboratory Information Management System
NEMA	National Electrical Manufacturers Association
NH_3	Ammonia
NH_4^+	Ammonium
NO_3	Nitrate
NO_2	Nitrite
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric turbidity units
NWIS	National Water Information System
ORP	Oxidation-Reduction Potential
OWQM	Online Water Quality Monitoring
PAC	Powdered Activated Carbon
PLC	Programmable Logic Controller
PWD	Philadelphia Water Department
RAIN	River Alert Information Network
RCRAInfo	Resource Conservation and Recovery Act Information

S&A	Sampling and Analysis
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Water Drinking Act
SRBC	Susquehanna River Basin Commission
SRS	Water Quality Surveillance and Response System
SW Threat	Source Water Threat
SWC	Source Water Collaborative
SWM	Source Water Monitoring
TOC	Total Organic Carbon
TRI	Toxic Release Inventory
TSCA	Toxic Substances Control Act
USGS	United States Geological Survey
UV	Ultra-violet
VSAT	Vulnerability Self-Assessment Tool
WVAW	West Virginia American Water

Section 1: Introduction

Source water[1] is water from natural resources (e.g., aquifers, lakes, rivers, and streams) that is treated to produce drinking water for a community. Source water monitoring (SWM) involves the use of online ***water quality instruments*** for ***real-time*** measurement of water quality in a source water. The understanding gained through SWM enables drinking water utilities to more efficiently treat the source water, identify significant changes in water quality, implement appropriate treatment strategies, and take actions to protect the source water for its intended use.

SWM can be implemented as a stand-alone monitoring program, or it can be incorporated into a ***Water Quality Surveillance and Response System*** (SRS). An SRS is a framework developed by the United States Environmental Protection Agency (EPA) to support monitoring and management of water quality from source to tap. The system consists of one or more ***components*** that provide information to guide drinking water utility operations and enhance a utility's ability to quickly detect and respond to water quality changes. An SRS overview can be found in the *SRS Primer* (EPA, 2015a). **Figure 1-1** illustrates the manner in which SWM can be integrated into an SRS.

[1] Words in bold italic font are terms defined in the Glossary at the end of this document.

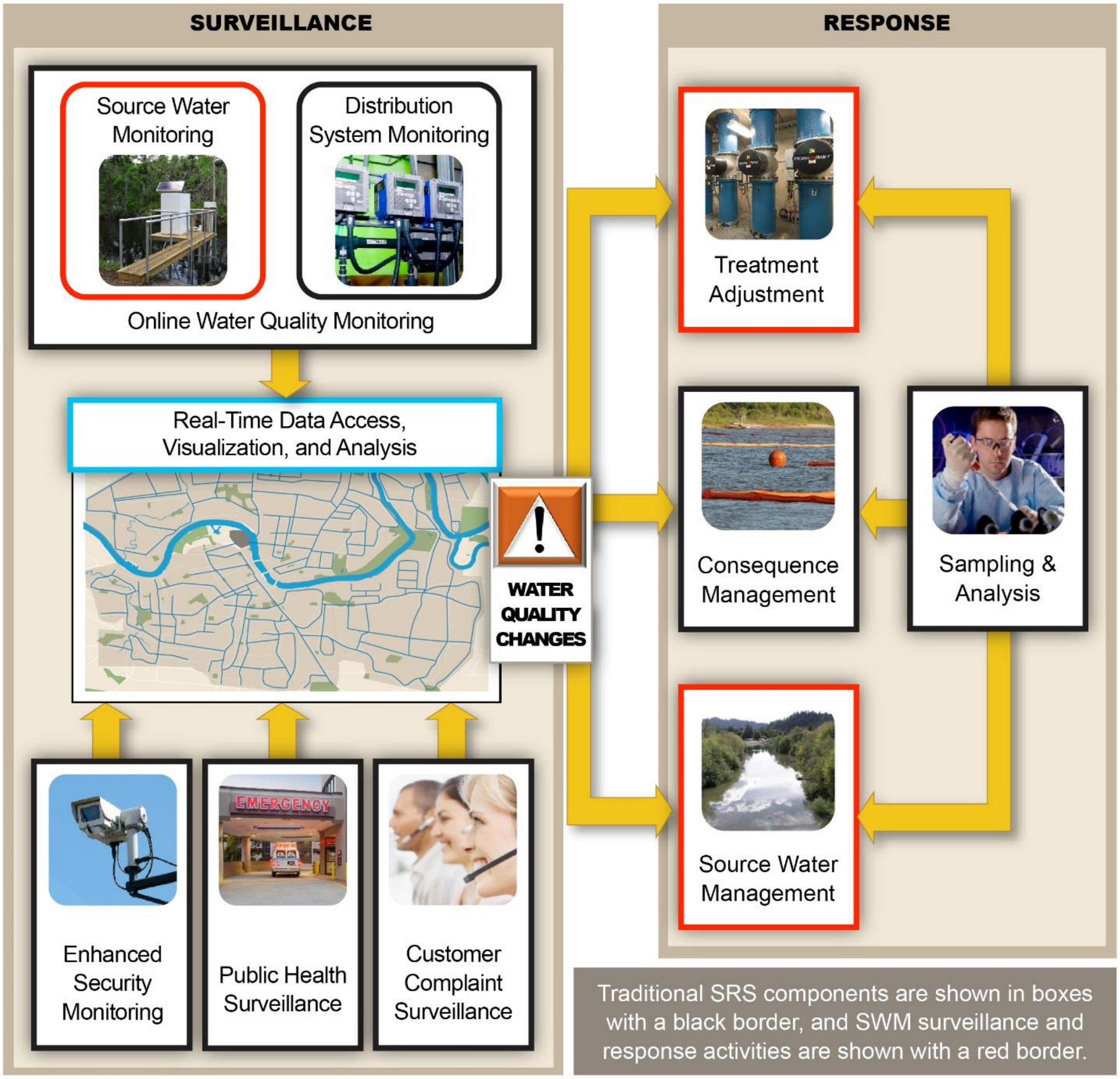


Figure 1-1. Incorporation of Source Water Monitoring into an SRS

The design of an SRS is flexible and can include any combination of components shown in Figure 1-1. However, it is recommended that all SRS designs include at least one surveillance component and basic capabilities for ***Sampling and Analysis*** (S&A) and ***Consequence Management*** (CM). S&A is important because the surveillance components of an SRS, including SWM, typically provide only a general indication of a potential water quality problem; S&A establishes capabilities for confirming or ruling out specific contaminants or contaminant classes. CM establishes procedures and relationships with response partners for responding to serious water quality problems such as contamination.

The guidance provided in this document treats SWM as an application of the ***Online Water Quality Monitoring*** (OWQM) component within an SRS. This allows many of the elements of an SRS, such as ***information management systems***, visualization tools, S&A capabilities, and contamination incident response plans, to be leveraged to support SWM operations. Furthermore, there is a substantial body of

SRS guidance that can support the design of SWM. These resources are cited throughout the document, where applicable.

1.1 Overview of Source Water Monitoring

Treatment plants are designed and operated to treat contaminants known to occur in source water, comply with drinking water standards, and meet customer expectations. Unanticipated changes quality or the presence of unusual contaminants in source water can adversely impact the ability of a utility to meet these objectives. SWM can improve a utility's ability to detect variations in source water quality.

SWM involves the measurement of various water quality parameters in source water or watersheds. An ***SWM location*** is the site in a waterbody where water is sampled for measurement. SWM locations are selected relative to ***control points***, which are locations where a treatment process can be modified (e.g., addition of pretreatment chemicals) or a response action can be implemented (e.g., closing an intake). ***SWM stations*** are installed at or near SWM locations and consist of online water quality instruments that measure parameters and communications equipment that transmits data to a central location, such as a utility ***control center***. A schematic of an example SWM system is shown in **Figure 1-2**.

REASONS TO IMPLEMENT SOURCE WATER MONITORING

- ☐ Provide information to facilitate protection of the public water supply for all intended uses
- ☐ Observe long-term trends in source water quality to prepare for future challenges or regulations
- ☐ Detect and respond to contamination incidents
- ☐ Optimize treatment processes to improve finished water quality and reduce costs
- ☐ Develop information that supports regulatory compliance
- ☐ Investigate and identify pollution sources and potentially responsible parties

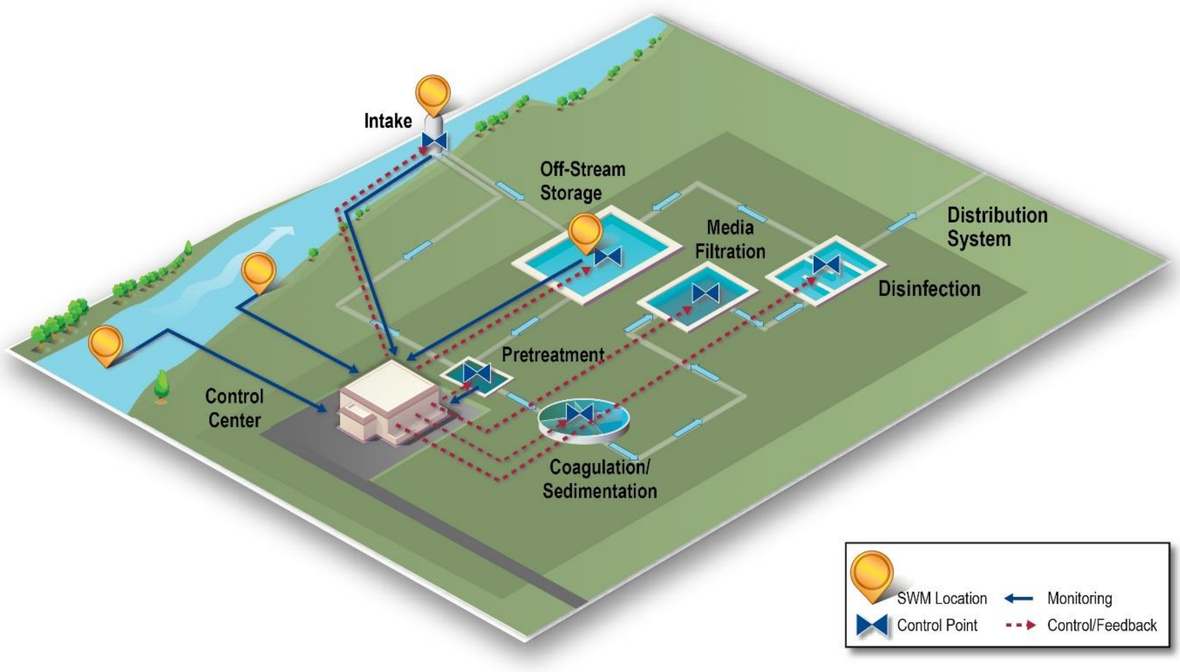


Figure 1-2. Example Schematic of Source Water Monitoring

The physical location where the SWM station is installed may not be the same as the SWM location. For example, source water can be pumped from an SWM location to an SWM station installed at a different site. **Figure 1-3** shows an SWM station installed at the SWM location (Exhibit A) and an SWM station installed away from the SWM location (Exhibit B).

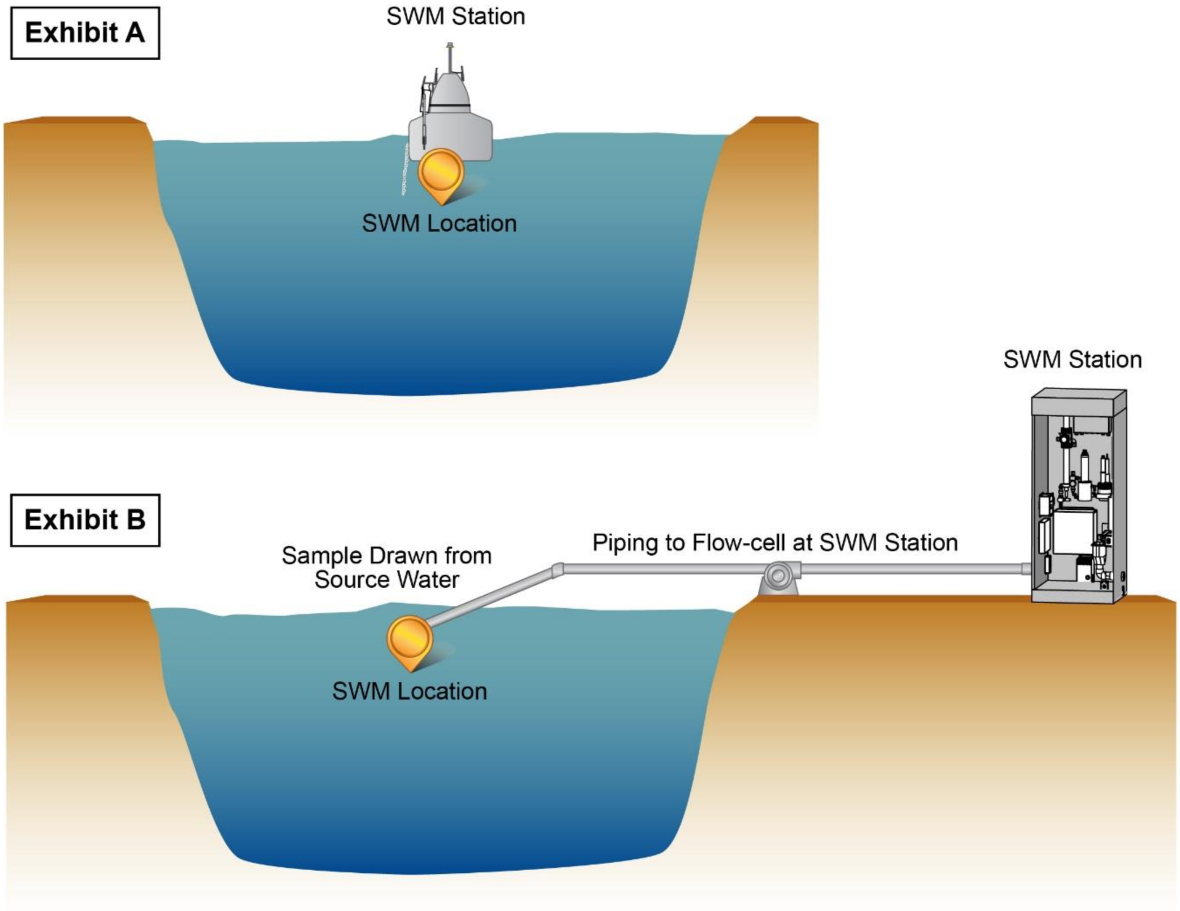


Figure 1-3. SWM Location vs. SWM Station

The scale of an SWM system can extend from an individual drinking water utility monitoring at its treatment plant intake to systems that monitor an entire watershed. The latter typically involve multiple organizations to provide coverage of a large area (e.g., an entire watershed or river basin) and share the cost required to install, operate, and maintain the system. Benefits of a watershed-scale SWM system include the ability to achieve extensive geographic coverage and maintain more monitoring locations than could be maintained by any single organization. However, such systems require sustained commitment by all partners and can present challenges if partner organizations decide to end their support.

1.2 Purpose and Overview of this Document

This document provides guidance on the design of an SWM system that is based on best practices and lessons learned from existing SWM systems. It introduces key concepts, provides examples, and directs the reader to additional resources for guidance on specific technical elements of SWM.

This document is primarily intended for use by water sector professionals, but might also be useful to organizations or individuals with an interest in source water quality. These additional stakeholders might include those responsible for assuring the quality of water for recreational purposes, those involved in aquaculture or other commercial ventures, those responsible for environmental protection, and those concerned with the quality of natural resources.

APPLICABILITY OF GUIDANCE

The methodology presented in this document can be used to design SWM systems that vary widely in complexity—from a simple system monitoring a single parameter at a single location to a system that monitors multiple parameters at several locations in a watershed.

The remaining sections of this document cover the following topics:

- **Section 2** describes a framework for designing an SWM system, introduces three high-level design goals for SWM, and presents a process for identifying and prioritizing potential source water threats.
- **Section 3** provides guidance on the selection of monitoring locations to support each of the three design goals for SWM.
- **Section 4** provides guidance on selecting water quality parameters to achieve each of the three design goals for SWM.
- **Section 5** provides guidance on the selection of monitoring equipment and the design of SWM stations.
- **Section 6** provides guidance on the development of an information management system and analysis techniques to support each of the three SWM design goals.
- **Section 7** provides guidance on developing investigation and response procedures to support SWM.
- **Section 8** presents an example of the SWM design process described in the previous sections.
- **Section 9** presents SWM case studies that illustrate a variety of designs and implementation approaches.
- **Resources** presents a comprehensive list of documents, tools, and other sources cited in this document, including a summary of and link to each resource.
- **Glossary** provides definitions of terms used in this document, which are indicated by bold, italic font at first use in the body of the document.

Section 2: Framework for Designing a Source Water Monitoring System

The design process for SWM follows the principles of project management and master planning that are described in Sections 2 and 3 of *Guidance for Developing Integrated Water Quality Surveillance and Response Systems* (EPA, 2015b) (referred to throughout this document as *SRS Integration Guidance*). This section presents a framework for implementing SWM, as shown in **Figure 2-1**. While depicted as a linear process, in practice it is iterative. Decisions or findings in downstream steps can require that earlier steps be revisited.

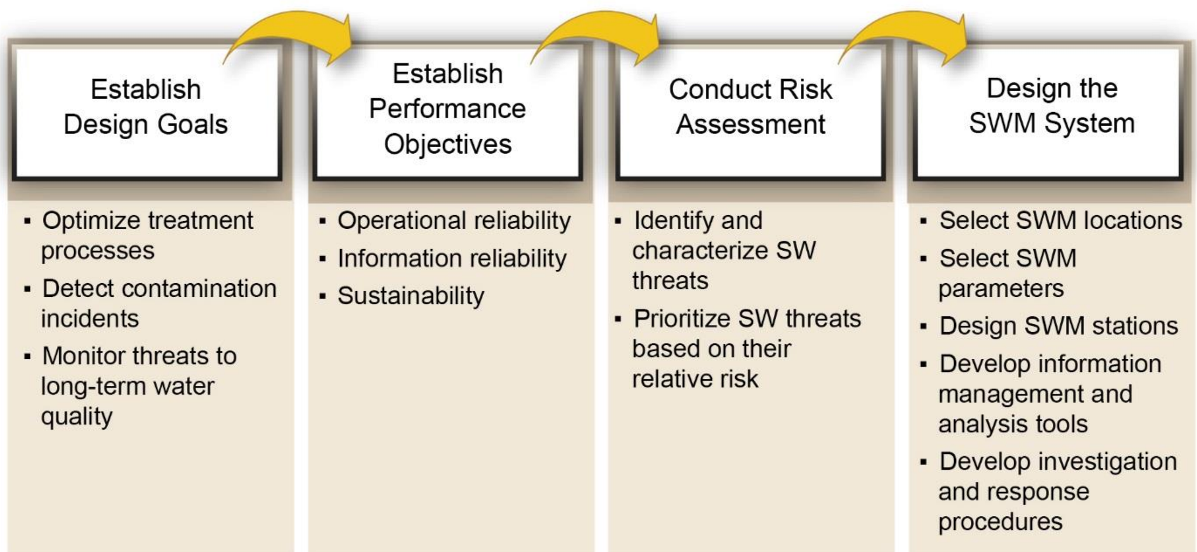


Figure 2-1. Source Water Monitoring Implementation Framework

2.1 Establish Design Goals

Design goals are the specific benefits a utility expects to achieve by implementing SWM. The establishment of design goals is critical to ensuring that SWM will be useful to the utility.

Three common, high-level design goals for SWM are to (1) optimize treatment processes, (2) detect ***contamination incidents***, and (3) monitor threats to long-term water quality. These design goals are presented and discussed in order of increasing complexity, with complexity generally defined in terms of the number of parameters monitored, the number of SWM locations, and the area covered by SWM locations. SWM designed for treatment process optimization is simplest in that it requires one to a few SWM locations for specific parameters that are directly related to the performance of treatment processes. Designing for detection of contamination incidents generally requires the addition of upstream SWM locations and parameters capable of detecting a wider range of water quality changes along with more sophisticated ***data analysis*** methods. Even more SWM locations may be necessary to monitor threats to long-term water quality.

These high-level design goals cover most SWM applications. However, a utility planning to implement SWM should first establish the overall purpose of SWM and the decisions that SWM data is intended to support. This will inform the development of detailed design goals to guide SWM implementation.

Optimize Treatment Processes

SWM data can be used to optimize treatment processes by monitoring water quality parameter variations that impact the performance of treatment processes, such as pH, turbidity, and total organic carbon (TOC).

The primary decisions that guide the design of SWM to optimize treatment processes include these:

- **Identify specific treatment targets.** This decision will guide the selection of parameters to monitor. Examples might include removal of particulate matter, removal of organic contaminants, or removal of algal toxins.
- **Determine the treatment processes that support these targets.** This information will help identify control points in the treatment plant that can be adjusted based on the information generated by SWM. For example, the following processes can be adjusted in response to a change in source water quality: pretreatment with powdered activated carbon (PAC), pretreatment with permanganate, coagulation/sedimentation, and disinfection.
- **Determine the time necessary to implement treatment process changes.** This time period is that between validation of a change in source water quality and adjustment of treatment processes in response to that validated change. The time available will influence the selection of SWM locations and the required frequency at which water quality instruments generate data.

Factors to Consider when Refining Design Goals to Optimize Treatment Processes

- ☐ Flexibility in utilization of the source, such as withdrawal at different depths at the intake, off-stream storage, etc.
- ☐ Treatment process control points that can be manipulated to handle variable source water quality
- ☐ Options to limit impact of poor quality source water on treatment processes, such as booms, pump and treat, adsorptive barriers, diversion, etc.

Detect Contamination Incidents

SWM can be used to detect transient source water contamination incidents that may upset or pass through a water treatment process. This includes detection of contamination resulting from accidents (e.g., chemical releases from spills on or near the source water), unusual discharges (e.g., untreated sewage discharge), and natural events (e.g., seasonal algal blooms).

The primary decisions that guide the design of SWM to detect contamination incidents include these:

- **Identify the specific types of contamination incidents that SWM should be able to detect.** A ***risk assessment*** should be undertaken to develop a prioritized list of ***source water threats*** (SW threats) that have the potential to contaminate the source water. This will guide the selection of both parameters to monitor and SWM locations.
- **Evaluate the response options available to mitigate the impacts of each type of contamination incident identified.** Consideration should be given to both the efficacy of the response actions in reducing the consequences of contamination as well as the cost associated with implementing the response actions. The cost of

Factors to Consider when Refining Design Goals to Detect Contamination Incidents

- ☐ Characteristics of SW threats and their associated contaminants
- ☐ Likelihood of natural events such as wildfires, floods, and harmful algal blooms that could contaminate the source water
- ☐ Hydrologic parameters affecting contaminant fate and transport
- ☐ Limitations of existing treatment processes to treat or remove identified contaminants
- ☐ Options for responding to various types of contamination incidents

implementing a response action will influence the necessary reliability of the information generated by SWM (i.e., more costly response actions will generally require a higher degree of information reliability).

- **Determine the time necessary to implement response options.** This is the time period between detection and investigation of a water quality change and implementation of an effective response. The time available from detection to response will influence the selection of SWM locations and the necessary frequency of data generation and analysis.

Monitor Threats to Long-Term Water Quality

SWM can be used to monitor the impact of SW threats on long-term water quality in the source water and surrounding watershed. SWM provides the information needed to assess the suitability of the source to serve as a drinking water supply, provide recreational opportunities, and support a healthy ecosystem. SWM can also be used to monitor the impacts of climate change on source water quality.

The primary decisions that guide the design of SWM to support monitoring of threats to long-term water quality include these:

- **Identify factors that influence long-term source water quality.** This understanding will guide the selection of SWM parameters and locations. A risk assessment can be conducted to identify and prioritize SW threats to long-term water quality.
- **Identify stakeholders in maintaining source water quality.** Coordination with stakeholders can provide opportunities to collect additional data and identify other uses of the data collected.
- **Identify potential mitigation strategies.** Monitoring long-term trends in source water quality can provide a better understanding of gradual changes in water quality and support selection of strategies for maintaining acceptable source water quality.

FACTORS TO CONSIDER WHEN REFINING DESIGN GOALS TO MONITOR THREATS TO LONG-TERM WATER QUALITY

- ☐ Seasonal variations in source water conditions such as temperature, precipitation, and flow
- ☐ Characteristics of SW threats and their associated contaminants
- ☐ Land use in the watershed
- ☐ Projected impacts of climate change in the region
- ☐ Uses of the source water beyond a drinking water supply

Another factor to consider during SWM design is that a single incident can alter source water quality in a number of ways over different time periods. As an example, consider a wildfire, which can produce a high loading of silt and ash during runoff events immediately following the fire. This transient contamination incident may require a utility to implement highly unusual, short-term treatment modifications. Long-term effects of wildfires might include an increase in TOC loading for multiple years, which would require sustained treatment plant optimization. Finally, long-term source water quality monitoring can provide stakeholders with information that can be used to gauge the effectiveness of watershed restoration efforts such as reseeding.

2.2 Establish Performance Objectives

Performance objectives and their associated metrics are measurable indicators of how well SWM meets the design goals established by a utility. Throughout design, implementation, and operation of SWM, a utility can use performance objectives determine whether the system is operating within acceptable tolerances. While specific performance objectives should be developed by each utility in the context of its unique design goals, common performance objectives are described as follows.

Operational Reliability

Operational reliability is the degree to which an SWM system is performing at a level capable of achieving the established design goals. It depends on proper maintenance of equipment and information management systems necessary to operate the system. Considerations for operational reliability include accessibility of SWM stations for maintenance, suitability of ***water quality sensors*** to the chemistry and quality of a source (e.g., turbidity, pH), environmental impact on SWM stations (e.g., source water temperature, humidity, and ambient temperatures), and adequacy of training for personnel responsible for maintaining the SWM equipment. Example metrics used to monitor operational reliability include the following:

- Percentage of time that the SWM system is fully operational
- Average response time to correct equipment problems

Information Reliability

Information reliability is the degree to which information produced by an SWM station is of sufficient quality to support decision-making. Specifically, utility personnel must be able to interpret the difference between typical water quality variability and changes indicative of a water quality issue requiring a response action or treatment process change. Considerations for information reliability include the representativeness of the water monitored at each SWM location, compatibility of the sensors with the water chemistry, sensor capabilities (e.g., detection limits), maintenance of sensors, and data analysis methods.

Information reliability can be characterized through ***data quality objectives***, which are metrics or criteria that establish the quality and quantity of data needed to support decisions. Examples of data quality objectives that might be considered for SWM include:

- Data ***accuracy***
- Data ***completeness***
- Number of ***invalid alerts*** per month

Establishing data quality objectives is an element of quality control/quality assurance that is important for any environmental monitoring program. Further information about quality assurance for online water quality data can be found in *Quality Assurance (ACRR) Matrix* (ASW, 2010).

Sustainability

Sustainability is the degree to which benefits derived from information generated by SWM justify the cost and level of effort required for its implementation and operation. Benefits are largely determined by the design goals that SWM data supports. For example, an annual reduction in chemical usage or sludge production can be achieved due to more efficient chemical dosing guided by SWM data. Other benefits may be difficult to quantify, such as increased confidence of utility managers and operators in their ability to detect source water quality problems. However, these benefits should still be captured and described as they are important to gauging the sustainability of the SWM system. Costs include the capital and ongoing expenditures required to implement and operate the equipment and systems, as well as the effort required to analyze the SWM data and investigate ***alerts***. Example metrics for sustainability include the following:

- Improvements in finished water quality and operations due to treatment process optimization
- Consequences avoided through early detection of and response to contamination incidents
- Value of non-monetary benefits gained from the operation of SWM
- ***Lifecycle cost*** to implement and maintain SWM

2.3 Conduct a Risk Assessment

A risk assessment is a systematic process for analyzing and prioritizing threats to inform the selection and implementation of risk mitigation strategies. The results of a risk assessment can guide the design of SWM by ensuring that the resulting system addresses the most serious threats. The most widely accepted and broadly applicable risk assessment methodology for the water sector is the J100 Standard (AWWA, 2010). In the context of this guidance document, the J100 methodology is used to assign values to the following three risk assessment parameters for each SW threat:

> **RISK ASSESSMENT TOOL**
>
> EPA has developed the Vulnerability Self-Assessment Tool (VSAT) (EPA, 2015c), which guides a water utility through the risk assessment process in a manner consistent with the J100 Standard.

- ***Likelihood*** is the probability that an SW threat will contaminate the source water and can range in value from 0 (contamination will not occur) to 1 (contamination is certain to occur). The likelihood value may be based on previous contamination incidents caused by the SW threat (or similar SW threats) or on projections and models.
- ***Vulnerability*** is the probability that a utility or its customers would be impacted by an SW threat and can range in value from 0 (no adverse impact will occur) to 1 (adverse impact is certain to occur). The vulnerability value is generally based on the ability of the utility to effectively respond to an SW threat, preventing or mitigating consequences to utility infrastructure, operations, and customers.
- ***Consequences*** are the adverse effects of an incident experienced by a utility (e.g., damaged infrastructure) or its customers (e.g., illness). Where possible, consequences are expressed in terms of monetary damage, providing a standard measure of consequence across all threats. However, it is not always possible to accurately monetize consequences, and values may need to be derived from qualitative factors. In such cases consequences can be normalized such that the SW threat with the greatest consequence has a value of 100 while the values for all other SW threats are less than 100.

The values for these three risk parameters are used to calculate the overall risk score, as shown in **Equation 2-1**.

$$R = L \times V \times C$$

Where:
R = Risk of a specific threat to a utility or its customers
L = Likelihood that a specific threat will occur (score range: 0 to 1)
V = Vulnerability of a utility to a specific threat (score range: 0 to 1)
C = Consequences of the specific threat (score range: 0 to 100)

Equation 2-1. Risk Equation

Identify and Characterize Potential SW Threats

To conduct a risk assessment, SW threats must first be identified and characterized. SW threats include any facility, discharge, land use, weather event, or other feature within a watershed that has the potential to degrade source water quality and impair its intended use. SW threats can be stationary or mobile.

Stationary threats are present at fixed, known locations such as:

- Chemical storage facilities (e.g., oil and gas storage facilities)
- Industrial facilities that use chemicals (e.g., tanneries, automotive body shops, dry cleaners)
- Agricultural facilities (e.g., concentrated animal feeding operations, large fertilized areas)
- Urban areas (e.g., runoff over impervious contaminated surfaces)
- Oil and natural gas extraction operations
- Wastewater treatment plant outfalls
- Stormwater outfalls

Mobile threats present a variable point of potential contaminant entry into the source water, making them more difficult to monitor. Examples of mobile threats include:

- Transportation corridors (e.g., vehicular traffic, rolling stock on railway tracks)
- Watercraft (e.g., barges and other vessels)
- Natural disasters (e.g., wildfires, floods, hurricanes, landslides)

A variety of resources are available to identify and characterize SW threats, some of which are described below. Additional information about these resources, including where to find them, is available in the Resources section.

- **State Primacy Agency Source Water Assessments** provide an inventory of known and potential SW threats within a state. This information can be used to identify known and potential sources of contamination and to characterize the vulnerability of source water to these threats (EPA, 2016a).
- ***Drinking Water Mapping Application to Protect Source Waters*** **(DWMAPS)** is a ***geographic information system*** (GIS)-based tool developed by EPA that provides layers of spatially referenced data using information from databases such as National Pollutant Discharge Elimination System (NPDES); Enforcement and Compliance History Online (ECHO); Toxic Release Inventory (TRI); Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS); Resource Conservation and Recovery Act Information (RCRAInfo); and Toxic Substances Control Act (TSCA). DWMAPS provides information about potential SW threats, including their locations and details of discharge permits (EPA, 2016b).
- **Land Use Maps** are often developed and maintained by a city, county, or state. These maps may be useful for identifying current and future potential SW threats, such as areas of urban or commercial expansion.

Each SW threat identified should be characterized to the fullest extent possible, capturing information such as the following:

- Location of the SW threat and the distance from the threat to the source water
- Owner or operator of the property or facility where the SW threat is located
- Potential contaminants associated with the SW threat (e.g., chemicals stored on site, pesticides or fertilizers applied to the land)
- Volume or mass of potential contaminants stored at the location of an SW threat or discharge rates from SW threats, such as outfalls
- Characteristics of the potential contaminants stored at the location of an SW threat (e.g., solubility, toxicity), which may be available in material safety data sheets that are required to be on file at the location where a chemical is stored or used
- Estimates of contaminant dispersion and dilution in the source water during a contamination incident from the SW threat (e.g., results from hydrology model simulations or tracer studies)

- Existing risk mitigation strategies to protect the source water from the threat (e.g., leak detection, spill containment, runoff control)

Some of this information may not be available for all types of SW threats, but the characterization of each SW threat should be as complete as possible. A detailed characterization of SW threats is useful not only for the risk assessment, but also for selecting SWM parameters and locations, as well as for response planning.

The process for identifying SW threats is the same for flowing water systems (e.g., rivers and streams), and still water systems (e.g., ponds and lakes). Some aspects of this process also apply to groundwater sources, which face some similar and unique risks as compared to surface water. The characteristics of the source water will inform the identification of SW threats as well as the assignment of values to the risk assessment parameters.

Prioritize Risk of Potential SW Threats

The risk assessment needs to provide a relative prioritization of the SW threats to ensure that SWM is designed to focus on the highest priority SW threats within the available budget. As such, it is important to assign values to each of the risk parameters in a consistent manner. For example, where SW threats are identified that do not have appreciably different characteristics that would influence likelihood, vulnerability, or consequence, the same or similar values should be assigned to the risk parameters for these similar threats.

A risk assessment is useful for designing an SWM system to detect contamination incidents and/or monitor threats to long-term water quality because it prioritizes the SW threats to be monitored. If the SWM system is intended to meet both of these design goals, it may be useful to identify and prioritize two sets of SW threats: (1) those that pose an acute risk to source water quality due to a contamination incident and (2) those that pose a chronic risk to long-term water quality. This strategy ensures that the SWM design will consider the highest priority SW threats to both short-term and long-term water quality. A risk assessment is generally not used to optimize treatment processes because this design goal is intended to meet specific treatment targets by adjusting treatment processes in response to typical source water quality variability.

The attributes of SW threats considered when assigning values to each risk assessment parameter will be different when assessing risk for the design goals of detection of contamination incidents and monitoring of threats to long-term water quality, as illustrated in **Table 2-1**.

Table 2-1. Scoring Considerations for Risk Assessment Parameters by Design Goal

Risk Assessment Parameter	Scoring Considerations	
	Detect Contamination Incidents (Short-Term Risks)	Monitor Threats to Long-Term Water Quality (Long-Term Risks)
Likelihood	The probability that an SW threat will cause a significant yet transient degradation in source water quality. The frequency of occurrence of previous, similar incidents can be used to estimate a likelihood score. Existing mitigation strategies at the SW threat such as leak detection systems, secondary containment, and spill response plans can reduce likelihood.	The probability that an SW threat will cause a sustained change in water quality (e.g., longer than one year). Characteristics of the SW threat, such as discharge rates or contaminant loading rates, can be used to estimate a likelihood score. Existing mitigation strategies such as runoff control systems can reduce likelihood.
Vulnerability	The probability that a contamination incident caused by an SW threat will adversely impact the utility or its customers. The ability of the utility to respond to a contamination incident in a manner that mitigates the consequences of the incident can be used to estimate a vulnerability score. Availability of treatment that can remove or neutralize a contaminant can reduce vulnerability.	The probability that a sustained change in water quality caused by an SW threat will adversely impact the utility or its customers. The ability of the utility to adapt to changing source water quality can be used to estimate a vulnerability score. Implementation of a source water protection plan, which considers threats to long-term water quality, can reduce vulnerability.
Consequence	The damage or negative impacts to the utility or its customers resulting from a contamination incident caused by an SW threat. Potential consequences include disruption or upsets to treatment plant operations, aesthetic changes that make the water unacceptable to customers, or adverse health effects in exposed customers. A consequence score may be determined by estimating the number of customers impacted, the duration of a disruption in service, or the cost of restoring a system to normal operations following a contamination incident.	The impact of a long-term water quality change on treatment plant operations or finished water quality. Potential consequences may include difficulty in meeting treatment targets, failure to comply with drinking water standards, aesthetic changes that are unacceptable to customers, or diversion of utility resources to modify the treatment plant in response to the water quality change. A consequence score may be determined through an analysis to estimate the impact of degraded source water quality on utility operations.

The results of a risk assessment are used to develop (1) a prioritized list of SW threats of contamination (short-term risks) and (2) a prioritized list of SW threats to long-term water quality design goal (long-term risks). These lists are used to identify high-priority threats that will be considered in an SWM design. It is also important to understand that risks may change over time and that the risk assessment may need to be updated when new potential SW threats are identified. A *Template for Conducting a Risk Assessment for Source Water Threats* can be opened and edited in Microsoft® Word by clicking the icon in the callout box.

This template can guide a risk assessment for source water threats.

2.4 Design the SWM System

The major design elements associated with SWM are summarized in **Figure 2-2** and briefly described in this section. Detailed guidance on each design element is presented in Sections 3 through 7.

Figure 2-2. Source Water Monitoring Design Elements

Select Source Water Monitoring Locations

SWM locations should be selected based on design goals established for SWM as well as the results from a source water risk assessment. Typical monitoring locations include the raw water intake to a treatment plant, various locations and depths in rivers and lakes, and strategic locations in the watershed. Monitoring locations for groundwater sources will generally be limited to an intake structure (for centralized groundwater treatment facilities), the wellhead, or monitoring wells. This document does not present methods for locating monitoring wells within an aquifer. Guidance on the selection of SWM locations is discussed in detail in Section 3.

Select Source Water Monitoring Parameters

The selection of SWM parameters is based on design goals established for SWM, as well as the results from a source water risk assessment. In particular, the contaminants associated with specific SW threats can inform the selection of SWM parameters. The parameters monitored determine the types of water quality variations, incidents, or trends that can be detected. Guidance on the selection of SWM parameters is discussed in detail in Section 4.

Design Source Water Monitoring Stations

The design of SWM stations is based on the locations and parameters selected for SWM. It includes selection of the specific water quality instruments and ancillary equipment necessary to bring sensors into contact with a water sample and transmit data. The station design can dramatically impact capital costs, operating costs, data accuracy, and data completeness. Guidance on the design of SWM stations is discussed in detail in Section 5.

Develop Information Management and Analysis Tools

Information management systems receive, process, analyze, store, and present data generated by SWM stations. An information management system may include data analysis tools that generate alerts and send notifications to designated personnel when water quality ***anomalies*** are detected. Information management and analysis are discussed in detail in Section 6.

Develop Investigation and Response Procedures

Once a water quality ***anomaly*** has been detected, an investigation should be undertaken to determine the cause of the anomaly and guide response actions appropriate to the situation. The procedure for responding to a water quality anomaly will depend on the design goals for the system. To optimize treatment processes, a response procedure will guide adjustments to treatment process settings to meet treatment targets. For detection of contamination incidents, a response procedure will guide actions that prevent potentially contaminated water from entering a treatment plant or finished water. Investigative activities that support monitoring long-term water quality involve the analysis of data over multiple years to determine whether a source water quality ***baseline*** is changing. Investigation and response procedures are discussed in detail in Section 7.

SWM designed to realize multiple design goals can be implemented in phases to progressively expand the system to meet these goals. An example of this approach is an initial phase with a single SWM location at an intake for treatment process optimization, followed by phases to provide capabilities for the detection of contamination incidents and monitoring of threats to long-term water quality. Subsequent phases would build on the previous installations, adding capabilities to meet additional goals.

SRS PLANNING

If an SWM system will be part of a larger SRS, it should be incorporated into a master plan, as described in Section 3 of *Guidance for Developing an Integrated Water Quality Surveillance and Response System* (EPA, 2015b). Master planning for an SRS involves the development of a complete SRS design, which is implemented in phases based on available resources.

If multiple potential designs emerge during the design process, an evaluation of alternatives should be conducted to consider the cost and benefits associated with each. For example, some alternatives may offer tradeoffs between the number of parameters monitored and the number of monitoring locations. Each of these alternatives will have different capabilities and a different cost for procurement, operation, and maintenance throughout the life of the system. *Framework for Comparing Alternative Water Quality Surveillance and Response Systems* (EPA, 2015d) provides a systematic process for comparing alternative designs that considers both the capabilities and cost of each design.

Once the SWM design elements have been developed, they should be captured in a design document. A *Template for Developing an SWM Preliminary Design Document* can be opened and edited in Microsoft® Word by clicking the icon in the callout box.

This template can be used to develop an SWM preliminary design.

SWM Funding Opportunities

Both financial and personnel resources are required to implement SWM. There are a variety of methods to fund the project, a few of which are described below. This list is not intended to be comprehensive, but it provides an indication of the types of funding options that may be available.

Pay-as-you-go. Funding SWM through a pay-as-you-go strategy involves incorporating the cost of implementation into the annual budget. This can be done through allocating existing cash reserves or developing new revenue sources such as capital improvement fees, increased property taxes, or tapping a portion of water sales revenue. This funding mechanism works best for a phased SWM implementation where pieces of the system are gradually deployed as the capital becomes available.

Bonds/Loans. Funding SWM through bonds or loans incurs debt at the beginning of the project, which is typically paid back over a 10- or 20-year period. The debt may be serviced through implementation of new revenue sources such as capital improvement fees, increased property taxes, or a portion of water sales revenue. Financing SWM using bonds or loans can allow for significant expenditures at the beginning of the project, accelerating design and implementation.

Grants/Federal Loans. Funding SWM through grants or federal loans (usually provided at or below market interest rates) involves applying to a government agency or other organization. To improve the likelihood of an award, the project description should meet all requirements specified in the grant/loan application. The following organizations are potential sources of grant funding for SWM:

- **Bureau of Reclamation.** Significant grant funding opportunities are available for systems that reduce energy consumption, address climate-related risks, and support sustainability of water systems. (http://watersmartapp.usbr.gov/WaterSmart)
- **Department of Agriculture.** Districts that provide water to agricultural customers, and possibly along with urban customers, can apply for grants related to improving water quality and water availability for agricultural customers. To be eligible for these grants, at least 30 percent of water production should go to agricultural use. (http://www.rd.usda.gov/)
- **Drinking Water State Revolving Fund.** These federal loans must address a serious risk to public health, bring the systems into compliance with the Safe Drinking Water Act, consolidate water supplies, or replace aging infrastructure. (https://www.epa.gov/drinkingwatersrf)
- **Global City Teams Challenge.** Provides funding for Smart Cities projects. (https://www.us-ignite.org/globalcityteams/)
- **Public-private partnership.** Funding SWM through public-private partnerships involves working with a private entity that would benefit from financing some aspect of SWM.

Some of these funding opportunities may require development and approval of specific documentation such as a Quality Assurance Project Plan, Data Management Plan, or Health and Safety Plan. To secure funding and support for an SWM project, a business case should be developed that clearly articulates the benefits of SWM.

Section 3: Source Water Monitoring Locations

An SWM location is the site in a source water where water is sampled for measurement. Selection of SWM locations should be guided by the design goals established for the system and the time required to implement a response action relative to the time a water quality change is detected. SWM locations are selected relative to control points, which are locations where a treatment process can be modified (e.g., addition of pretreatment chemicals) or a response action can be implemented (e.g., closing of an intake). For detection of contamination incidents and monitoring of threats to long-term water quality, SWM location selection should also be informed by the location of high-priority SW threats.

Selection of SWM locations and SWM installation sites will also be influenced by a variety of site-specific considerations, such as accessibility and natural hazards as discussed in *Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting* (USGS, 2006). Performance objectives, such as operational reliability and sustainability should also be considered when selecting these locations. The final selection of SWM locations will be a compromise between the ideal location that meets the design goals and practical implementation considerations.

The following sections present a series of examples demonstrating how each of the three design goals covered in this document influence the selection of SWM locations. All of these examples are based on a single hypothetical utility with a river source. The sequence of the examples is intended to illustrate how an SWM system can be expanded from a single monitoring location at an intake to multiple monitoring locations throughout the source water and watershed.

3.1 SWM Locations to Support Treatment Process Optimization

To support treatment process optimization, SWM data needs to be available to operators in sufficient time to make process adjustments in response to changes in source water quality. Many common treatment process adjustments, such as changes to chemical feed rates, process loading rates, and filter backwash frequency, can be made in a matter of minutes. As such, an SWM location selected for treatment optimization does not need to be far from control points in a treatment plant to provide adequate time for operators to respond. SWM locations within the infrastructure that conveys water from the intake to the treatment plant may provide sufficient time to make operational changes, simplifying SWM station installation and ensuring that the water sampled by the SWM station is representative of the water to be treated. Where water is drawn from multiple sources, monitoring water quality at the intake for each source can provide information that guides decisions to switch sources or adjust the blend ratio from different sources. **Figure 3-1** shows an SWM location at the intake structure for the plant.

MONITORING AT THE INTAKE

While monitoring source water quality at the intake offers several advantages, it may not always be the best choice. If pretreatment chemicals are added at the intake, it may be preferable to conduct monitoring upstream of the intake to provide adequate time between detection of a water quality change and adjustment to a pretreatment process.

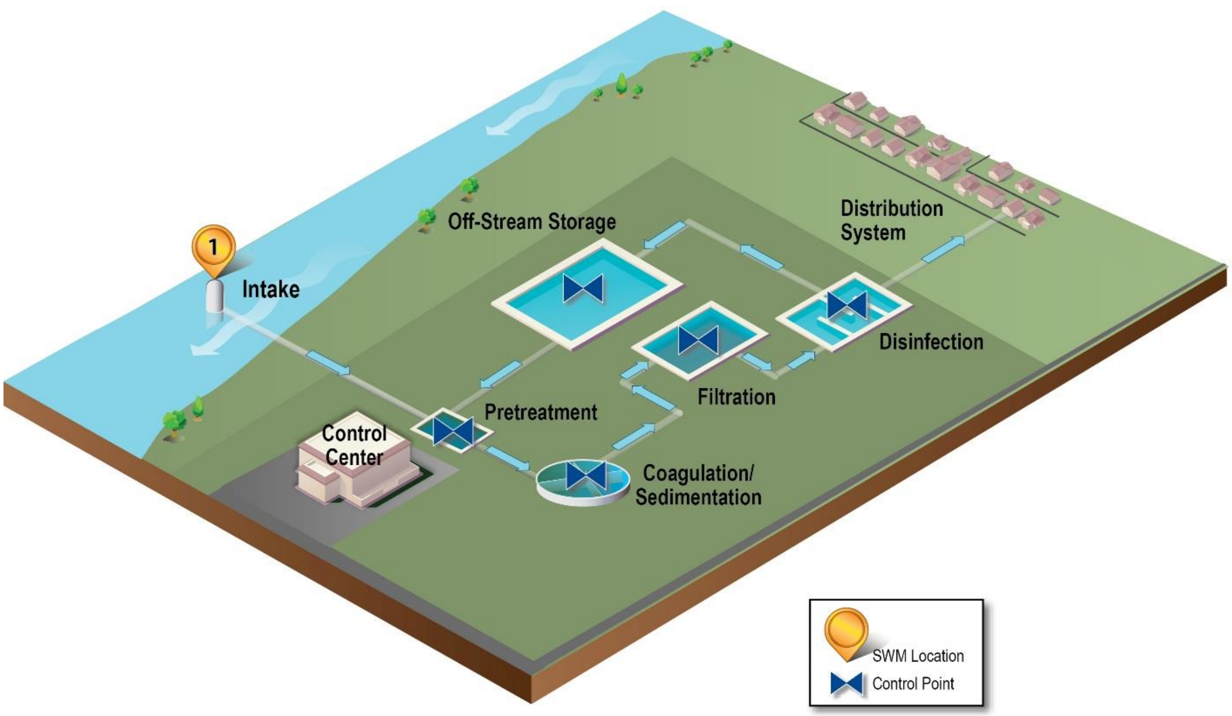


Figure 3-1. SWM Location Selected to Support Treatment Process Optimization

3.2 SWM Locations to Detect Contamination Incidents

The process of selecting SWM locations for the purpose of detecting contamination incidents, such as chemical spills, is an iterative process consisting of the following steps:

1. Calculate the time required to investigate a water quality change and implement a response
2. Determine the ***critical detection point***
3. Select the SWM locations based on the results of Steps 1 and 2

Calculate Investigation and Response Times

The investigation and response time should be calculated for each unique action that may be taken in response to a source water quality change. It is the sum of the following two segments:

- **The time to confirm that a water quality change is real and requires a response.** Once a change in source water quality is detected, the change should be investigated to ensure that it is not due to an equipment problem. The time required for this investigation can be estimated using data from previous investigations or using the results from drills and exercise. The process for investigating a source water quality change is described in detail in Section 7.
- **The time to implement a response action.** After determining that a change in source water quality requires a response, a specific response action is selected and implemented. A range of response actions should be considered for different source water contamination scenarios. The time to implement each response action can be estimated using information from previous implementation of those actions and/or the experience of utility operators. Response actions are described in detail in Section 7.

Determine Critical Detection Point

The critical detection point is the location on the source water where detection of a water quality change provides enough lead time to implement a response action. Conservatively, the critical detection point is determined using the response action that takes the most time to implement or the response action associated with the control point furthest upstream. The distance from the control point to the critical detection point is calculated by multiplying the flow rate for the source water by the total response time. Use of a conservative (high) source water flow rate for calculating the distance to the critical detection point is recommended. If source water is piped to sensors in a flow-cell, as described in Section 5, the time for the water sample to travel from the source to the sensors should be added to the total response time to determine the critical detection point.

STILL WATER

In still water, such as lakes and reservoirs, a contaminant will generally spread slowly and persist for an extended period of time. Thus, it is generally not necessary to determine a critical detection point in lakes and reservoirs for the purpose of selecting SWM locations. Monitoring at or near the intake typically provides sufficient time to implement a response.

Any SWM location upstream of the critical detection point should provide adequate time to implement a response action. SWM locations farther upstream and closer to an SW threat may be selected to increase the likelihood of detecting a water quality change caused by the SW threat (i.e., by minimizing the opportunities for dilution as a contaminant plume flows downstream from the SW threat).

If there is a high-priority SW threat downstream of the critical detection point, the hydraulic travel time from the SW threat to the control point where it can be mitigated (e.g., an intake structure that can be closed) should be calculated to develop an alternative response that, although not ideal, can still provide a level of mitigation. It is recommended that hydraulic travel time be calculated using a conservative (high) source water flow rate.

Select the SWM Locations

The process for selecting SWM locations should consider the location of the critical detection point, the locations of SW threats, and the locations of control points associated with response actions. The practicalities of SWM station installation, as discussed in Section 5, will impact SWM location selection as well.

> **SENSOR DEPTH**
>
> When using immersed sensors, consider the impact of sensor depth on the ability of the sensor to detect a water quality change. For example, if the contaminant associated with the SW threat floats, select a monitoring depth near the surface of the waterbody. Additional guidance on these considerations is available in other resources (USGS, 2006).

Several examples follow to illustrate the selection process. Note that all of these examples include SWM Location 1 at the intake (see Figure 3-1). While Location 1 was selected to support treatment process optimization, it is also available to support detection of contamination incidents.

The simplest SWM design can be implemented when all SW threats are upstream of the critical detection point. This situation requires only one additional SWM location (SWM Location 2) to be selected downstream of the SW threat closest to the intake (SW Threat A) but upstream of the critical detection point, as shown in **Figure 3-2** (this figure is zoomed out from Figure 3-1 to show a longer stretch of the river). This approach uses the minimum number of SWM locations and provides enough hydraulic travel time between the SWM location and the control point to implement an appropriate response. A single SWM location may also be sufficient in situations where SW threats upstream of the critical detection point are clustered (not shown).

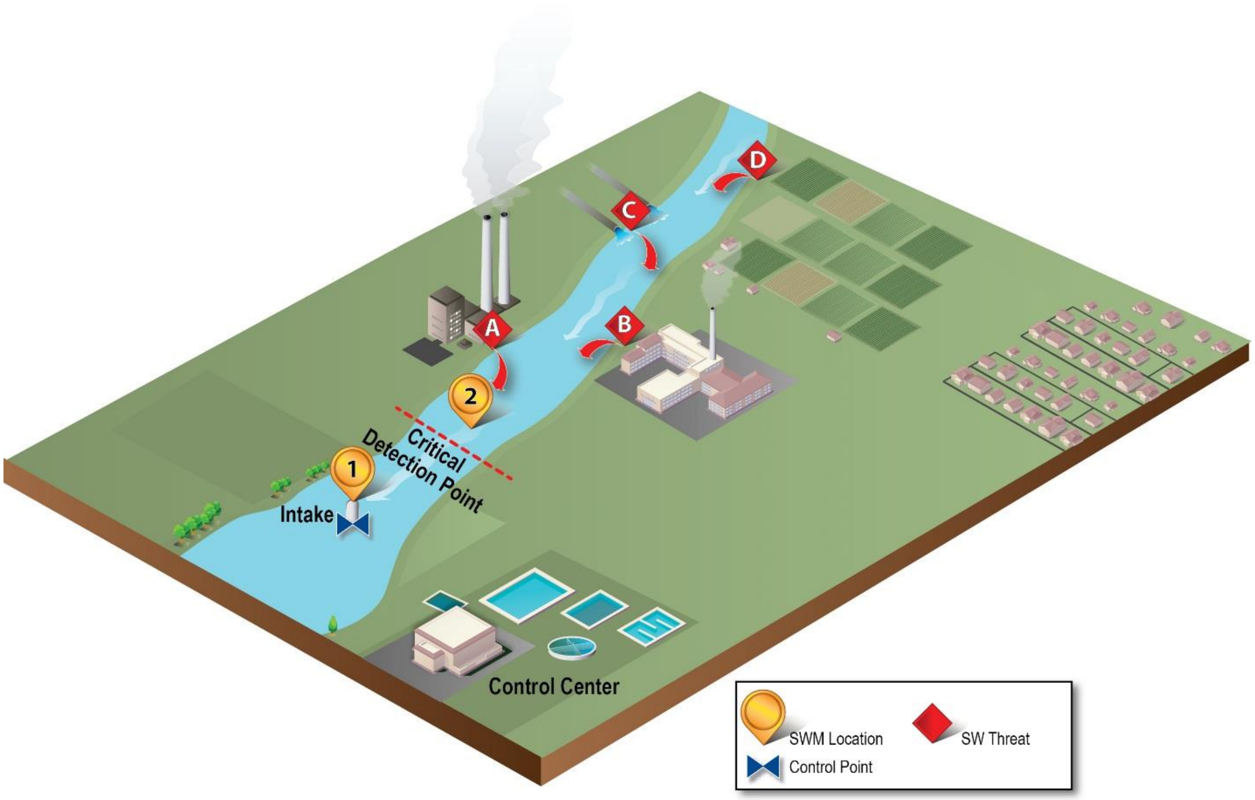


Figure 3-2. A Single Upstream SWM Location to Monitor Multiple SW Threats

There may be situations where it is desirable to include an SWM location near each SW threat, as shown in **Figure 3-3**, such as:

- When the benefit of early detection outweighs the cost of additional SWM stations
- When attribution of an incident, such as a spill, to a specific SW threat is important
- When SW threats involve contaminant volumes or flows that can rapidly dilute to a concentration that is difficult to detect but still high enough to present a risk to the utility or its customers
- When there is a need to follow the progression of a contaminant plume and provide confirmation of the initial detection

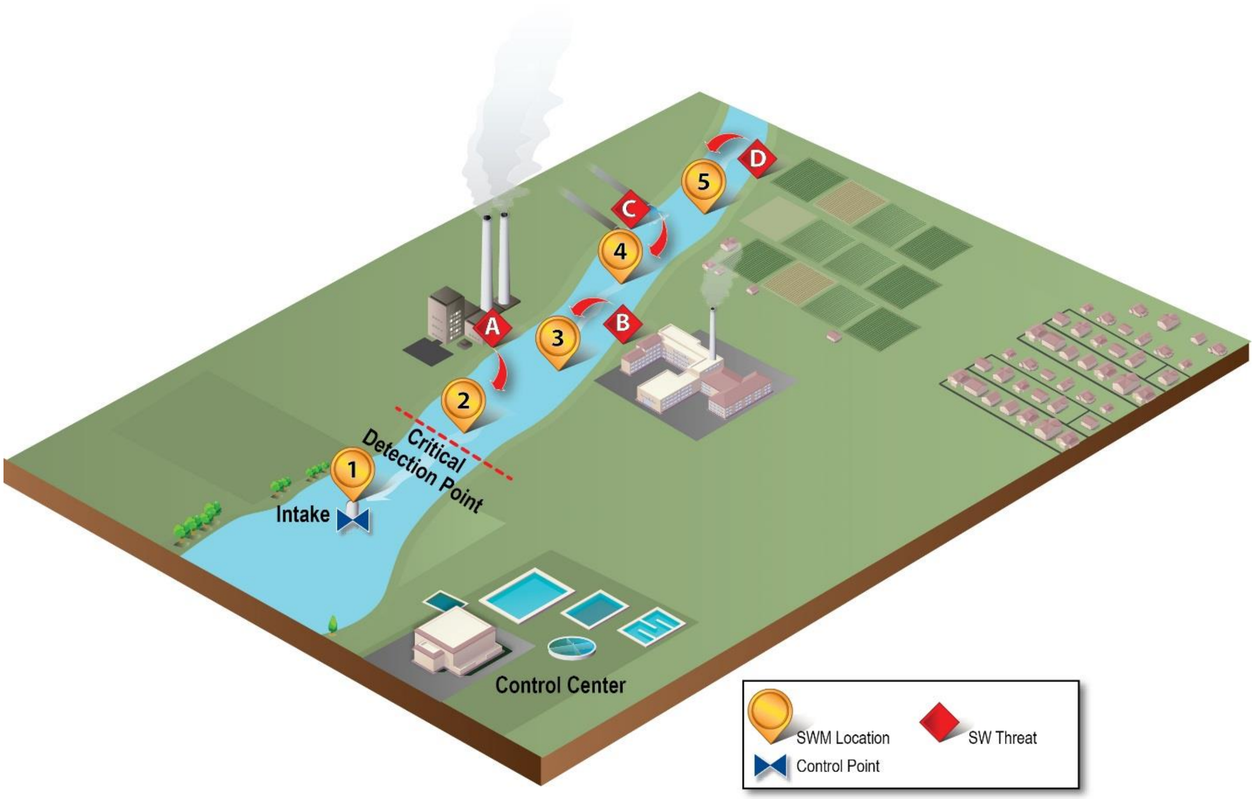


Figure 3-3. Multiple Upstream SWM Locations to Monitor Multiple SW Threats

The SWM locations shown in Figures 3-2 and 3-3 were selected based on the location of stationary threats. Mobile SW threats, such as road or rail traffic moving adjacent to a long stretch of source water or a vessel on the source water, require a different approach to SWM location selection. One approach to monitoring for mobile SWM threats is to locate an SWM station at the critical detection point, which would allow adequate time to respond to a spill from a mobile threat that occurs upstream of this point. Also, the SWM location at the intake (SWM Location 1 in the figures) would provide detection capability for mobile SW threats. While monitoring at the intake would not provide time for an optimal response, it can still detect a water quality change in time to implement a response that will mitigate the consequences of the incident.

ALTERNATIVE NOTIFICATIONS

Notifications of spills, leaks, or discharges from an SW threat owner can provide another means of detecting contamination incidents. This method can be particularly useful for SW threats downstream of the critical detection point.

3.3 SWM Locations to Monitor Threats to Long-Term Water Quality

SWM locations can be selected to monitor threats to long-term water quality. **Figure 3-4** is a zoomed out image of Figure 3-3 that shows areas of future industrial and agricultural expansion that could degrade water quality in the tributaries feeding the river source. To monitor these SW threats, additional SWM locations were selected in the tributaries, upstream of their confluence with the river, as indicated by SWM Locations 6 and 7.

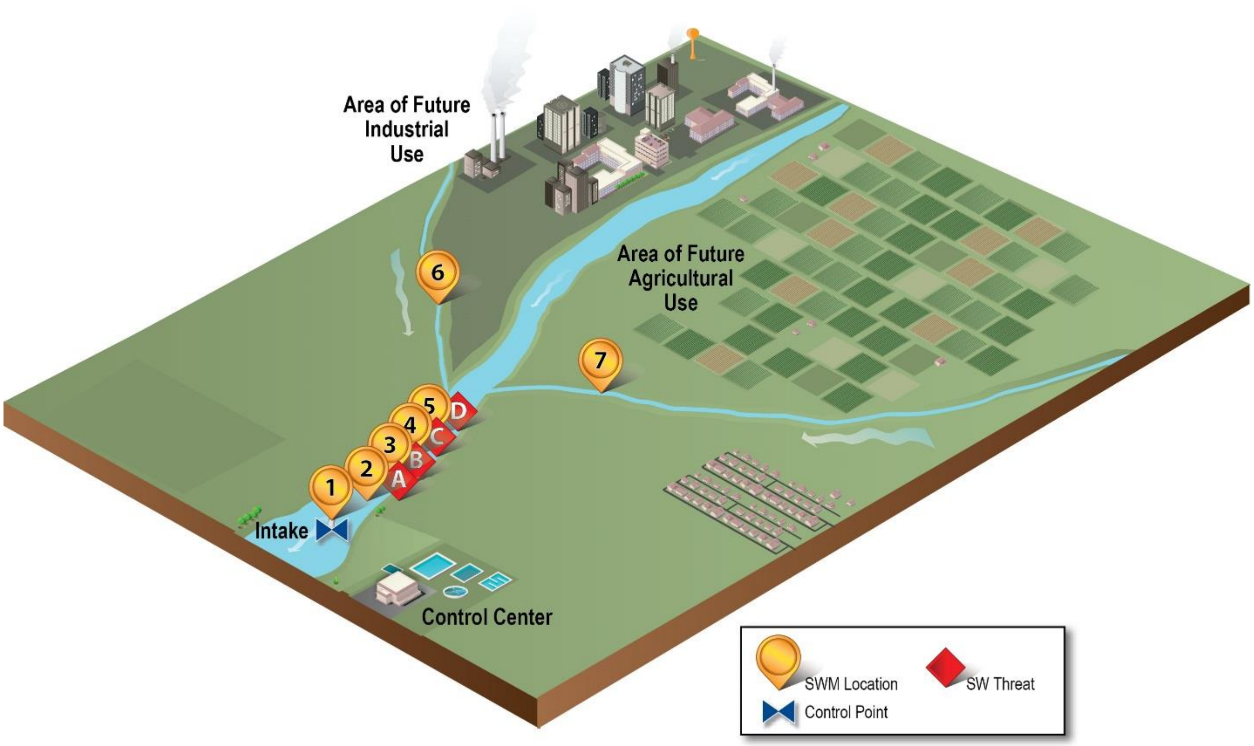


Figure 3-4. SWM Locations to Monitor Threats to Long-Term Water Quality

The examples presented in this section consider each of the three design goals separately and identify SWM locations accordingly. However, it can be seen that careful placement can allow individual SWM locations to support more than one design goal. SWM Location 1 is an example where a single location supports all three design goals. Also, while SWM Locations 2 through 5 were selected for detection of contamination incidents, they could also monitor threats to long-term water quality. The ability of a single SWM station to support multiple design goals will improve the sustainability of the SWM system.

Section 4: Source Water Monitoring Parameters

This section describes water quality parameters that may be useful to optimize treatment processes, detect contamination incidents, and monitor threats to long-term water quality.

4.1 Useful SWM Parameters

Table 4-1 provides an overview of water quality parameters that are potentially useful for SWM and that can be monitored using online instruments. Additional information about the online instruments used to measure these parameters is available in *Guidance for Selecting Online Water Quality Monitoring Parameters and Evaluating Sensor Technologies for Source Water and Distribution System Monitoring* (EPA, 2016c).

Table 4-1. Overview of SWM Parameters

Parameter	Parameter Description
Ammonia (NH_3)	• Concentration of dissolved ammonia (NH_3) in solution • Can occur naturally or originate from agricultural and urban runoff, wastewater treatment plants, or sanitary sewer overflows • Can impact drinking water treatment and distribution operations (e.g., chlorine demand, nitrification) • Can be highly toxic to aquatic organisms
Alkalinity	• Measure of a water's buffering capacity (i.e., its ability to resist a change in pH when an acid or base is added), typically measured in carbonate equivalents • Can result from pollutant loadings (e.g., metals) from transportation • Will impact the quantity of treatment chemicals (e.g., coagulant, acid, or base) that need to be added to achieve acceptable process performance • Will influence the stability of finished water pH in distribution systems • Can affect the bioavailability of contaminants, particularly metals, in natural systems
Dissolved Oxygen (DO)	• Concentration of dissolved oxygen in solution (the location of the DO sensor can influence DO concentration measured) • DO concentrations can be reduced by pollutants in stormwater runoff and sanitary sewer overflows • Low DO concentrations can impact oxidation-reduction potential, adversely impacting the performance of some treatment processes, although mixing during pumping and flocculation can bring DO concentrations to near saturation • Low DO can be lethal to certain aquatic organisms
Dissolved Organic Carbon (DOC) Total Organic Carbon (TOC)	• Concentration of organic carbon (compounds that contain carbon and hydrogen) • TOC includes suspended and dissolved organic carbon • DOC is the fraction of organic carbon that passes through a filter with a 0.45 micrometer pore size • Decaying natural organic matter may increase DOC/TOC concentrations • Presence of DOC/TOC during chlorination results in disinfection byproducts • Assimilable organic carbon can support biological regrowth in distribution systems
Hydrocarbons	• Concentration of long-chain, unsaturated organic compounds that include hydrogen and carbon • Can occur due to urban runoff, transportation, or spills • Can be an indicator of source water contamination with petroleum products • Can impart an objectionable odor to water, and can be difficult to remove from distribution system and household plumbing materials • Can be toxic to aquatic organisms

Parameter	Parameter Description
Nitrate and Nitrite	• Concentration of nitrate (NO_3) and nitrite (NO_2) in solution • Can occur in wastewater treatment plant discharge, agricultural runoff, or urban runoff • Regulated contaminants that can be difficult to remove through conventional treatment • Can promote algal and bacterial growth
Ortho-phosphates	• Concentration of inorganic compounds consisting of phosphorus and oxygen • Can occur naturally or originate from agricultural and urban runoff • Used to protect drinking water distribution pipelines and household plumbing from corrosion • Can promote algal and bacterial growth
Oxidation-Reduction Potential (ORP)	• Measure of the potential flow of electrons between reducers and oxidizers, which characterizes the oxidizing or reducing power of a solution • Low ORP can reduce the efficacy of oxidation treatment processes • Can serve as an indicator of natural processes in source water (e.g., turnover)
pH	• Negative logarithm of the concentration of hydrogen ions in an aqueous solution • Fundamental to understanding aqueous chemistry • pH variation can be caused by natural biological and chemical processes • Can affect the performance of coagulation/sedimentation treatment processes • Changes in pH can affect chemical and biological processes in source water • Significant changes in pH levels are often toxic to aquatic organisms
Photosynthetic Pigments	• Amount of chemicals present that are used by photosynthetic organisms to capture solar energy in chemical bonds • Includes chlorophyll a and phycocyanin (direct measure of cyanobacteria levels) • Can be an indicator of autotrophic biomass and algal blooms • *In-vivo* fluorescence can characterize the relative proportion of algal species
Specific Conductance	• Measure of the ionic strength of a solution and commonly used as a surrogate for total dissolved solids • Can increase due to sanitary sewer overflows, combined sewer overflows, and wastewater treatment plant discharges • Can indicate salt water or brackish water intrusion • Can interfere with osmotic balance in aquatic organisms
Spectral Absorbance	• Measure of wavelength absorption across the ultra-violet (UV)/visible spectrum • Spectral absorption profiles of a source water can provide a baseline ***spectral fingerprint*** used to detect anomalous water quality • Can provide derived measurements for other water quality parameters (e.g., nitrate and nitrite) • Spectral absorption at 254 nm (UV-254) is commonly used as a surrogate for the concentration of natural organic matter
Streaming Current (Zeta Potential)	• Determination of the surface charge (zeta potential) by measuring particle velocities when a potential difference is applied • Commonly used as a process monitoring tool for coagulation, sedimentation, and filtration

Parameter	Parameter Description
Temperature	• Measure of the thermal energy in water • Influences chemical equilibrium and kinetics, which may impact treatment process performance • Can indicate blending of water from different sources (e.g., wastewater treatment plant effluent blending with a source water) • Integrated into water quality sensors that measure temperature-dependent parameters (e.g., pH, specific conductance) to enable temperature compensation to those parameter measurements
Toxicity	• Aggregate measure of the adverse effects to aquatic organisms resulting from exposure to chemicals in their environment • Indicator of the presence of chemicals or toxins in water that could harm people or aquatic organisms
Turbidity	• Measure of the cloudiness of water due to suspended particles • Can increase due to sanitary sewer overflows, combined sewer overflows, and wastewater treatment plant discharges • High turbidity levels can overload some treatment processes due the associated increase in suspended solids • Can serve as an indicator of bacteria and other particulate pollutants • High turbidity levels can decrease light passage, impacting the subsurface ecosystem

4.2 Parameter Selection

This section describes the SWM parameters useful for each of the design goals presented in Section 2.1. When selecting parameters, consider that some provide innate benefits while others may complement other monitored parameters, providing more useful information when measured together. For example, pH impacts ammonia speciation, with lower pH levels shifting the equilibrium toward the ammonium ion (NH_4^+), which is more toxic to aquatic organisms. Thus, both ammonia and pH should be monitored if ammonia is a known or potential source water contaminant.

The following sections list parameters that could be potentially useful for specific applications under each of the three design goals. The parameters listed for each application are generally complementary, meaning that monitoring multiple parameters would more effectively meet the listed design goal. However, parameter selection should always be informed by the SWM location and other site-specific considerations.

Parameter Selection to Optimize Treatment Processes

The parameters useful to optimize treatment processes will depend on the processes that will be optimized. **Table 4-2** lists SWM parameters that are useful for optimizing conventional treatment processes.

Table 4-2. SWM Parameters that Support Treatment Process Optimization

Treatment Process	Parameters	Rationale for Parameter Selection
Permanganate Pretreatment	ORP	ORP can indicate the presence of reducing agents in the source water, which would increase the required dose of permanganate.
	DO	Low DO concentrations in the source water can indicate a reducing environment, increasing the required dose of permanganate.
	DOC/TOC	High DOC/TOC concentrations in the source water can exert an oxidant demand, increasing the required dose of permanganate.
	Spectral Absorbance	Removal of iron and manganese is often the treatment target for pre-oxidation using permanganate. Spectral absorbance can be used to measure the iron and manganese concentrations in the source water, which can be used to determine the permanganate dose needed to achieve iron and manganese removal targets.
	pH	pH can impact the efficacy of permanganate as a pre-oxidant.
PAC Pretreatment	Photosynthetic Pigments	PAC may be added to remove harmful algal toxins and byproducts. An increase in photosynthetic pigments can provide a direct indication of algal activity and thus might serve as a trigger for PAC addition.
	DOC/TOC	High DOC/TOC concentrations can compete for active adsorption sites on PAC particles, thus increasing the concentration of PAC needed to achieve other treatment targets, such as removal of harmful algal toxins or taste & odor-causing compounds.
	pH	pH can impact the efficacy of PAC in adsorbing specific contaminants.
Coagulation/ Sedimentation	Turbidity	Turbidity can be used to determine the coagulant dose necessary to meet process effluent water quality targets.
	DOC/TOC	The treatment target for enhanced coagulation is typically established as either a percent removal of DOC/TOC during conventional treatment or a target DOC/TOC concentration in filter effluent. DOC/TOC data can be used to determine the coagulant dose needed to achieve optimized coagulation.
	pH	pH has a significant impact on the performance of coagulation processes and the ability to achieve enhanced coagulation.
	Spectral Absorbance	Spectral absorbance can detect changes in the chemical composition of a source water, which may impact the performance of coagulation processes.
	Alkalinity	Alkalinity can impact the amount of coagulant or acid/base that needs to be dosed to reach a pH range necessary for optimized coagulation.
Filtration	N/A	Because upstream conventional treatment process alter the water quality parameters important to filtration performance, most notably turbidity, source water quality data has little application to optimization of filtration.
Disinfection	Ammonia	Ammonia is generally not removed by upstream conventional treatment processes, thus, changes in the concentration of ammonia in the source water can impact the chlorine dose required for breakpoint chlorination and adequate disinfection.

Note: Temperature should also be monitored for each of these treatment processes due to its impact on reaction rates and process performance.

Parameter Selection to Detect Contamination Incidents

Table 4-3 lists several contaminant groups, potentially useful SWM parameters, and the rationale for how each parameter can support detection of the listed contaminant group. The information in this table is general, and parameter selection should be guided by the specific contaminants associated with SW threats identified during the risk assessment. Parameter selection can also be guided by studies, such as *Distribution System Water Quality Monitoring: Sensor Technology Evaluation Methodology and Results* (EPA, 2009), that have evaluated the responsiveness of various water quality parameters to different contaminants in drinking water. The ability of any of the listed parameters to detect the presence of a contaminant is contingent upon a contaminant concentration that is sufficiently high to change the parameter value from the baseline. Detection capabilities are also dependent on the configuration of the data analysis tools used to detect anomalies as described in Section 6.

Table 4-3. SWM Parameters that Support Detection of Contamination Incidents

Contaminant Group and Associated SW Threats	Parameters	Rationale for Parameter Selection
Inorganic Industrial Chemicals from SW threats, such as: • Chemical storage tanks • Pesticide and fertilizer storage tanks • Transportation corridors • Watercraft	Spectral Absorbance	Some inorganic chemicals absorb in the UV-visible spectrum. As such, a change in spectral absorption may indicate contamination with an inorganic industrial chemical. Furthermore, some spectral instruments allow users to add spectral fingerprints to a library. If the spectral fingerprint for a specific inorganic chemical associated with an SW threat is produced, it can be added to a utility's fingerprint library to facilitate future detection of the contaminant.
	Specific Conductance	Some inorganic chemicals have charged functional groups that can dissociate and form ionic species when dissolved in water. An increase in specific conductance could indicate the presence of inorganic industrial chemicals.
	Toxicity	Toxicity provides a general indication of the presence of a potentially toxic substance and thus may detect the presence of toxic industrial chemicals. Note that toxicity monitors vary widely in how they respond to different chemicals.
Organic Industrial Chemicals from SW threats, such as: • Chemical storage tanks • Pesticide and fertilizer storage tanks • Transportation corridors • Watercraft	DOC/TOC	DOC/TOC can be used to determine the carbon concentration associated with organic compounds, including organic industrial chemicals. Thus, an increase in DOC/TOC may indicate the presence of an organic industrial chemical.
	Spectral Absorbance	Many organic chemicals absorb in the UV-visible spectrum. Thus, a change in spectral absorption can indicate contamination from an organic industrial chemical. Furthermore, some spectral instruments allow users to add spectral fingerprints to a library. If the spectral fingerprint for a specific organic chemical associated with an SW threat is produced, it can be added to a utility's fingerprint library to facilitate future detection of the contaminant.
	Specific Conductance	Some organic chemicals have charged functional groups that can dissociate and form ionic species when dissolved in water. An increase in specific conductance could indicate the presence of organic industrial chemicals.

Contaminant Group and Associated SW Threats	Parameters	Rationale for Parameter Selection
Organic Industrial Chemicals from SW threats, such as: • Chemical storage tanks • Pesticide and fertilizer storage tanks • Transportation corridors • Watercraft	Toxicity	Toxicity provides a general indication of the presence of a potentially toxic substance and thus may detect the presence of toxic industrial chemicals. Note that toxicity monitors vary widely in how they respond to different chemicals.
Petroleum Products from SW threats, such as: • Petroleum storage tanks • Shale gas and oil drilling • Transportation corridors • Watercraft	DOC/TOC	DOC/TOC can be used to determine the carbon concentration associated with petroleum products. An increase in DOC/TOC could indicate the presence of petroleum products.
	Hydrocarbons	Hydrocarbon monitoring can provide a direct measure of hydrocarbon concentrations in a source water.
	Toxicity	Toxicity provides a general indication of the presence of a potentially toxic substance, and thus may detect the presence of petroleum products. Note that toxicity monitors vary widely in how they respond to petroleum products.
Algal Toxins/Harmful Algal Blooms (HABs) from SW threats, such as: • Agricultural runoff • Urban runoff • Wastewater treatment plant discharges	Ammonia	Ammonia can be monitored to detect increases in nutrient loading that can support harmful algal bloom formation.
	DO	Sharp decreases in DO concentrations can indicate the formation of algal blooms.
	Nitrate and Nitrite	Nitrate and nitrite can be monitored to detect increases in nutrient loading that can support harmful algal bloom formation.
	Ortho-phosphates	Ortho-phosphates can be monitored to detect increases in nutrient loading that can support harmful algal bloom formation.
	Photosynthetic Pigments	An increase in photosynthetic pigments can provide a direct indication of algal activity.
	pH	Increases in pH can occur due to photosynthetic activity and microbial respiration, and thus may be an indication of algal bloom formation.
	Turbidity	Increased turbidity can indicate the formation of algal blooms.
	Toxicity	Toxicity provides a general indication of the presence of a potentially toxic substance and thus may detect the presence of toxins. Note that toxicity monitors vary widely in how they respond to algal toxins.
Wastewater from SW threats, such as: • Wastewater outfall • Wastewater holding ponds • Spray field runoff	Ammonia	Ammonia is typically the most prominent nitrogen species in raw wastewater. Thus, monitoring for ammonia can be an effective method of detecting wastewater discharges.
	DO	Sharp decreases in DO concentrations can indicate the release of wastewater, which would elevate the bio-chemical oxygen demand.
	Nitrate and Nitrite	Nitrate and nitrite concentrations can be significant in wastewater effluent from plants that practice nitrification. Thus, monitoring for nitrate and nitrite can be an effective method of detecting wastewater discharges.

Contaminant Group and Associated SW Threats	Parameters	Rationale for Parameter Selection
Wastewater from SW threats, such as: • Wastewater outfall • Wastewater holding ponds • Spray field runoff	Ortho-phosphates	Phosphates can be present in wastewater effluent. As such, monitoring for ortho-phosphates can be an effective method of detecting wastewater discharges.
	DOC/TOC	DOC/TOC can be used to determine the carbon concentration associated with all organic compounds. An increase in DOC/TOC could indicate the release of wastewater.
	Specific Conductance	Some contaminants in wastewater have charged functional groups that increase the ionic strength of a solution. An increase in specific conductance could indicate a higher concentration of wastewater.
	Toxicity	Toxicity provides a general indication of the presence of a potentially toxic substance and thus may detect the presence of toxic chemicals present in wastewater. Note that toxicity monitors vary widely in how they respond to different chemicals.
	Turbidity	An increase in turbidity can indicate an increase in the concentration of suspended solids and microorganisms that may be present in wastewater.

Note: It is recommended that pH and temperature be selected for all contaminant groups and SW threats as these parameters are important for the fundamental understanding of aqueous chemistry.

Parameter Selection to Monitor Threats to Long-Term Water Quality

The parameters useful for monitoring of threats to long-term water quality will depend on the specific contaminants associated with high-risk SW threats. Selected parameters should be capable of providing useful information about the specific contaminants or contaminant classes identified during the risk assessment. **Table 4-4** lists several contaminant groups, potentially useful SWM parameters, and the rationale for how parameters can be used to detect contaminant groups. For this design goal, parameter selection should consider how the SW threats are likely to alter water quality over time.

Table 4-4. SWM Parameters that Support Monitoring of Long-Term Water Quality

Contaminant Group and Associated SW Threats	Parameters	Rationale for Parameter Selection
Wastewater/stormwater from SW threats, such as: • Wastewater outfalls • Wastewater holding ponds • Stormwater outfalls • Combined sewer overflows • Septic systems • Climate change	Ammonia	Elevated concentrations of ammonia can harm aquatic life, adversely impact beneficial uses (e.g., fisheries), and adversely impact treatment processes such as disinfection.
	DO	Insufficient DO can damage the aquatic ecosystem and adversely impact beneficial uses (e.g., recreational activities).
	DOC/TOC	Elevated concentrations of DOC/TOC can indicate higher pollutant loading, which would be harmful to the overall health of the waterbody. In extreme cases, a sustained increase in DOC/TOC may require modifications to treatment processes.
	Nitrate and Nitrite	Elevated concentrations of nitrate and nitrite can indicate higher nutrient loading, with the potential to trigger algal blooms and HABs. In extreme cases, a sustained increase in nitrate and nitrite may require the addition of a treatment process for nitrate removal to meet drinking water regulations.

Contaminant Group and Associated SW Threats	Parameters	Rationale for Parameter Selection
Wastewater/stormwater from SW threats, such as: • Wastewater outfalls • Wastewater holding ponds • Stormwater outfalls • Combined sewer overflows • Septic systems • Climate change	Ortho-phosphates	Elevated concentrations of ortho-phosphates can indicate higher nutrient loading with the potential to trigger algal blooms and HABs.
	Photosynthetic Pigments	An increase in photosynthetic pigments is a direct indicator of the level of algal activity and the potential for HABs.
	Specific Conductance	Elevated specific conductance could result in an exceedance of secondary drinking water standards and decreased customer acceptance of the water. If bromide is one of the inorganic chemicals contributing to the increase, it could result in higher concentrations of disinfection byproducts (DBPs), potentially requiring source water blending or addition of advanced treatment (e.g., reverse osmosis).
	Toxicity	Can indicate the presence of toxins that are harmful to aquatic life and degrade the overall health of the waterbody. Specific toxins could require additional treatment processes.
	Turbidity	Increased turbidity could adversely impact the overall health of a waterbody by reducing the depth of sunlight penetration. A significant and sustained increase in turbidity could require treatment process adjustments to maintain acceptable effluent water quality.
Inorganic and organic nutrients from SW threats, such as: • Agricultural runoff • Urban runoff • Wastewater outfalls • Wildfires • Climate change	Ammonia	Elevated concentrations of ammonia can harm aquatic life, adversely impacting beneficial uses (e.g., fisheries), and can adversely impact treatment processes such as disinfection.
	DO	Insufficient DO can damage the aquatic ecosystem and adversely impact beneficial uses (e.g., recreational activities).
	DOC/TOC	Elevated concentrations of DOC/TOC can indicate higher pollutant loading, which would be harmful to the overall health of the waterbody. In extreme cases, a sustained increase in DOC/TOC may require modifications to treatment processes.
	Nitrate and Nitrite	Elevated concentrations of nitrate and nitrite can indicate higher nutrient loading, with the potential to trigger algal blooms and HABs. In extreme cases, a sustained increase in nitrate and nitrite may require the addition of a treatment process for nitrate removal to meet drinking water regulations.
	Ortho-phosphates	Elevated concentrations of ortho-phosphates can indicate higher nutrient loading with the potential to trigger algal blooms and HABs.
	Photosynthetic Pigments	An increase in photosynthetic pigments is a direct indicator of the level of algal activity and the potential for HABs.

Contaminant Group and Associated SW Threats	Parameters	Rationale for Parameter Selection
Inorganic and organic nutrients from SW threats, such as: • Agricultural runoff • Urban runoff • Wastewater outfalls • Wildfires • Climate change	Specific Conductance	Elevated specific conductance could result in an exceedance of secondary drinking water standards and decreased customer acceptance of the water. If bromide is one of the inorganic chemicals contributing to the increase, it could result in higher concentrations of DBPs, potentially requiring source water blending or addition of advanced treatment (e.g., reverse osmosis).
Pesticides and herbicides from SW threats, such as: • Agricultural runoff • Urban runoff • Transportation runoff	DOC/TOC	An increase in DOC/TOC can indicate a higher loading of pesticides and herbicides, which may adversely impact the overall health of the waterbody and require significant treatment modification.
	Spectral Absorbance	An increase in spectral absorbance can indicate a higher loading of pesticides and herbicides, which may adversely impact the overall health of the waterbody and require significant treatment modification.
	Toxicity	An increase in the toxicity of a waterbody could be directly attributed to increased loading of pesticides and herbicides.

Note: It is recommended that pH and temperature be selected for all contaminant groups and SW threats as these parameters are important for the fundamental understanding of aqueous chemistry.

Section 5: Source Water Monitoring Stations

Once SWM locations and SWM parameters have been selected, SWM stations can be designed. Each SWM station will consist of the water quality instruments used to measure the selected parameters and the ancillary equipment needed to bring a sample into contact with sensors, power the station, communicate data to a utility control center, and protect the station from the environment, vandalism, or tampering. The actual design of a station will depend on:

- SWM location
- Parameters to be monitored at the location
- Practical considerations for installation and maintenance of the station at the location

A basic functional block diagram of an SWM station is shown in **Figure 5-1**, which delineates the SWM station functions as follows:

- **Instrumentation.** Providing the means to measure the selected parameters.
- **Sampling.** Placing the sensors in contact with the source water and, as necessary, disposing of the waste stream.
- **Power Supply and Distribution.** Supplying sufficient power to the energized equipment in the SWM station.
- **Communications.** Providing the means to transfer the data collected by the SWM station to a control center and transfer instructions from the control center to the SWM station.
- **Packaging.** Providing a structure to mount and protect the instrumentation and ancillary equipment both from the environment and potential tampering.

The following sections describe each of the functions identified in Figure 5-1.

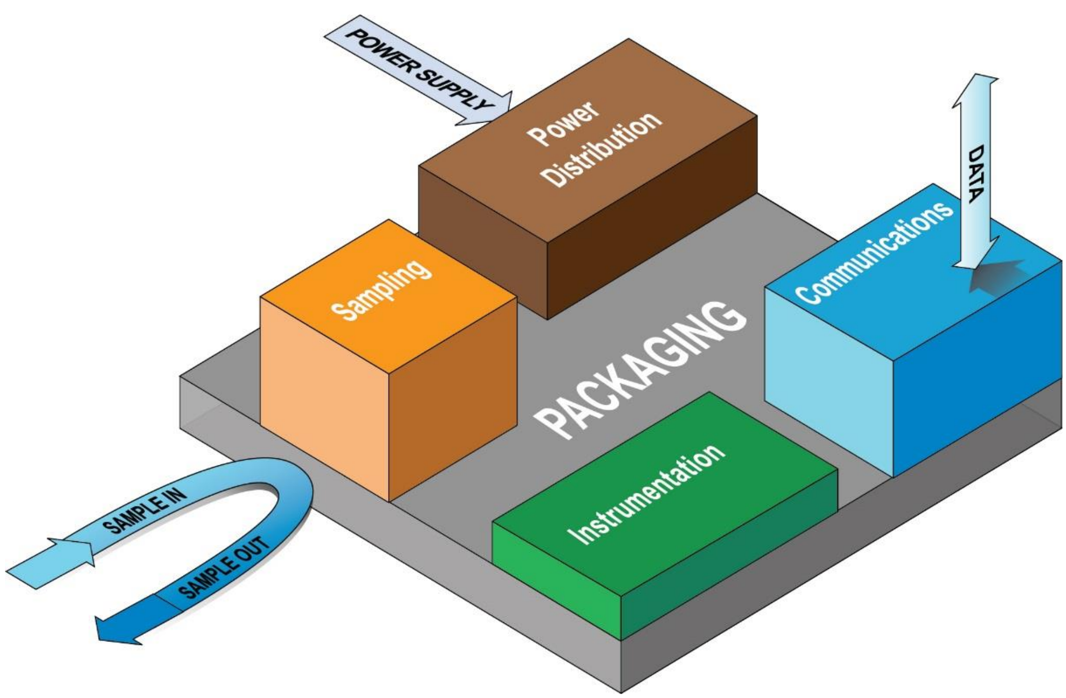


Figure 5-1. Functional Block Diagram of an SWM Station

5.1 Instrumentation

In many cases, multiple sensor technologies are available to measure a given parameter, and specific instruments will need to be selected for an SWM station. Several factors warrant consideration when selecting an instrument, including instrument performance, sampling and analysis interval, environment at the SWM installation site, lifecycle cost, and vendor support. An overview of SWM parameters and related sensor technologies, as well as factors that should be considered during the selection process, are covered in *Guidance for Selecting Online Water Quality Monitoring Parameters and Evaluating Sensor Technologies for Source Water and Distribution System Monitoring* (EPA, 2016c).

5.2 Sampling

Two commonly used approaches to source water sampling for online measurement are:

- Immersion of sensors directly into a waterbody
- Pumping the source water to sensors housed in a flow-cell

Immersion of sensors directly into a waterbody ensures that the sensors are measuring water quality with minimal disturbance or change to the sample. This sampling method is useful for parameters such as DO, which can change due to mixing and transport to a flow-cell. Many parameters can be monitored by sensors that can be immersed directly into a waterbody. A sensor designed for use in this manner is usually equipped with a protective housing and a means of cleaning the measurement surface using wipers, brushes, or compressed air.

REPRESENTATIVE SAMPLES

When sampling a waterbody, the sample represents only the actual point where it was taken. A waterbody is complex in its composition in all three dimensions, so a truly representative view of the waterbody would require profiling in three dimensions, which is impractical to do in real time. However, sensors placed at thoughtfully selected positions in a waterbody can provide information needed for a specific SWM application.

The second sampling approach involves pumping a water sample to sensors inserted into a flow-cell that is not immersed in the waterbody. This method requires installation of a pump and associated piping to move the sample to the SWM station and a flow-cell to ensure steady flow to all sensors. Some sensors designed for use in a flow-cell are equipped with wipers, brushes, or compressed air to control fouling. Flow-cells are useful in the following situations:

- When using sensors that only operate correctly at specific flow rates and pressures, and cannot be placed directly into a waterbody (e.g., many ammonia sensors).
- When using instruments that require a controlled environment to operate correctly.
- When instruments use reagents that cannot be discharged directly into a waterbody.

A comparison of the key attributes of the two sample measurement options (immersion and flow-cell) is provided in **Table 5-1**. The attributes used for the comparison are:

- **Measurement Interference.** The degree to which the sampling method introduces artifacts that could interfere with measurement.
- **Measurement Delay.** The degree to which the sampling method increases the time between when a sample is taken from a source water and when a sensor makes a measurement.
- **Exposure to Environment.** The degree to which the sampling method exposes instrumentation to variable or hostile environmental conditions.
- **Lifecycle Cost.** The degree to which the sampling method increases the cost of installing and maintaining the instrumentation.

- **Maintainability.** The degree to which the sampling method increases the time and effort necessary to maintain the instrumentation.

Table 5-1. Comparison of Key Attributes of Two Sample Measurement Options

Attribute	Immersion	Flow-cell	Comments
Measurement Interference	●	◒	Placing sensors directly in the waterbody eliminates many sources of measurement interferences that may be introduced when using a flow-cell, such as turbulence and potential contamination from pumps and piping.
Measurement Delay	●	○	When sensors are immersed in the source, measurement delay is negligible. When a flow-cell is used, the sample is pumped from the point it is extracted from the source to the sensors in the flow-cell. The transit time to the flow-cell is determined by the distance between the SWM location and SWM station as well as the flow rate. This delay can vary from minutes to hours depending on the distance and flow.
Exposure to Environment	○	●	Use of a flow-cell allows for more control over the environment in which the instruments operate.
Lifecycle Cost	◒	◒	The use of a flow-cell requires additional piping and possibly pumps, which can increase installation costs. However, sensors installed directly into a waterbody may be more costly to maintain.
Maintainability	○	◒	Use of a flow-cell allows the sensors to be placed in a more convenient location for maintenance. However, this option also requires piping and pumps that must be maintained.

Rating: ● = Positive; ◒ = Neutral; ○ = Negative

If reagents are used during measurement, the effluent sample stream should be properly disposed. This may require disposal into a sewer unless there is an NPDES permit to discharge the effluent sample stream into a waterbody. In cases where reagentless sensors are used and nothing is added to the sample stream, it may be possible to return the effluent sample stream to the source water following measurement.

5.3 Power Supply and Distribution

The choice of power supply for an SWM station will be limited by the location where the SWM station will be installed as well as the power requirements for the station equipment. Where it is readily available, grid power is often the simplest and least expensive power supply. However, if grid power is not available nearby, extending it to an SWM station may be equally or more expensive than using an alternative supply (e.g., wind or solar supported by batteries). When using grid power, it is suggested that the SWM stations have a dedicated circuit on the main breaker panel or a line conditioner to avoid erratic voltage or circuit breaker trips. To ensure continued operation of an SWM station during minor power outages, an uninterruptible power supply should also be installed. Additional guidance on power distribution is available in *Guidance for Building Online Water Quality Monitoring Stations* (EPA, 2016d).

5.4 Communications

The selection of a communications solution to transmit data from an SWM station to a control center is strongly influenced by the station's location. Communications solutions may include wired and wireless technologies. One potential advantage of using a flow-cell for sampling is that wired communication methods may be available near an SWM station installation site. *Guidance for Designing Communications Systems for Water Quality Surveillance and Response Systems* (EPA, 2016e) provides further details for common communications options as well as a set of evaluation criteria to support the selection process.

5.5 Packaging

Packaging for an SWM station includes the materials and devices used to mount or house sensors and ancillary equipment. To achieve the various design goals and performance objectives, SWM stations may need to be installed in buildings, near other equipment, or in remote areas near or directly in the source water, all of which will influence the station packaging. SWM stations are typically constructed using one of five primary design types:

- **Wall-mounted racks** are assembled by securing instruments and related equipment to a mounting panel that is attached to a wall.
- **Free-standing racks** are constructed by securing instruments and related equipment to a mounting panel that is attached to an open, structural frame that provides access on both sides of the panel.
- **Enclosed stations** house instruments and related equipment inside a custom-made, prefabricated, or National Electrical Manufacturers Association (NEMA) enclosure.
- **Compact stations** are smaller versions of enclosed stations that can be designed around one or two reagent-based instruments or a reagentless instrument that measures multiple parameters.
- **Floating platforms** allow for a station to be located on the surface of a waterbody. These stations typically consist of one or more cabinets containing instrumentation and electronics, which are mounted on a pontoon or buoy. Only reagentless instruments are used on floating platforms to avoid the difficulties associated with replacing reagents and properly disposing of the waste stream.

Details for each of these SWM station designs are provided in *Guidance for Building Online Water Quality Monitoring Stations* (EPA, 2016d).

Section 6: Information Management and Analysis

The data generated by the SWM stations must be converted into actionable information to achieve the selected design goals and provide the utility with the maximum value for its investment in SWM. Actionable information is produced by analyzing SWM data, along with supporting information, and presenting relevant results to the end user in a manner that is easy to understand. To achieve these objectives, an SWM information management system must provide data storage, access, analysis, notification, and visualization capabilities.

The development process discussed in this section is consistent with the general principles of information management system design presented in Section 4 of the *SRS Integration Guidance* (EPA, 2015b), with additional considerations that are specific to an SWM information management system. This section covers the following topics:

- Analysis and visualization techniques
- SWM information management system ***architecture***
- SWM information management system requirements

INFORMATION UTILIZATION

During a forum with chief information officers (CIOs) from 50 major utilities across the United States, the CIOs estimated that only 10 to 15 percent of the information gathered by their organizations is properly evaluated. Automated analysis and effective visualization of data can help to address this underutilization of collected data.

6.1 Analysis and Visualization Techniques

SWM data is analyzed to identify changes in source water quality that require attention from utility personnel and may prompt actions to meet the SWM design goals. Analysis of SWM data generates information that visualization tools display in a manner that is easily interpreted and applied by utility personnel. Analysis and visualization techniques will vary for each design goal as described below.

PREPARATION FOR SWM DATA ANALYSIS

To use SWM data effectively, it is first necessary to verify that it meets data quality objectives (e.g., ***accuracy*** and completeness) and characterize normal variability:

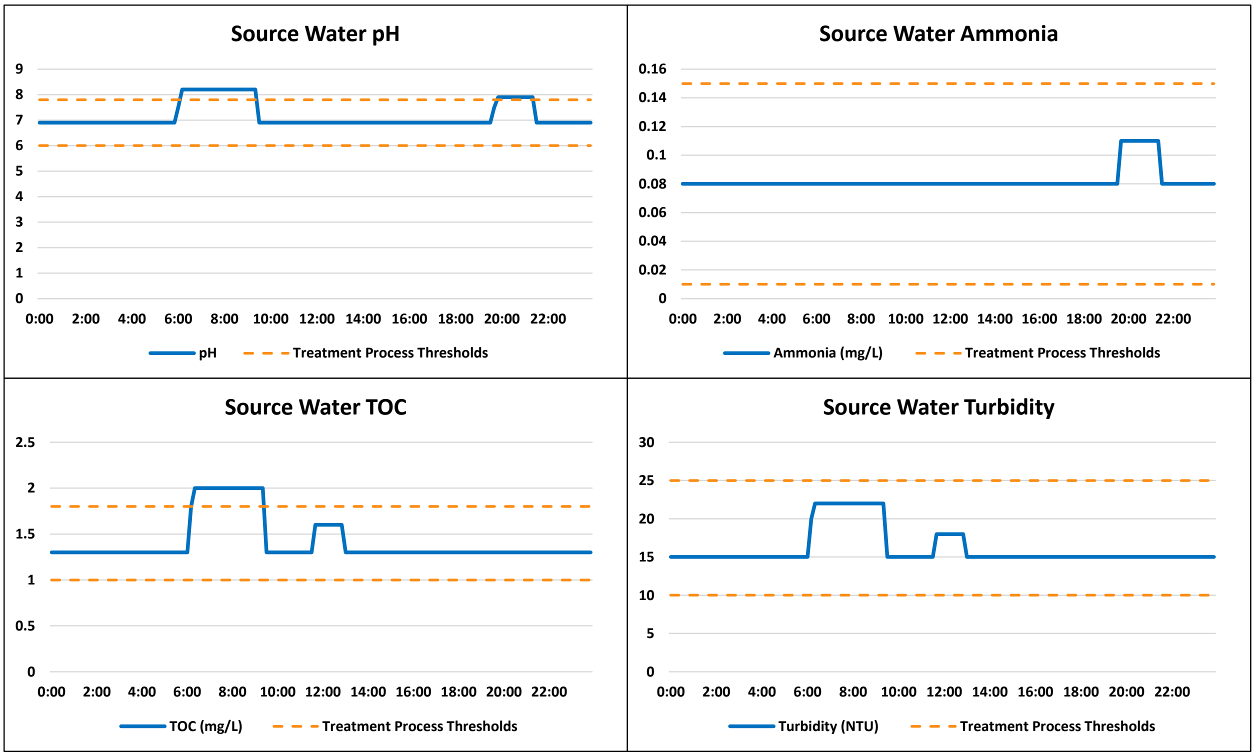
1. **Verify that the data being used for analysis meets data quality objectives.** All available water quality sensors produce data that exhibits an inherent level of noise and outliers on occasion. When performing the types of analyses described in this document, it is important to have reliable data that meets data quality objectives. Before using the data collected from SWM stations, obvious errors should be removed or corrected, a process referred to as data validation. Data validation may be performed by a computer at an SWM station or as part of the analytics layer of a centralized information management system as described in Section 6.2.
2. **Establish the normal variability, or *baseline*, for SWM water quality data.** The data analysis approaches described in this section rely on understanding the normal variability for each parameter at each SWM location to establish a baseline.

Additional guidance on techniques for data validation and establishment of a baseline can be found in *Exploratory Analysis of Time-series Data to Prepare for Real-time Online Water Quality Monitoring* (EPA, 2016f).

Analysis and Visualization to Optimize Treatment Processes

SWM for treatment process optimization involves monitoring SWM data in real-time to identify changes in source water quality that require treatment process adjustments. It requires an understanding of the relationships between source water quality and the process adjustments necessary to improve treatment process performance. This knowledge can be gained through bench- or pilot-scale studies, or through application of institutional knowledge developed through operation of the full-scale plant. Two methods of analyzing SWM data to support treatment optimization are ***thresholds*** and ***treatment process models***.

The use of thresholds to optimize treatment processes involves real-time monitoring of the parameters that affect the treatment process performance and adjusting the process when the monitored parameters cross previously defined thresholds. Most processes are impacted by multiple parameters, so individual parameter thresholds should not be considered in isolation. To help operators identify potentially significant changes in water quality, an alert can be generated based on a parameter crossing a threshold (minimum or maximum). Threshold analysis is often visualized using time-series plots that show a moving window of recently measured values along with the minimum and maximum thresholds, as illustrated in **Figure 6-1**. The thresholds, shown as dashed orange lines, represent the range of variability in which the current treatment process settings can achieve optimized treatment. In this example, the x-axis displays the time of day in hours and the y-axis displays the parameter concentration in the units specified in the legend. The information provided through these plots, along with operator knowledge about the treatment process, can then be used to make process adjustments.



Note that this figure displays idealized data, without noise, to clearly demonstrate the concept of threshold analysis.

Figure 6-1. Time-Series Plots and Thresholds for Treatment Process Optimization

Thresholds must be defined for each monitored parameter and each treatment process. A combination of statistical analysis of historic water quality data and knowledge of treatment process performance can be used to establish thresholds for treatment optimization. Statistical analysis can be used to develop thresholds based on typical variability in a water quality parameter over a relevant time period (e.g., daily or weekly for highly variable parameters, monthly or seasonally for less variable parameters). Knowledge of treatment process performance can help to correlate process settings with different source water quality types. A five to ten percent factor of safety should be applied to thresholds such that a process will continue to produce water of acceptable water quality as the parameter value begins to cross the threshold. This provides operators with time to investigate and respond to a source water quality change.

The second analysis approach involves the use of treatment process models. These models codify the relationship among influent water quality, treatment process settings, and treatment process effluent water quality. Models for treatment processes can be categorized as mechanistic, statistical, or knowledge-based (McEwen, 1998). Mechanistic models relate inputs and outputs to the fundamental properties of the processes and use empirically determined coefficients to calibrate the model to a specific treatment plant. Statistical models are used when reliable mechanistic models are unavailable; inputs are related to outputs based on statistical analysis of historic data. Knowledge-based models use techniques such as neural networks and expert systems to describe complex systems where there is a limited understanding of the specific principles that drive the system. These models use knowledge of the inputs, outputs, human experience, and past performance to predict future process performance.

Treatment process models use validated SWM data, current treatment process settings, and process effluent water quality to determine the process adjustments necessary (e.g., chemical dosing, loading rates) to maintain optimized treatment. If the model is connected to a supervisory control and data acquisition (SCADA) system, it could be configured to automatically adjust treatment process settings. If not, operators can manually adjust treatment process settings as described in Section 7.1.

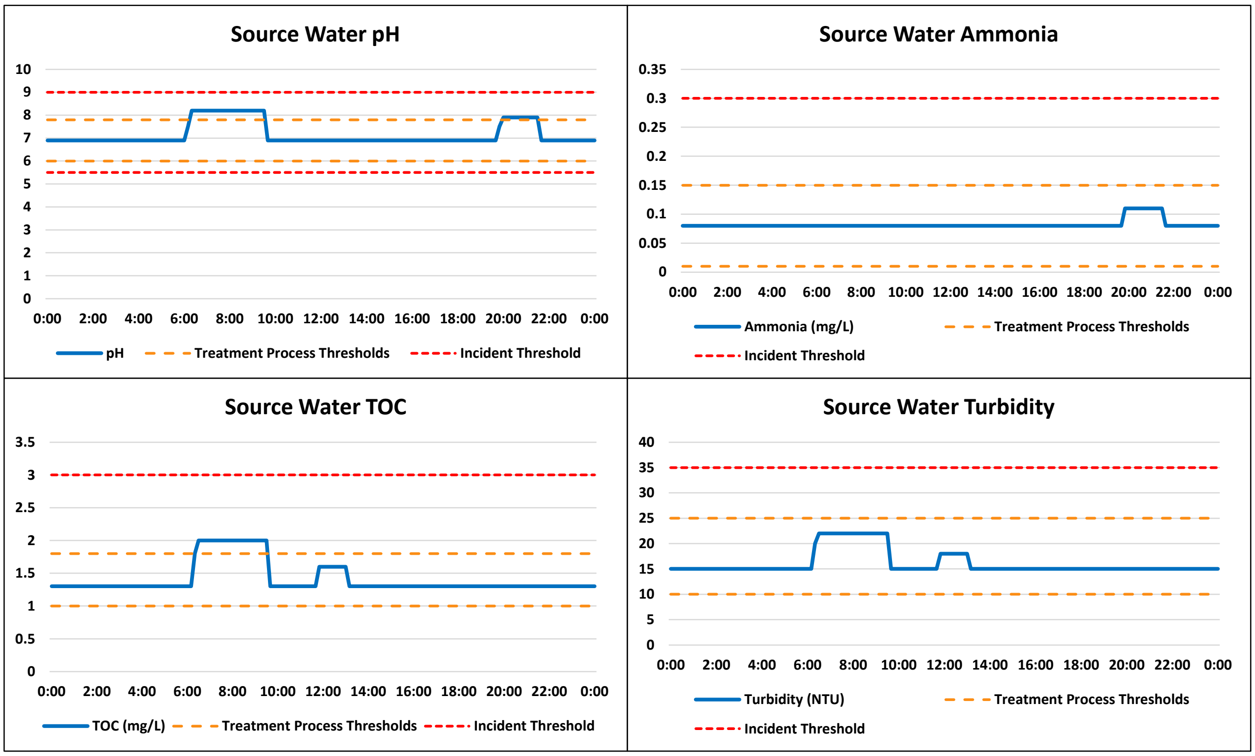
Analysis and Visualization for Detection of Contamination Incidents

SWM for detection of contamination incidents involves monitoring SWM data in real-time to identify water quality anomalies. Two methods of using SWM data to support detection of contamination incidents are threshold analysis and automated ***anomaly detection systems*** (ADSs).

A simple approach for detecting contamination incidents uses thresholds for individual SWM parameters. The thresholds are based on the normal variability of each parameter at each location so that a threshold exceedance is indicative of a water quality anomaly. The use of individual parameter thresholds for the detection of contamination incidents in drinking water distribution systems is discussed in detail in the article *Parameter Set Points: An Effective Solution for Real-Time Data Analysis* (Umberg and Allgeier, 2016).

Thresholds can be established using statistical analysis of historical data gathered over a representative period, although it may be necessary to use specialized software packages to analyze the large volume of SWM data needed to perform these analyses. Alternatively, the analytics necessary to calculate statistically derived thresholds may be built into an information management system. Threshold values are generally set to avoid excessive invalid alerts while maintaining sufficient sensitivity to detect contamination incidents. If there are significant shifts in water quality, such as seasonal changes, unique thresholds may need to be established for each time period with a significantly different water quality baseline.

An example of a visualization technique to support threshold analysis is shown in **Figure 6-2**. In this example, the thresholds used for treatment process optimization are shown as dashed orange lines, as described in Figure 6-1. The red dashed lines indicate thresholds for detection of contamination incidents, which are set at the 99.9th ***percentile***, as calculated from a statistical analysis of six months of data. In this figure, the thresholds for detection of contamination incidents are further from the typical parameter values compared with the thresholds for treatment optimization. Also, with the exception of pH, only upper thresholds were established for detection of contamination incidents because a contamination incident would not be expected to decrease ammonia, TOC, or turbidity. The reason for the differences between thresholds for treatment optimization and contamination incident detection is that the former are intended to guide treatment process changes in response to typical water quality changes, whereas the latter are intended to identify anomalies that are outside of the range of typical water quality variability.



Note that this figure displays idealized data, without noise, to clearly demonstrate the concept of threshold analysis.

Figure 6-2. Time-Series Plots and Thresholds for Detection of Contamination Incidents

More complex ADSs use software-based algorithms that are generally able to analyze the behavior of multiple parameters measured at a single monitoring location to identify anomalies. Some ADSs require manual input of algorithm coefficients based on guidelines provided by the developer and basic knowledge of the monitored datastreams. These ADSs use an initial set of coefficients that can then be modified as typical water quality patterns are better characterized. Some ADSs learn normal variability using training datasets to balance the number of invalid alerts against the possibility of missing a true anomaly. These software tools may include features that allow a user to assign a specific cause to alerts and classify each as valid or invalid, which can reduce the future occurrence of invalid alerts without compromising detection capabilities.

ANOMALY DETECTION SYSTEMS

ADSs that were evaluated as part of the Event Detection System Challenge (EPA, 2013a) under EPA's SRS program include:

- CANARY (EPA)
- ana::tool (s::can)
- Hach Event Monitor (Hach)

Prior to selecting an ADS, a utility should evaluate multiple options using representative historical data to determine which option is able to most reliably differentiate between true water quality anomalies and typical water quality variability at each SWM location.

A ***dashboard*** is a visually oriented user interface that integrates and displays data from multiple sources spatially and graphically. An example of a GIS-based dashboard designed to display data from SWM locations and United States Geological Survey (USGS) stations is shown in **Figure 6-3**. Additional information resources that support the interpretation of water quality data, such as weather and streamflow data, can be incorporated into a dashboard design. Presenting information from a variety of resources in a spatial context can be valuable during the investigation of a water quality anomaly, as discussed in Section 7.1. Additional information about the features and design of dashboards is available in *Dashboard Design Guidance for Water Quality Surveillance and Response Systems* (EPA, 2015e).

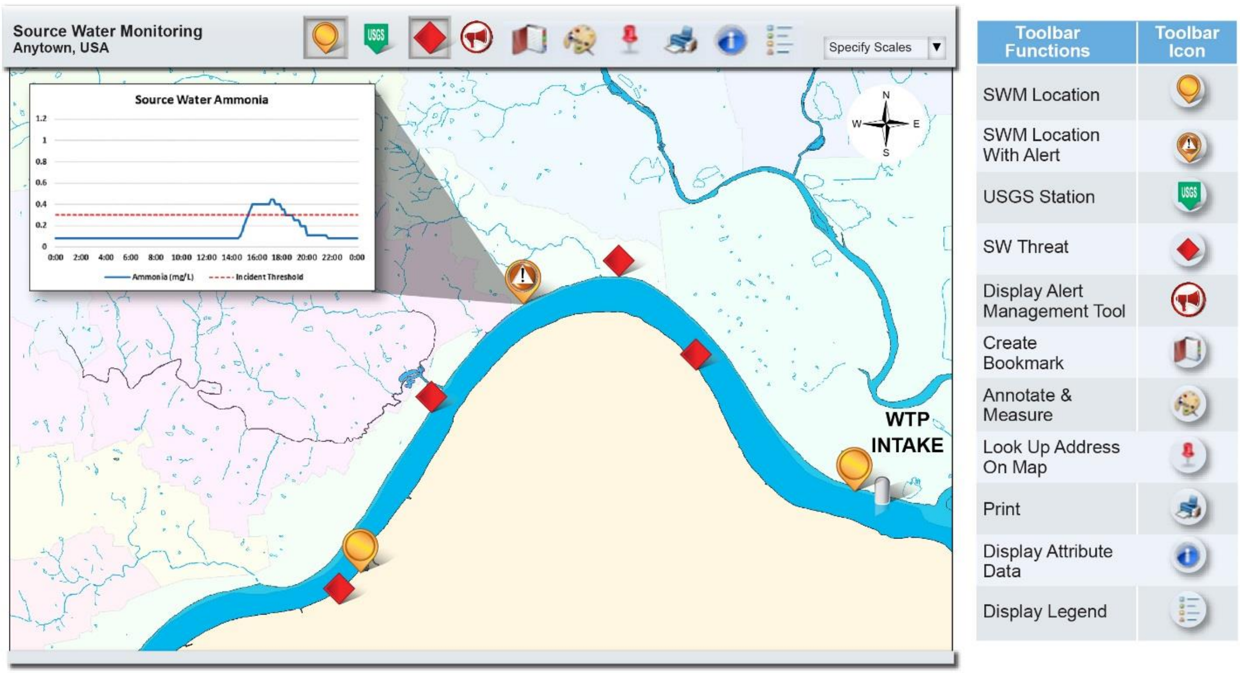


Figure 6-3. SWM Display showing Alert Status and Time-Series Data for an SWM Location

To support real-time analysis of SWM data, water quality baselines should be regularly updated to reflect recent conditions. When there is a change in the baseline, threshold values or ADS settings will need to be updated accordingly. The required frequency of these updates depends on the variability of the monitored parameters at each SWM location. For example, updates to the baseline may coincide with seasonal changes. Many ADSs can automatically adapt to a changing baseline as part of their learning algorithms.

When potential water quality anomalies are detected by any method, SWM information systems should generate an alert and provide notifications to operators to inform them of water quality changes that require attention. As operators may not have the time to frequently review new data as it is generated, notifications should be provided using flashing icons on a screen, emails, or text messages. Where possible, notifications should contain details about the alert (e.g., time, SWM location, alerting parameter, current parameter value). An example of a text message notification of an SWM alert, and the associated alert details available through the dashboard, is shown in **Figure 6-4**.

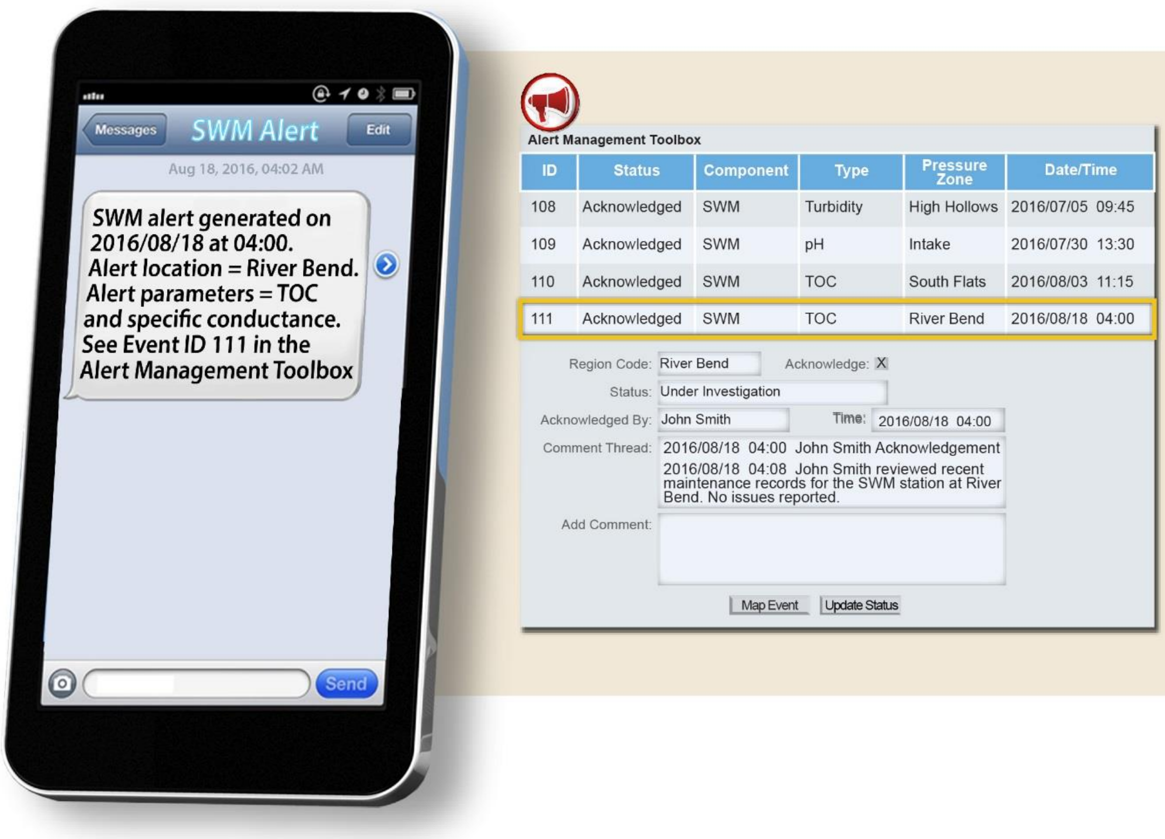


Figure 6-4. Text Message and Dashboard Alert Notifications

Analysis and Visualization for Monitoring Threats to Long-Term Water Quality

Monitoring threats to long-term water quality relies on the ongoing analysis of SWM data over the course of multiple years to identify trends and sustained changes in the baseline. Information derived from SWM can inform development of strategies to respond to a deterioration in source water quality that impacts utility operations and water quality goals.

Multiple years of data should be analyzed for a given parameter and location to distinguish statistically significant changes in the baseline from typical seasonal patterns. After each parameter at each location has been characterized, a systematic analysis can be performed to determine whether (1) the baseline for multiple parameters has changed at a specific SWM location and (2) the baseline for a given parameter has changed at multiple SWM locations. These results can help to assess whether the change is widespread throughout the source water and watershed or isolated to a specific area.

A variety of visual and statistical techniques can be used to identify significant, sustained changes in the baseline for a parameter. Examples include graphical analysis, hypothesis testing, correlations, and trend analysis, as briefly described in **Table 6-1**. More detail about the types of statistical analysis appropriate for characterizing long-term water quality are provided in *Statistical Methods in Water Resources* (USGS, 2002).

Table 6-1. Statistical Analysis Techniques for Characterizing Long-Term Water Quality

Type of Analysis	Statistical Methods	Example Applications
Graphical Data Analysis	Time Series	Display temporal trends in the data
	Histograms	Display data sorted into meaningful categories
	Box and Whisker Plots	Compare statistics for SWM data from different SWM locations
	Scatterplots	Explore a potential relationship between two variables, such as flow and turbidity
Hypothesis Testing (Nonparametric)	T-Test	Confirm that a specific parameter has changed over a defined period of time
	Rank-Sum Test	Determine whether the values of a parameter at two different locations are similar or different
	Matched Pair Testing	Determine whether a parameter has changed from year to year
Correlation	Correlation Coefficient	Establish the strength of the relationship between two items, e.g., recreational river usage and source water turbidity
	Linear Regression	Determine whether there is a statistically significant relationship between two items, e.g., source water TOC and turbidity
	Multivariate Analysis	Consider the combined impact of multiple variables on a system or process
Trend Analysis	Mann-Kendall Test	Determine whether values either only increase or only decrease
	Seasonal Kendall Test	Determine whether parameters have changed over time, taking into account seasonal variability

Figure 6-5 provides an example of a time-series plot used to display a long-term trend in water quality. This figure shows a plot of monthly TOC averages as the blue line and the yearly TOC averages as the red dotted line. The increasing trend in yearly TOC averages over a 10-year period can be clearly seen in this chart. This is one of the simpler visualization approaches for exploring potential trends, and the results of such simple analyses may lead to the use of more complex statistical techniques as presented in Table 6-1.

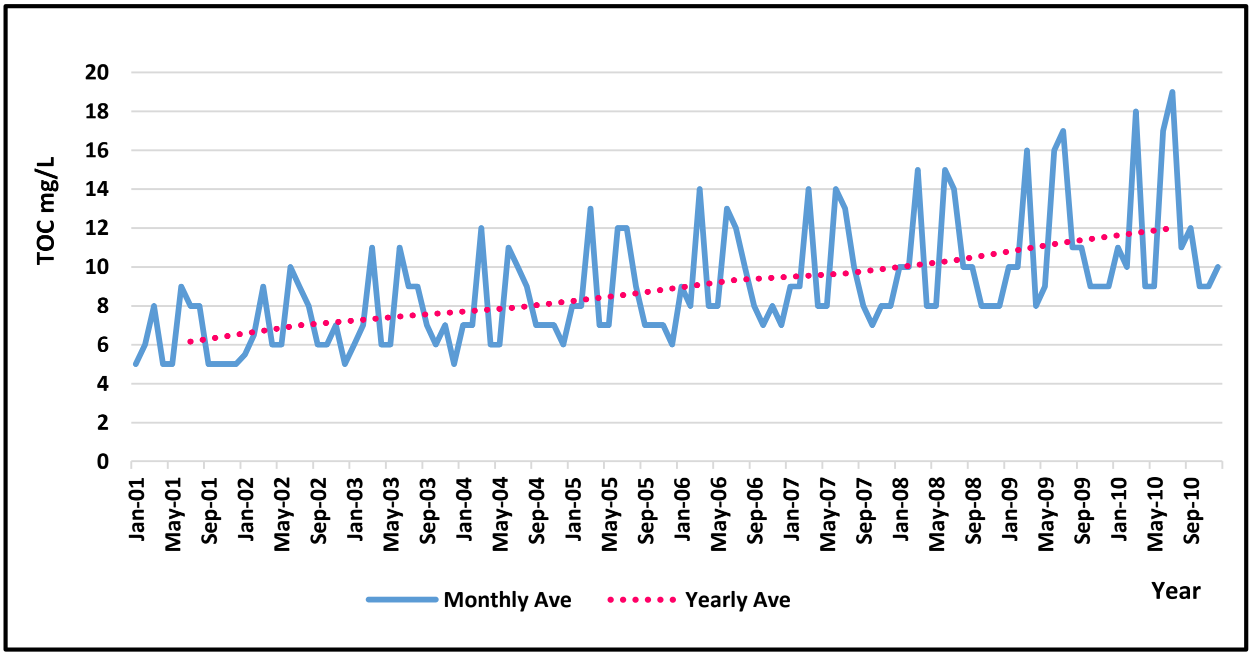


Figure 6-5. Example Plots of Monthly Average and Yearly Average for Source Water TOC

When considering multiple SWM locations in a watershed, a GIS-based presentation can provide an overview of parameter changes across the entire monitored area. The example in **Figure 6-6** shows the GIS display of the watershed with the SWM locations color-coded to indicate the change in TOC over a 10-year period.

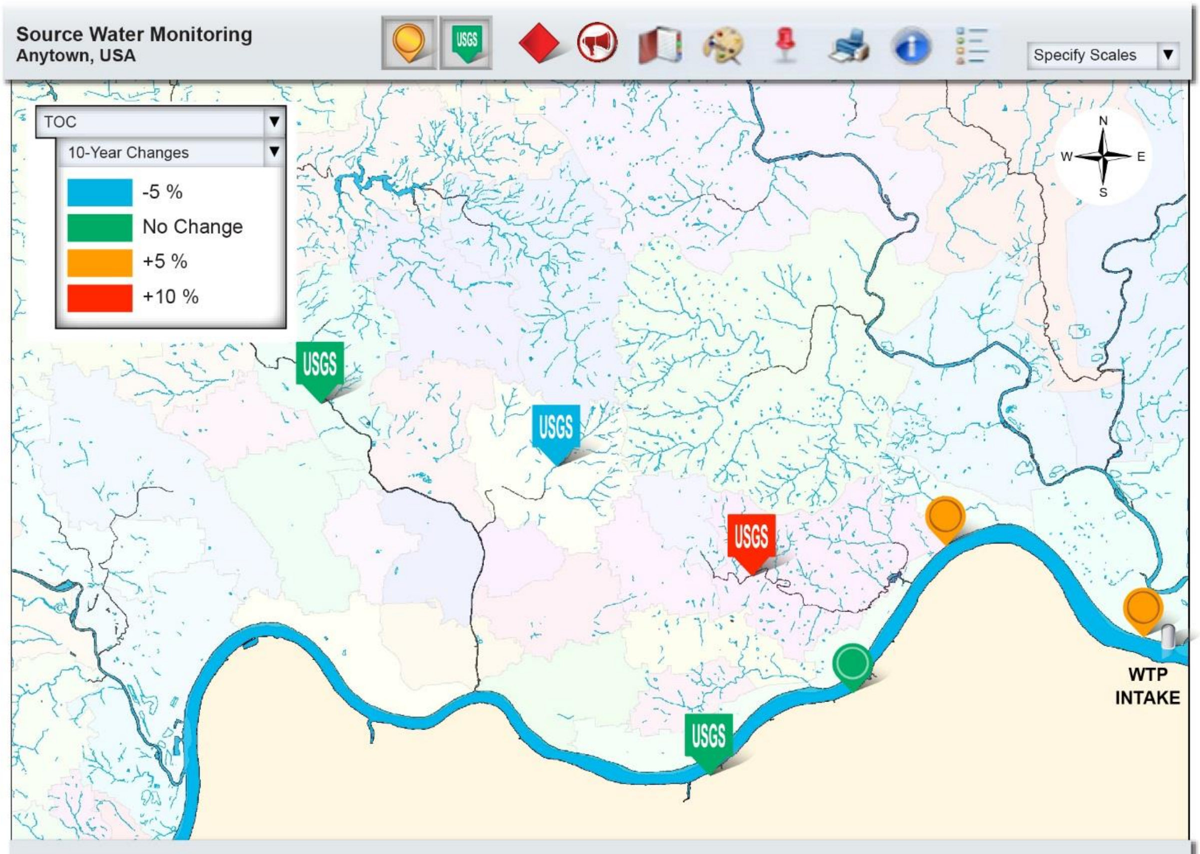


Figure 6-6. Geospatial Presentation Showing the Change in TOC over a 10-Year Period

6.2 SWM Information Management System Architecture

SWM information management functions can be integrated into an existing information management system, or a dedicated SWM information system can be developed. In either case, a system will likely be centralized (e.g., at a utility's control center), and data will be transmitted from remote monitoring locations to this centralized system. The design of the information management system will be captured in the architecture, which is a conceptual representation of hardware, software, and processes that are part of the system.

Options for an SWM information management system architecture discussed in this document include:

- **SCADA system.** Integrating SWM functions into an existing SCADA system.
- **Dedicated information management system.** Implementing a dedicated information management system to provide the functions required for SWM, such as analysis, notification, and visualization.
- **Cloud-based solutions.** Using cloud services to provide the functions required for SWM.

SCADA System

SWM stations can be added to an existing SCADA system, such as that used to monitor and control a treatment plant. Familiarity with SCADA may make it relatively simple and inexpensive to incorporate datastreams generated by SWM. An example of a SCADA architecture expanded to include SWM is shown in **Figure 6-7**. This arrangement leverages existing SCADA elements, such as a historian for data storage and a human machine interface (HMI) for visualization of SWM data. The same type of Programmable Logic Controllers (PLCs) used at existing monitoring locations can be used to provide monitoring and control functions at SWM stations. However, an existing SCADA system may impose some limitations on SWM information management, such as the functionality for visualization, the number of users that can access the HMI, and the types of water quality instrumentation that can be used. Furthermore, utility information security policies may regulate connectivity outside of the utility, limiting connections to external sources of information that may be useful for understanding the source water and assisting with an investigation.

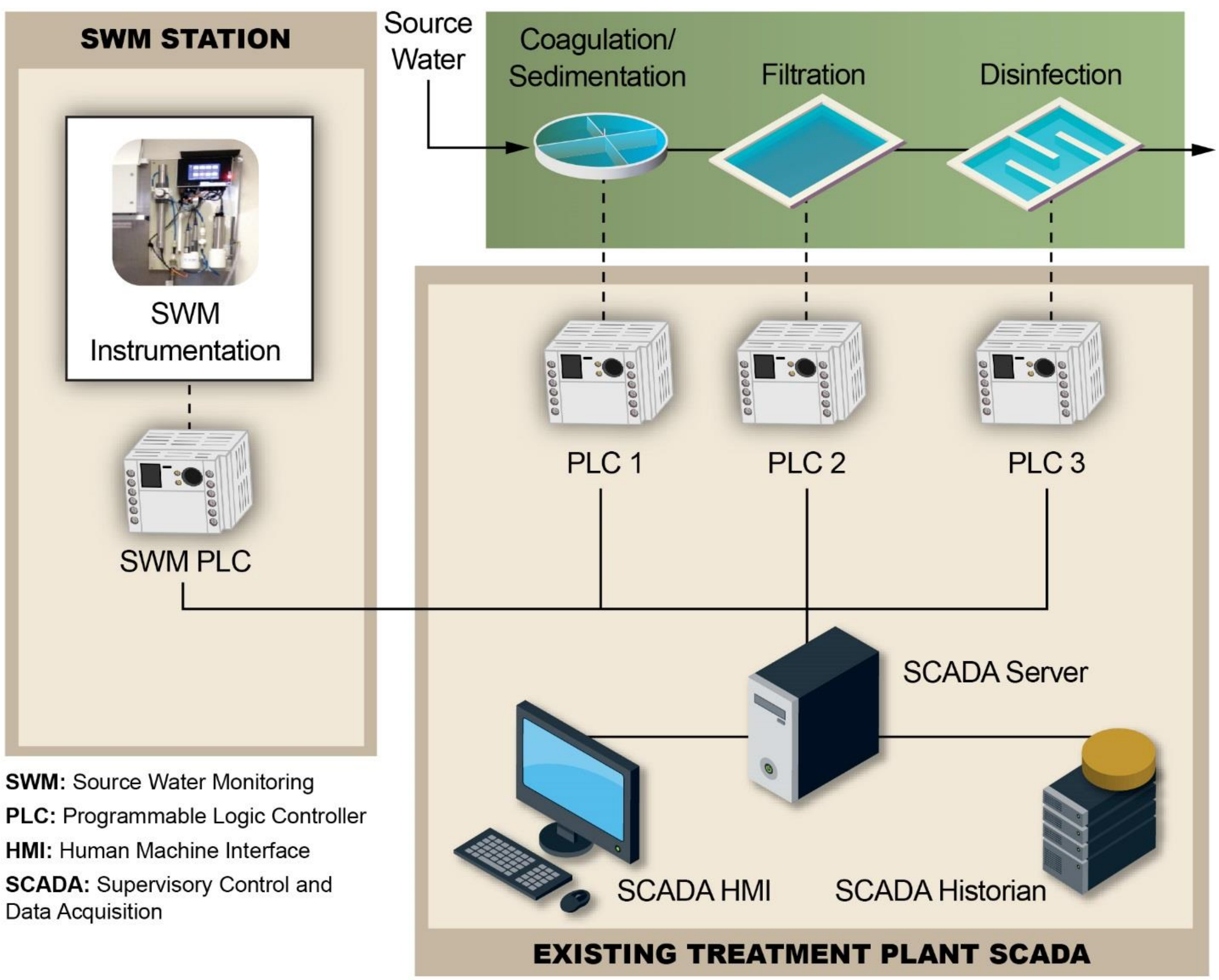


Figure 6-7. SWM Information Management as an Extension of an Existing SCADA Architecture

Dedicated Information Management System

A dedicated information management system for SWM may be useful when:

- SWM produces data that is difficult to store in a SCADA historian. For example, spectral absorbance over multiple wavelengths can generate a spectral profile as an array of 256 data points for each sample. The design of some SCADA historians is not optimal for storing such arrays, but alternate database structures can be built to store these complex datastreams efficiently.

- SWM requires access to data on networks that cannot be accessed by the SCADA system due to security policies. For example, a requirement to display weather data or USGS flow data via an internet connection may preclude the use of SCADA.
- Remote access to SWM data is required, and security policies prohibit remote access to the SCADA system.

The use of a dedicated SWM information management system provides greater flexibility for achieving the required functionality, and it allows for connection with other information management systems, within and external to the utility. **Figure 6-8** illustrates a conceptual architecture for a dedicated SWM information management system with connections to a treatment plant SCADA system, laboratory information management system (LIMS), and external data from the National Weather Service and USGS. This type of architecture can also incorporate more powerful analytics and visualization tools to assist with the investigation process.

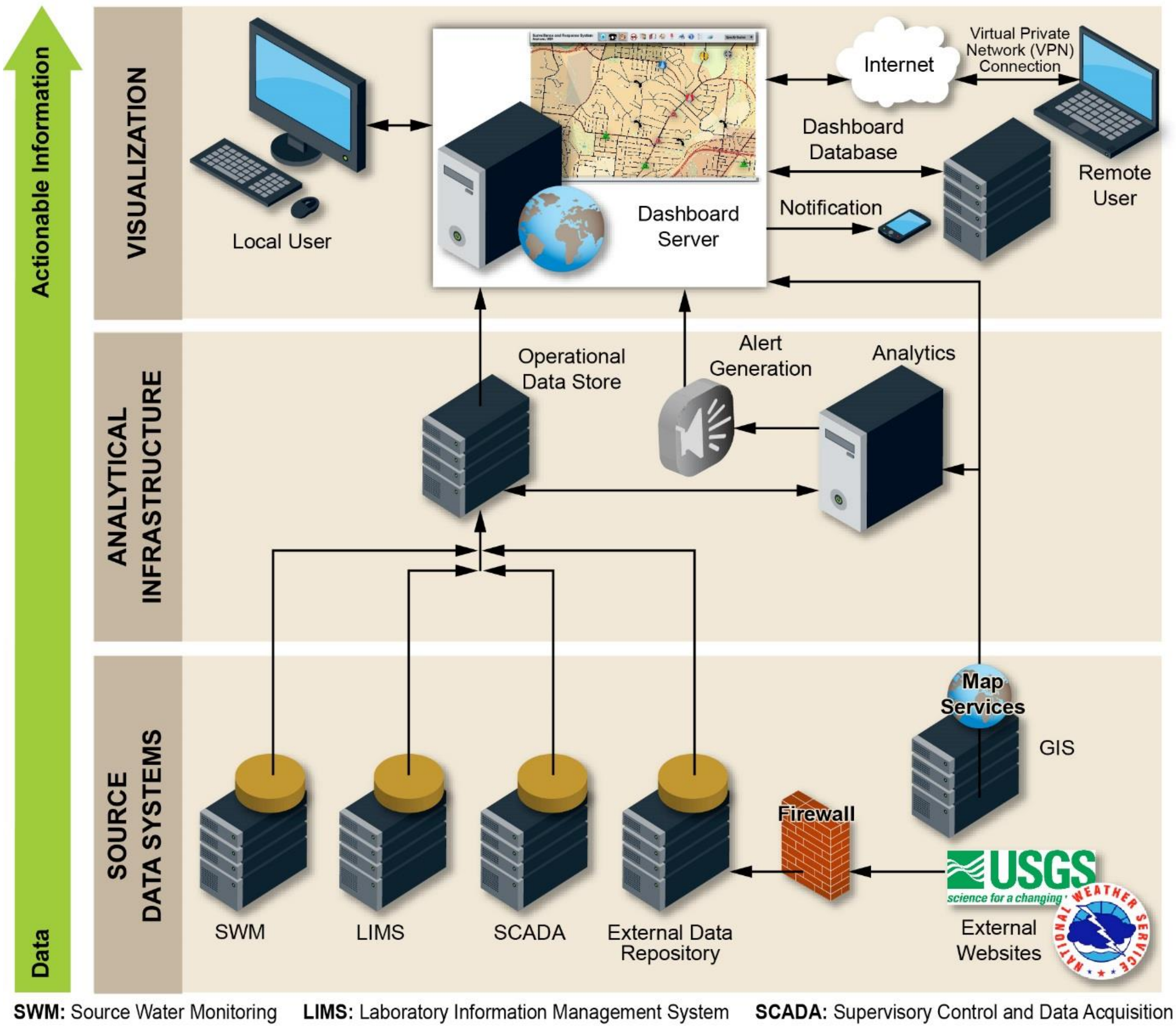


Figure 6-8. Example of a Dedicated SWM Information Management System

Cloud-Based Solutions

Cloud-based solutions provide another option for SWM information management. There are three types of cloud-based solutions:

- A hosted cloud is owned and maintained by a third party where the utility pays only for the portion of the cloud that it uses, usually on a lease-type of arrangement.
- A private cloud is owned by the utility, but uses cloud technology to provide the required services.
- Proprietary clouds are provided by vendors of many water quality instruments to interact with the instruments and collect the data generated.

Both SCADA-based and dedicated SWM information management systems can be implemented using cloud technology.

A hosted cloud may be attractive for a utility that wants to contract development and operation of the information management system as a third-party service rather than maintain the information technology (IT) infrastructure in-house. This approach may also allow for expedited implementation of the SWM information management system. The main advantage of a hosted system is that there is little capital expenditure required as the utility does not need to purchase hardware and software for the system.

A private cloud provides the same capabilities as a hosted cloud except that the utility owns the hardware and software. This requires capital expenditure to set up; however, the cloud would be under the utility's control.

Proprietary clouds provided by instrumentation vendors are used to collect, store, and process data, and provide a user interface for their specific sensors. This service often provides a low-cost and readily available method for manually or automatically accessing the data directly for each one of the devices, which can be useful when a small number of devices are deployed. However, this approach can present challenges when the data in the proprietary cloud requires integration with other data that resides within other utility information management systems. In many cases this integration may require the development of unique software (often referred to as "listener" software) to identify that new data has been uploaded to the cloud and transfer it to the utility system for further processing and storage.

6.3 SWM Information Management System Requirements

SWM information management systems are unique for every utility due in part to differences in existing information management systems and capabilities, expertise of utility personnel responsible for developing and using the information management system, and resources available to develop an information management system to support SWM. Each utility will also establish unique design goals and performance objectives for SWM. These factors collectively influence the manner in which the SWM information management system is utilized by utility personnel and thus impact the requirements.

To develop an information management system that meets users' expectations and provides them with the information they need, when they need it, and in a usable format, information management requirements must be defined. This section references Section 4.2 of the *SRS Integration Guidance* (EPA, 2015b), which describes a methodical, end-user driven process for developing requirements and selecting an information management system.

Two categories of requirements need to be developed for an SWM information management system:

- ***Functional requirements*** define key features and attributes of the system that are visible to end users. Examples of functional requirements include the manner in which data can be accessed, the types of tables and plots that can be produced through the user interface, the means by which alerts are transmitted to utility personnel, and the ability to generate custom reports. Functional requirements should be informed by end users.

- ***Technical requirements*** are system attributes and design features that are often not readily apparent to end users but are essential to meeting functional requirements and other design constraints. Examples include attributes such as system availability, information security and privacy, backup and recovery, data storage needs, and integration requirements. Technical requirements are generally developed by IT personnel or derived from IT standards.

Functional Requirements

Before developing functional requirements, expected uses of the SWM information management system should be defined. Expected uses are simply the manner in which users expect to interact with the system. For example, users may want to review recent source water quality data daily to guide treatment plant operations, be notified of anomalous water quality conditions, and access a variety of information resources to investigate the cause of a source water quality anomaly. The expected uses of an information management system will guide the development of detailed functional requirements, such as the examples described in **Table 6-2**.

Table 6-2. Examples of SWM Information Management Functional Requirements

Title	Description
Presentation of SWM Station Operating Status	Colored icons are used to identify the current operating status of each SWM station on the GIS display using the following attributes: • Green – Normal operation, all systems functioning properly • Yellow – Some of the subsystems (e.g., sensors) malfunctioning • Grey – Station not communicating and assumed to be offline • Red – Station producing an ADS alert
Mouse Over and Drill Down	When users hover over an icon on the map, a pop-up box appears that displays detailed data associated with the icon (e.g., values, time-stamps, location, instrument status). A hyperlink is available in the pop-up box that opens a detailed data history in the user interface (e.g., time-series plots for SWM parameters).
External Data Sources	The SWM information management system will provide a connection to and obtain the latest information from: • USGS river flow and water quality data • National Weather Service data
Display of Overlays	Multiple overlays can be displayed at the same time. Overlays that may be displayed concurrently include: • SWM station location and status • Current source water flow data • Recent water quality data from grab samples • Active spill reports
Generation of SWM Station Reports	Reports can be manually generated for any time period, and a report can be generated for a selected station that includes box-and-whisker plots for the parameters at the station and statistics on station equipment diagnostics.
Remote Access	Notifications and summary information can be accessed remotely using mobile devices, such as smartphones or tablets, over a secure connection.
Automated Report Generation	The system will automatically generate customizable reports that provide validated data, analysis output, time-series plots, and statistical summaries even when there are no alerts produced in the reporting period.
Parameter Adjustment	The system will include a user interface that provides users with the ability to easily adjust key parameters and display features without modifying the underlying code.

Technical Requirements

Technical requirements are often dependent on the functional requirements and should be developed after the functional requirements have been defined. Generally, development of technical requirements is the responsibility of IT personnel who consider the technical aspects of the SWM information management system design that are necessary to meet the functional requirements. Technical requirements will also be informed by IT policies, such as security protocols, and the need to adapt the system over time to incorporate new functions, datastreams, and features. Examples of technical requirements are provided in **Table 6-3**.

Table 6-3. Examples of SWM Information Management System Technical Requirements

Title	Description
Encryption	All interactions with the SWM information management system will be encrypted via Secure Socket Layer.
Map Service Utilization	The SWM information management system will be able to read and display map services provided by the utility's GIS using a configurable list of map services.
Size of the Operational Data Store	The operational data store will provide ready access to the last 90 days of data for all source data systems used in the SWM information management system.
Parameter Data Storage	The SWM information management system will provide storage of datastreams for spectral profiles (256 data points per sample) and toxicity monitors.
External Data Sources	National Weather Service and USGS data will be accessed via a secure connection. Information resources associated with specific SW threats (e.g., spill reports, leak detection alerts from SW threats, discharge rates) will be accessed using a secure connection.
Design Flexibility and Ability to Accommodate New Requirements	Because the SWM system will be implemented in phases and expanded in the future, the system will have the flexibility to incorporate additional datastreams, monitoring locations, and external data sources.

The *Information Management Requirements Development Tool* (EPA, 2015f), a software package designed to help users define and prioritize requirements for an information management system, can be used to develop and document the requirements for an SWM information management system. This tool is populated with common functional and technical requirements for an information management system designed to support OWQM operations. It also provides a feature for generating a consolidated list of functional and technical requirements that can be used to develop design and/or bid documents as appropriate.

Section 7: Investigation and Response Procedures

Utilization of SWM data to guide utility decisions related to treatment operations and response to water quality anomalies requires an investigation into the cause of a change in source water quality. Procedures should be developed to guide these activities.

Investigation and response activities will be different for transient water quality anomalies versus sustained, long-term water quality changes. Thus, this section provides guidance on the development of two unique procedures, as briefly described below:

- **Investigation of and Response to SWM Alerts.** This procedure supports treatment optimization and detection of contamination incidents. Both of these design goals rely on alerts generated when a transient water quality anomaly is detected. The procedure involves the investigation of an alert to determine its cause and decide on immediate response actions to address a change in source water quality. Examples of response actions include adjusting treatment process settings to maintain optimized treatment or closing a source water intake if the source water has been contaminated. Guidance for developing this procedure is provided in Section 7.1.
- **Investigation of and Response to Long-Term Water Quality Changes.** This procedure supports monitoring of threats to long-term water quality. It involves the investigation of sustained changes to source water quality to determine the cause and inform the development of long-term strategies to manage significant changes in the source water quality baseline. An example of such a strategy is the implementation of a runoff control program to reduce contaminant loadings from non-point sources of pollution. Guidance for developing this procedure is provided in Section 7.2.

Once investigation and response procedures for the relevant design goals have been developed, they should be tested and refined before putting them into practice. Section 7.3 provides guidance on the steps necessary to implement these procedures, including training, ***preliminary operation***, and real-time operation.

7.1 Procedures for Investigation of and Response to SWM Alerts

For SWM design goals that rely on rapid response to transient changes in source water quality, such as treatment optimization and detection of contamination incidents, the SWM information management system should include a means of identifying an anomaly and generating an alert in real time (see Section 6.1). This section provides guidance on developing procedures for investigating and responding to SWM alerts. The elements of this procedure should cover the following:

- ***Alert Investigation Process.*** A detailed, sequential list of steps for investigating the cause of an alert, as well as information resources to support an investigation.
- **Response Actions to Optimize Treatment Processes.** A process for making treatment process adjustments in response to a change in source water quality to maintain optimal performance.
- **Response Actions for Detection of Contamination Incidents.** A process for making decisions in response to a ***possible*** source water contamination incident.
- **Roles and Responsibilities.** A list of all personnel who have a role in the investigation of an alert or a response to a verified water quality anomaly.

The *Template for Developing SWM Investigation and Response Procedures* includes editable process flow diagrams, checklists, and tables that can be used to build utility-specific SWM procedures. The template can be opened in Microsoft® Word by clicking the icon in the callout box.

This template provides an editable SWM Investigation and Response Procedure.

Examples of alert investigation tools that support these procedures (e.g., quick reference guide, alert investigation record) can be found in Section 5 of the *SRS Integration Guidance* (EPA, 2015b).

SWM Alert Investigation Process

An alert investigation process can be visually represented in a diagram that shows the progression of steps from beginning to end. This simplified representation of the process allows individuals with responsibilities for discrete steps to see how their activities support the overall investigation. **Figure 7-1** provides an example of an alert investigation process flow diagram.

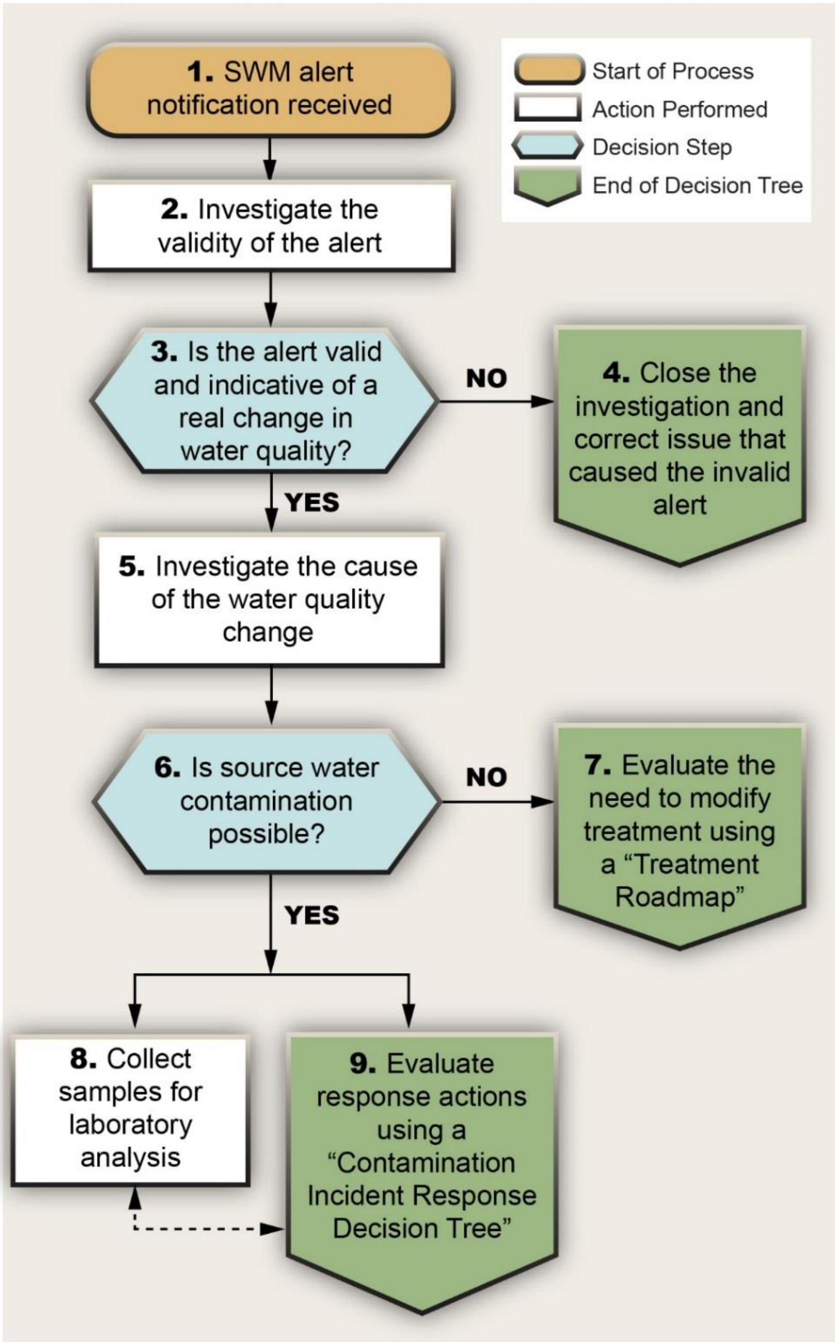


Figure 7-1. Example of an SWM Alert Investigation Process Flow Diagram

Table 7-1 describes the steps of the alert investigation process depicted in Figure 7-1 providing:

- Instructions for completing the step
- The individual or position assigned to complete the step
- Information resources that should be consulted during the step (see **Table 7-2** for descriptions)

Table 7-1. Example SWM Alert Investigation Process Description

ID	Name	Assigned To	Information Resources
1	**Designated personnel receive SWM alert notification.**	On-duty plant operator	• SWM user interface • Smartphone
2	**Investigate the validity of the alert.** Evaluate recent SWM station maintenance records and compare data from the alerting station against patterns typical of equipment malfunction. If possible, inspect the SWM station to determine whether it is functioning properly.	Instrument technician	• SWM station maintenance records • Sensor diagnostic tools • Data patterns for known instrument problems • Results of SWM station inspection
3	**Is the SWM alert valid and indicative of a real change in source water quality?** • **No** – Go to Step 4. • **Yes** – Go to Step 5.	On-duty plant operator	• Findings from Step 2 of the investigation
4	**Close the investigation.** The SWM alert is not due to a real water quality change. Correct the issue that caused the invalid SWM alert.	Instrument technician	• Findings documented in alert investigation record
5	**Investigate the cause of the water quality change.** Review available information resources to determine if the following caused the SWM alert: • Change in source supplying the treatment plant • Weather (e.g., rainfall) • Natural disasters (e.g., floods, fires) • Known pollution incident (e.g., spills)	Water quality specialist	• On-duty plant operator • National Weather Service or local weather stations • USGS online stream and watershed data • State environmental protection agency • Spill reporting hotline • Visual inspection of the waterbody
6	**Is source water contamination possible?** • **No** – Go to Step 7. • **Yes** – Go to Steps 8 and 9.	Water quality specialist	• Findings from Step 5 of the investigation
7	**Evaluate the need to modify treatment process settings to maintain optimal performance.** Follow separate procedure to decide if and how to adjust treatment process settings in response to the change in source water quality	On-duty plant operator	• Treatment Process Optimization Procedure • Treatment Roadmap
8	**Collect samples for field or laboratory analysis.** Follow separate procedure for collecting samples and deciding the analyses to conduct.	Water quality technician	• Sampling and analysis procedures
9	**Evaluate response actions to mitigate consequences of possible contamination.** Follow separate procedure to decide how to respond to the possible contamination incident.	Water quality supervisor	• Source Water Contamination Incident Response Procedure

Table 7-2. Typical Information Resources Useful during the Investigation of an SWM Alert

Resource	Description
SWM Station Maintenance Records	Information about recent maintenance activities, ongoing sensor issues, and previous sensor problems
Sensor Diagnostic Tools	Some sensors include diagnostic tools that evaluate sensor performance in real time
USGS Monitoring Stations	Results from USGS water quality and stream gauge monitoring stations in the watershed
Watershed Monitoring Programs	Results of watershed monitoring or surveillance programs (e.g., formal source water monitoring collaborative) as well as informal monitoring networks (e.g., citizen science initiatives, field observations)
National Weather Service	Current and recent weather conditions in the watershed and upstream areas that impact water quality in the watershed
Local Weather Monitoring Station	Data from weather monitoring stations located in the watershed can provide greater resolution than that from the National Weather Service
State Environmental Protection Agencies	Reports of ongoing environmental monitoring programs (e.g., for nutrient pollution, algal blooms), environmental emergencies (e.g., flooding, fires), and regulated discharges
Spill Reporting Hotlines	Reports of recent spills into the source water
Owner/Operator of an SW Threat	Alerts from spill detection systems, reports of recent incidents at an SW threat, and observations of current facility operations
Other Utility Information Management Systems	Information from operational control systems and work management systems that may provide information about utility activities that could have contributed to the source water quality change (e.g., a change in the source water supplying the treatment plant)

At the conclusion of the alert investigation process, the cause of the alert should be documented. **Table 7-3** lists and describes common causes of alerts. The causes are grouped into invalid alerts (triggered by something other than a true change in source water quality) and ***valid alerts*** (triggered by a true change in source water quality). Invalid alerts typically occur more frequently than valid alerts, especially during the initial phases of system startup.

Table 7-3. Common Causes of Invalid and Valid SWM Alerts

	Alert Cause	Description
Invalid Alerts	Equipment Issue	Inaccurate data values caused by a sensor maintenance activity, sensor malfunction, loss of power, or a data transmission error Flow-cells may produce inaccurate data if there is an interruption in the supply of water to the flow-cell Immersed sensors may produce inaccurate data if they are not submerged or are buried in sediment
	Data Analysis Issue	An artifact of the data analysis system in which an alert is generated even though data is accurate and within the normal range of values and variability
Valid Alerts	Change in Source Water Supply	For treatment plants that use multiple source waters, a water quality change caused by a change in the source supplying the plant
	Weather	A water quality change caused by a weather event (e.g., rainfall, snowpack melt)
	Natural Disaster	A water quality change, and possibly a contamination incident, caused by a natural disaster (e.g., flood, fire, landslide)
	Environmental Condition	A water quality change, and possibly a contamination incident, caused by an environmental condition (e.g., lake turnover, an algal bloom)
	Discharge	A contamination incident caused by a discharge from a storm water outfall, wastewater outfall, or other NPDES permit holder
	Spill	A contamination incident caused by a spill or unauthorized discharge from an SW threat (e.g., chemical storage facility, watercraft)

If an alert is determined to be valid but unrelated to contamination, the water quality change is evaluated to determine whether it could impact the ability of the utility's treatment plant to meet treatment targets.

If all reasonable causes of the water quality change that triggered the alert have been considered and ruled out, contamination is deemed possible. At this point, samples should be collected and analyzed in an attempt to confirm and identify the contaminant, and contamination incident response procedures should be activated.

Response Actions to Optimize Treatment Processes

If the investigation of a valid alert concludes that a source water quality change is not due to contamination, the change may still warrant a response for the purpose of treatment optimization (Step 7 in Figure 7-1). This response will typically be guided by a treatment roadmap or a treatment process model.

A ***treatment roadmap*** is a set of instructions for adjusting treatment processes to achieve treatment targets based on information generated by SWM. These instructions are typically developed using historical data from full-scale operations to establish relationships between optimal treatment process settings and a specific source water quality type. Typically, multiple water quality parameters (e.g., turbidity, TOC, alkalinity, pH) are used to define a source water quality type. The roadmap specifies the range of source water quality parameter values under which a set of treatment process settings would achieve defined treatment targets. A treatment process optimization procedure, such as that shown in **Figure 7-2**, guides the application of a treatment roadmap based on SWM data.

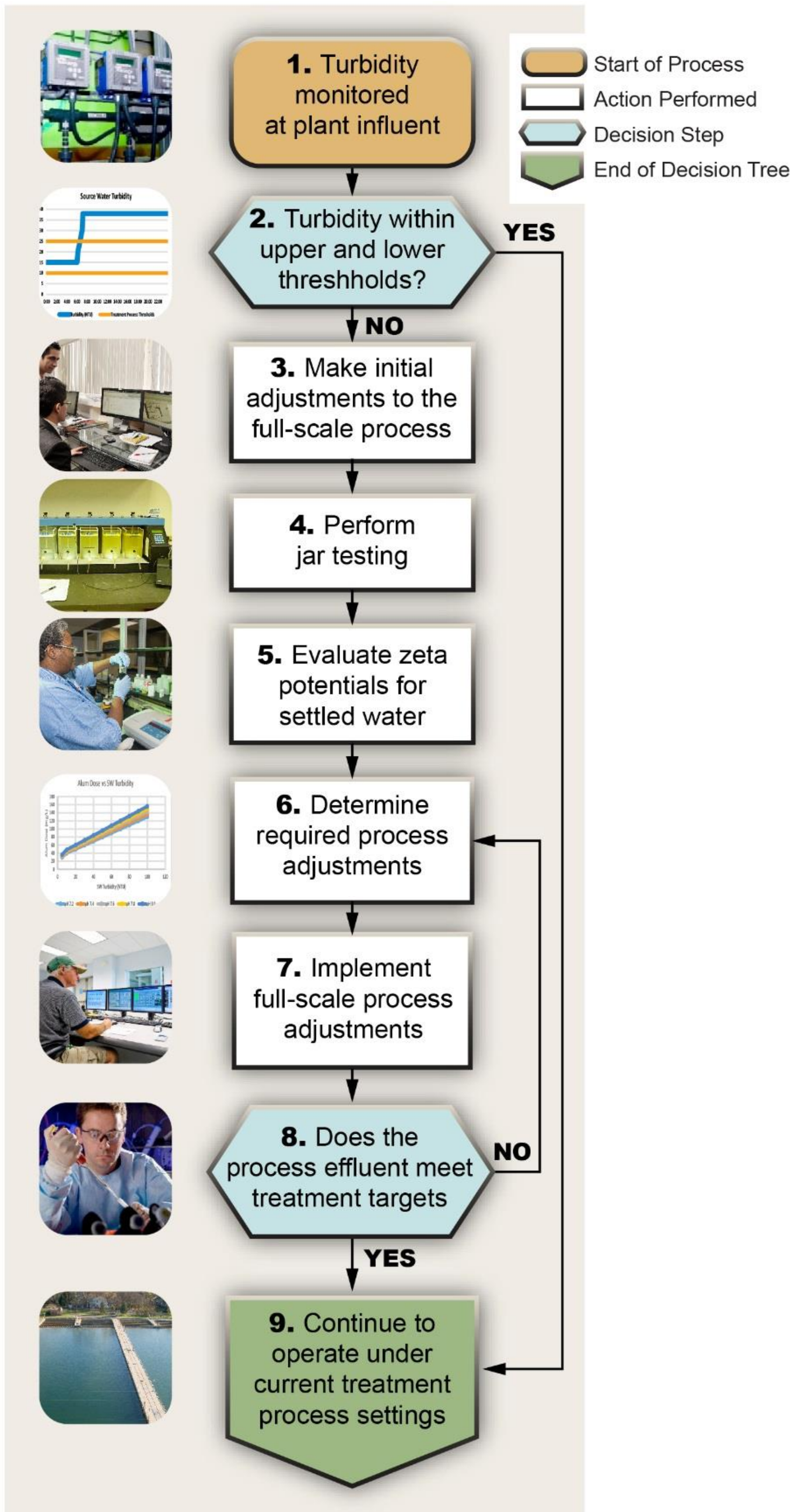


Figure 7-2. Example Treatment Optimization Procedure Flow Diagram

Table 7-4 describes the steps of the treatment process optimization procedure depicted in Figure 7-2 and lists responsibilities and information resources used during each step.

Table 7-4. Example Treatment Process Optimization Procedure Description

ID	Name	Assigned To	Information Resources
1	**Real change in turbidity detected and verified.**	On-duty plant operator	• SWM user interface • Smartphone
2	**Is the turbidity data within the thresholds for the current treatment process settings?** • **Yes** – Go to Step 9. • **No** – Go to Step 3.	On-duty plant operator	• SWM user interface • Treatment roadmap or standard operating procedure
3	**Make initial adjustments to the full-scale treatment process.** Using a treatment roadmap, standard operating procedure, or operator judgement, adjust treatment process settings to treat the new source water quality.	On-duty plant operator	• Treatment roadmap or standard operating procedure
4	**Perform jar testing.** Conduct jar tests with the source water using a range of doses likely to encompass the dose required to treat the new source water quality.	Water quality technician	• Jar testing standard operating procedure
5	**Evaluate zeta potentials for settled water.** Measure the zeta potential of the settled water from the jar tests and compare with the zeta potential of the settled water from the full-scale plant.	Water quality technician	• Zeta potential measurement procedure
6	**Determine required process adjustments.** Use the results from the jar tests and zeta potential measurements, along with the treatment roadmap, to refine the treatment process settings for the full-scale plant.	On-duty plant operator	• Results from Steps 4 and 5 • Treatment roadmap or standard operating procedure
7	**Implement full-scale process adjustments.** Implement the process adjustments determined in Step 6 and monitor the process to determine whether the process adjustments have brought the process back into the range of optimized performance.	On-duty plant operator	• Treatment roadmap or standard operating procedure
8	**Does the process effluent meet treatment targets?** • **Yes** – Go to Step 9. • **No** – Go to Step 6.	On-duty plant operator	• Results from treatment process monitoring
9	**Continue to operate under the current treatment process settings.**	On-duty plant operator	N/A

An alternative to a treatment process optimization procedure is use of a treatment process model, which can be used to predict optimal treatment process settings. If the treatment process model is connected to the SCADA system, it can be configured to automatically adjust treatment process settings to maintain optimal treatment.

Treatment process monitoring can be used to confirm that the treatment process adjustments have had the desired effect. Confirmation can be accomplished through measurement of water quality in the process effluent using online instrumentation or grab sampling. Additionally, visual inspection of flocculation (floc size) and sedimentation (floc carry over) can provide an operator with a sense of whether the process is operating properly. If treatment process monitoring indicates that treatment targets are not being met, processes can be further adjusted.

Response Actions for Contamination Incident Detection

If the investigation of a valid alert concludes that source water contamination is possible, S&A activities should be implemented in an attempt to confirm that contamination has taken place, identify the contaminant, and determine its concentration as noted in Step 8 of Figure 7-1. *Building Laboratory Capabilities to Respond to Drinking Water Contamination* (EPA, 2013b) provides guidance on identifying analytical methods and laboratories to test for contaminants of concern during a possible contamination incident.

As described in Figure 7-1, Step 9, response actions should be evaluated with respect to their ability to mitigate the consequences of a contamination incident to a utility and its customers. Decisions regarding an appropriate response to a source water contamination incident depend on a number of factors, such as:

- Confidence in the information indicating that the source water has been contaminated
- Whether the identity of the contaminant is known, and if known, the characteristics of the contaminant
- The risk that contaminated water presents to the utility and its customers
- Response options available to the utility
- Consequences of implementing response actions (e.g., impact on sanitation, firefighting, businesses, the local economy)

The logic for making these response decisions can be codified in a decision tree, as shown in the example in **Figure 7-3**.

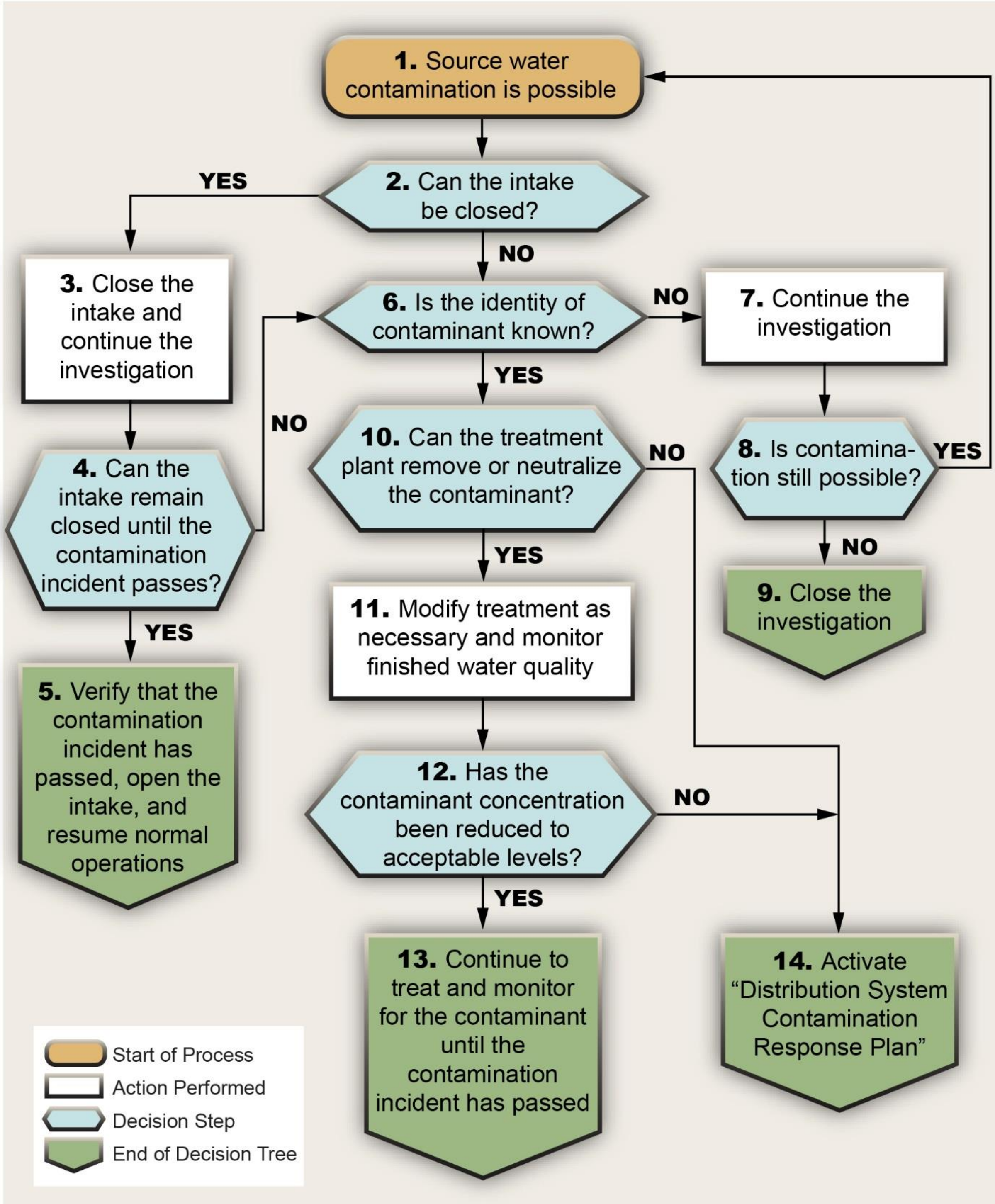


Figure 7-3. Example Source Water Contamination Incident Response Decision Tree

Table 7-5 describes the steps of the contamination incident response decision tree depicted in Figure 7-3 and lists responsibilities and information resources used during each step.

Table 7-5. Example Source Water Contamination Incident Response Decision Tree Description

ID	Name	Assigned To	Information Resources
1	**Source water contamination is possible.** And potentially contaminated water could enter the intake currently in use.	Water quality supervisor	• SWM user interface • Smartphone
2	**Can the intake be closed?** • **Yes** – Go to Step 3. • **No** – Go to Step 6.	Treatment plant supervisor	• Current raw water storage • Availability of an alternate source or intake
3	**Close the intake and continue the investigation.** Determine how long the intake can remain closed. Determine how long the potentially contaminated water will pose a risk to the treatment plant.	Treatment plant supervisor Water quality supervisor	• Current system storage and demand • Information about the contamination incident
4	**Can the intake remain closed until the contamination incident passes?** • **Yes** – Go to Step 5. • **No** – Go to Step 6.	Treatment plant supervisor	• Estimate of the time when storage will be exhausted • Estimate of the time until contamination incident passes the intake
5	**Verify that the contamination incident has passed, open the intake, and resume normal operations.** Collect samples at the intake and analyze them for suspected contaminants or indicators.	Water quality supervisor	• Results from sampling and analysis • Information about the contamination incident
6	**Is the identity of the contaminant known?** • **No** – Go to Step 7. • **Yes** – Go to Step 10.	Water quality supervisor	• Information about the contamination incident
7	**Continue the investigation.** Gather information and collect samples for analysis in an attempt to identify the contaminant (or rule out potential contaminants).	Water quality supervisor	• Information about the contamination incident • Investigation procedures and resources
8	**Is contamination still possible?** • **No** – Go to Step 9. • **Yes** – Go to Step 1.	Water quality supervisor	• Information about the contamination incident • Results from sampling and analysis
9	**Close the investigation.** Contamination has been ruled out. Close the investigation and return to normal operations.	Water quality supervisor	• Findings documented in alert investigation record
10	**Can the treatment plant remove or neutralize the contaminant?** • **Yes** – Go to Step 11. • **No** – Go to Step 14.	Treatment plant supervisor	• Water Contamination Information Tool • Treatability Database
11	**Modify treatment as necessary and monitor finished water quality.** Confer with stakeholders to determine an acceptable contaminant concentration in finished water. Collect samples from the finished water for analysis, and arrange for rapid laboratory analysis.	On-duty plant operator Water quality technician	• Health advisories • Treatment process standard operating procedures • Sampling and analysis procedures

ID	Name	Assigned To	Information Resources
12	**Has the contaminant concentration been reduced to acceptable levels?** • **Yes** – Go to Step 13. • **No** – Go to Step 14.	Water quality supervisor	• Results from sampling and analysis • Input from the drinking water primacy agency and other stakeholders
13	**Continue to treat and monitor the contaminant until the contamination incident has passed.** Collect samples in the plant influent and finished water and analyze for the target contaminant(s)	On-duty plant operator Water quality technician	• Information about the contamination incident • Results from sampling and analysis
14	**Activate the "Distribution System Contamination Response Plan"** If contaminated water has entered the distribution system, or is likely to, take actions to mitigate consequences and protect public health. These actions are documented in a Distribution System Contamination Response Plan.	Water quality supervisor	• Distribution System Contamination Response Plan • Information about the contamination incident • Results from sampling and analysis

The example incident response decision tree shown in Figure 7-3 considers three possible responses to source water contamination:

- **Closing the intake** can be the most effective response strategy by preventing contaminated water from coming into contact with utility infrastructure and customers. The ability to close an intake will depend on the availability of alternate raw water sources, availability of distribution system interconnections with neighboring utilities, distribution system storage, anticipated customer demand, and the expected duration of the contamination incident. Even if the intake can remain closed for only a short period, this action provides additional time to collect and analyze samples in order to identify the contaminant and determine its concentration. Ideally, the intake could remain closed until contaminated water no longer presents a risk to the utility or its customers.
- **Modifying treatment** to remove or neutralize the contaminant may be effective depending on the specific contaminant that is present and the treatment processes that are utilized. However, this response option should only be considered if the identity and approximate concentration of the contaminant are known. Resources such as the *Water Contaminant Information Tool* (EPA, 2016h) and the *Treatability Database* (EPA, 2016i) can be used to evaluate the potential of various treatment processes to remove or neutralize specific contaminants. If this response strategy is used, samples of finished water should be collected and analyzed to ensure that the contaminant has been removed.

HARMFUL ALGAL BLOOMS

EPA's website for Cyanobacterial Harmful Algal Blooms provides information and resources useful for treating HABs (EPA, 2016g).

- **Activating a *Distribution System Contamination Response Plan*** if there is a risk that contaminated water has or will pass into the distribution system at concentrations above acceptable levels. A Distribution System Contamination Response Plan is an annex or appendix to a utility's ***Emergency Response Plan*** (ERP), which guides utility decisions for responding to distribution system contamination. Potential response actions considered at this stage include isolation of portions of the distribution system to minimize the spread of contaminated water, diversion and flushing to remove contaminated water from the distribution system, and public notification and use restrictions to prevent customers from coming into contact with contaminated water. A template and guide for developing a Distribution System Contamination Response Plan can be found in *Guide for Developing a Distribution System Contamination Response Plan* (EPA, 2016j).

- **Activating a *Risk Communication Plan*** in anticipation of the public becoming aware of the incident, regardless of whether there is a potential risk to the public. Planning for risk communication should begin as soon as source water contamination is considered to be possible. Guidance for issuing public notification and communicating with customers during a drinking water contamination incident is provided in *Developing Risk Communication Plans for Drinking Water Contamination Incidents* (EPA, 2013c).

Roles and Responsibilities

Roles and responsibilities will need to be assigned for implementation of each activity during the investigation of and response to SWM alerts.

Alert investigation and response for treatment optimization will likely occur with some regularity, especially in surface water sources with frequent changes in water quality. As such, these procedures should be incorporated into routine operations, and roles and responsibilities for implementing these procedures should align with existing job functions to the extent possible. Leveraging existing expertise in this manner will reduce the amount of new training required and can result in increased acceptance of new responsibilities. **Table 7-6** provides an example of roles and responsibilities for investigating alerts and adjusting treatment processes for optimal performance.

Table 7-6. Example Roles and Responsibilities during SWM Alert Investigations and Treatment Optimization

Role	Description of Responsibilities
On-duty Plant Operator	• Receives notification of alerts • Assesses the validity of the alert and determines if it may be indicative of a real-water quality change • Notifies other utility personnel with a role in the investigation • Adjusts treatment processes to maintain optimal performance • Monitors treatment process to verify performance
Water Quality Technician	• Performs jar testing • Collects samples for field or laboratory analysis
Water Quality Specialist	• Reviews the source water quality data that generated the alert • Reviews the results of investigations for previous alerts with similar water quality patterns • Investigates potential causes of the alert
Instrument Technician	• Provides information about recent sensor issues or equipment maintenance • Conducts an on-site inspection of the SWM station that generated the alert to determine whether it is operating properly

Response actions implemented following a determination that source water contamination is possible may include significant deviations from normal operations (e.g., closing an intake) and thus will often require a higher level of authorization than is typical for normal operations. As such, members of a utility's senior management team will likely play a role in making decisions. **Table 7-7** provides an example of roles and responsibilities during response to source water contamination. Some of these roles and responsibilities may be covered, at least in a general manner, in a utility's ERP.

Table 7-7. Example Roles and Responsibilities during Response to Source Water Contamination

Role	Description of Responsibilities
Utility Director (Incident Commander)	• Decides if and when to implement the Incident Command System • Reviews and approves significant response decisions • Directs and oversees implementation of the response
Public Information Officer	• Implements the Risk Communication Plan • Coordinates communications among partners and stakeholders • Prepares for and implements public notification plans
Water Quality Supervisor	• Coordinates sampling and analysis efforts • Investigates the characteristics of confirmed or probable contaminants • Verifies proper QA/QC on field and laboratory results • Decides if and when to implement the Distribution System Contamination Incident Response Plan
Treatment Plant Supervisor	• Evaluates the ability of treatment processes to remove or neutralize a contaminant • Directs and oversees implementation of operational response actions such as closing the intake or modifying treatment
Water Quality Technician	• Collects samples for field or laboratory analysis • Supports monitoring of treatment process performance
Laboratory Personnel	• Conducts laboratory analyses on water samples

Because possible source water contamination incidents rarely occur, these procedures will be implemented infrequently. To maintain familiarity with these procedures, they should be exercised at least once per year. Resources to plan and implement exercises are described in Section 7.3.

7.2 Procedures for Investigation of and Response to Long-Term Source Water Quality Changes

For the SWM design goal of monitoring threats to long-term water quality, the SWM information management system should include a means of identifying statistically significant changes in the source water quality baseline. This section provides guidance for investigating and responding to a long-term change in source water quality. The elements of this procedure include:

- **Investigation Framework.** A process that guides the investigation into the cause of a sustained change in source water quality.
- **Response Framework.** A process used to identify, evaluate, and select strategies to manage a sustained degradation in source water quality.
- **Roles and Responsibilities.** A list of all personnel who have a role in the investigation of or response to a sustained change in source water quality.

Investigation Framework

Monitoring threats to long-term water quality involves the analysis of source water quality trends over the course of multiple years to identify sustained, and potentially irreversible, changes in the source water quality baseline. This is accomplished through the routine analysis of SWM data using the techniques described in Section 6.1. The purpose of the investigation framework is to attribute water quality changes to a cause, which will inform the development of mitigation strategies.

The investigation considers the locations where a long-term change in source water quality has occurred to determine the geographic extent of the change. Furthermore both the locations and the parameters that have changed can be useful in identifying SW threats responsible for a degradation in water quality. Identification of the cause(s) of a sustained change in source water quality is necessary for evaluating the impact of the change on utility operations and developing effective mitigation strategies. This process will require consideration of a variety of information resources, such as those listed in **Table 7-8**.

Table 7-8. Typical Information Resources Useful to the Investigation of Sustained Change in Source Water Quality

Resource	Description
National Weather Service	Trends in key weather variables (e.g., temperature, precipitation, cloudy/sunny days) over the past several years
Local Weather Monitoring Station	If the data available from the National Weather Service or other weather services is insufficient, data from weather monitoring stations located in the watershed may provide the necessary level of detail.
Climate Resilience Evaluation and Awareness Tool (CREAT)	CREAT uses climate models to predict changes in key weather variables under various climate change scenarios. The information generated by CREAT can be used as inputs to hydrology models, which in turn may be used to estimate future changes in source water quality (EPA, 2012).
Facility Owner/Operators	Discharge data over the past several years, including flow and quality
Watershed Surveys	Watershed surveys (conducted by foot, vehicle, or drone), informed by data generated through SWM, to identify potential sources of pollution.
Focused Sampling and Analysis	Sampling programs designed to provide a full characterization of water quality in a specific area over a limited period of time, informed by data generated through SWM
USGS Watershed Monitoring Data	Basic water quality parameters (e.g., pH, temperature, specific conductance) along with flow and depth data over the past several years
Watershed Monitoring Programs	Results of watershed monitoring or surveillance programs (e.g., formal source water monitoring collaborative) as well as informal monitoring networks (e.g., citizen science initiatives, field observations)
Watershed Stakeholders	Information from watershed stakeholders and partners about the health, uses, and features of the watershed
Land-use Maps and Satellite Imagery	Graphical representations of land use in the watershed, viewed over the past several years
Land-use Projections	Documentation of planned uses of land areas in the watershed over the next several years
Physical Changes to the Source Waterbody	Man-made or natural activities that change the physical condition of the waterbody, such as dredging operations and rechanneling

Response Framework

Identification of the probable cause(s) of a long-term degradation in source water quality can provide the basis for developing a mitigation or restoration strategy. These strategies may include efforts to slow the deterioration of the source water, reverse the deterioration, or adapt to the new source water quality baseline. While the most effective strategy will depend on the specifics of the SW threats, the watershed, and utility resources, a few potential strategies include:

- Reducing contaminant loadings from specific point sources of pollution, either by reducing flow or reducing contaminant concentrations prior to discharge
- Reducing contaminant loadings from non-point sources of pollution through strategies such as runoff control programs
- Convincing local authorities and land owners to alter their land-use policies to reduce contamination in the watershed
- Implementing additional drinking water treatment capable of handling the projected source water quality
- Developing a new drinking water source

Approaches to mitigate a deterioration in source water quality will be strategic and may be implemented over the course of several years. These strategies should be incorporated into existing source water protection planning activities. A number of resources are available to support local source water protection initiatives (EPA, 2016k; SWC, 2016).

After a mitigation strategy has been implemented, data from SWM can be used to assess the efficacy of the strategy. If the desired change is not realized within a reasonable amount of time, the strategy may need to be altered or discontinued.

Roles and Responsibilities

Roles and responsibilities will need to be assigned for implementation of each activity necessary to monitor long-term water quality. Implementation of these activities will require front-line personnel to implement investigation activities, planners to consider potential mitigation strategies, senior management to decide which mitigation strategies to implement, and stakeholders to commit to strategies that are outside of the utility's control. **Table 7-6** provides an example of roles and responsibilities for monitoring of threats to long-term water quality. While many of these roles are assumed by utility personnel, other stakeholders may be engaged, such as managers of recreational uses of the waterbody, land use managers, local regulatory authorities, and government agencies (e.g., U.S. Army Corps of Engineers).

Table 7-9. Example Roles and Responsibilities for Monitoring Threats to Long-Term Water Quality

Role	Description of Responsibilities
Utility Director	• Selects strategies to implement to mitigate the effects of a degradation in source water quality • Ensures the availability of sufficient resources to implement the selected strategies
Water Quality Manager	• Manages the analysis of long-term trends in source water quality • Oversees the investigation into the cause of a sustained change in source water quality • Evaluates strategies for mitigating the effects of a degradation in source water quality
Water Quality Specialist	• Performs detailed review of long-term trends in source water quality • Oversees water quality or watershed surveys to investigate the cause of a sustained degradation in source water quality • Considers the results of climate, weather, and water quality modeling and forecasting when assessing the cause of a sustained change in source water quality
Plant Supervisor	• Evaluates the ability of existing or modified treatment processes to adequately treat the projected source water quality baseline
Engineers and Planners	• Evaluates the ability of new, or significantly retrofitted, treatment processes to adequately treat the projected source water quality baseline • Provides information on long-term programs and develops requirements for protecting the source water
Community and Stakeholders	• Provides input to, and collaborate on, long-term programs to protect source water quality.

Due to the long-term, strategic nature of these activities, implementation of this procedure will likely be intermittent and sequential. For example, an investigation into the potential causes of a sustained change in source water quality will occur only after analysts have confirmed the trend. Furthermore, consideration of possible mitigation strategies will occur only after the cause of the change in source water quality has been identified and is determined to have significant implications for utility operations.

7.3 Implementation of SWM Procedures

This section describes a suggested process for putting SWM procedures into practice. Recommended activities include:

- Training and Exercises
- Preliminary Operation
- Real-time Operation

Training and Exercises

Training and exercises are necessary to ensure that all utility personnel with a role in SWM investigation and response procedures are aware of their responsibilities. It is suggested that training on these procedures include the following:

- An overview of the purpose and design of SWM
- A detailed description of the investigation and response procedures
- A review of checklists, quick reference guides, user interfaces, and other tools available to support alert investigation and response activities
- Instructions for documenting the results of alert investigations

Section 6 of *SRS Integration Guidance* (EPA, 2015b) provides general guidance on implementing a training and exercise program. In general, classroom training is used first to orient personnel to their responsibilities during implementation of new procedures. Once they are comfortable with the procedures, drills and exercises provide the opportunity to practice implementing their responsibilities in a controlled environment. The *SRS Exercise Development Toolbox* (EPA, 2016l) is an interactive software program developed to assist utilities in the design and execution of exercises.

Preliminary Operation

Following initial training, a period of preliminary operation allows personnel to practice their responsibilities before transitioning to real-time operation. For example, personnel can be asked to investigate alerts in batches as they have time, not necessarily as alerts are generated. The duration of preliminary operation will depend on how quickly personnel become proficient with operating the system and implementing their responsibilities under the procedures, but a minimum duration of six months is recommended.

One useful way to provide practice and support during this period is to hold regular meetings with all investigators to discuss recent data and alerts. It is generally most effective if participants are asked to perform specific analyses or alert investigations before each meeting and then discuss conclusions, observations, insights, and challenges as a group. The frequency of these meetings would likely decrease as the group gains more experience in conducting investigations.

Preliminary operation provides an opportunity for investigators to clarify responsibilities, streamline the procedures, refine alert investigation tools, and better integrate SWM responsibilities into existing job functions. Also, the rate of invalid alerts may be higher than desired during preliminary operations, but this experience can be used to fine-tune the ADS to achieve the desired balance between detection capabilities and occurrence of invalid alerts.

Real-Time Operation

During real-time operation, personnel are expected to fully execute their responsibilities and investigate all alerts as they are generated. Also, SWM response procedures are implemented if an alert is determined to be valid. The transition from preliminary to real-time operation, including timing and expectations for how investigations are performed and documented, should be clearly communicated to all personnel with a role in SWM. Furthermore, sufficient time in the workday must be allocated for personnel to investigate alerts as they are generated. If the ADS is properly configured to minimize the occurrence of invalid alerts, this time commitment will be minimal.

As part of real-time operation, investigation and response procedures may need to be updated to maintain their usefulness. Recommendations for updating procedures include:

- Designate one or more individuals with responsibility for maintaining alert investigation materials
- Establish a review schedule (an annual review should suffice in most cases)
- Review the record of alert investigations, conduct tabletop exercises, and solicit feedback from investigators to identify necessary updates
- Track and review the time required to complete investigations and implement response actions, and update the procedures if times are not acceptable
- Establish a protocol for submitting and tracking change requests

Section 8: Example of SWM Design

This section presents a hypothetical example of a comprehensive SWM design process using the principles presented in the previous sections of this document. Section 8.1 presents the overall design approach, while Sections 8.2 to 8.6 describe each design element.

8.1 Design Approach

A hypothetical drinking water utility, Anytown Water, uses river water and a storage reservoir as its sources. The utility uses conventional treatment processes that include pretreatment (PAC and permanganate), coagulation/sedimentation (ferric chloride), filtration (dual media), and disinfection (free chlorine).

As part of its commitment to producing high-quality drinking water for its customers, Anytown Water wants to use SWM data to optimize its treatment processes. To do so, the following treatment targets were established:

- **Turbidity Target.** Achieve turbidity levels in the filter effluent of 0.10 Nephelometric Turbidity Units (NTU) 95 percent of the time. This treatment target exceeds regulatory requirements and is intended to improve barriers to *Cryptosporidium* and *Giardia*, as well as remove particles that could shield other pathogenic organisms from free chlorine during the disinfection process.
- **TOC Removal Target.** Achieve 50 percent TOC reduction through enhanced coagulation, which helps the utility to meet its goal to keep total trihalomethane at or below 75 percent of the maximum contaminant level.

Anytown Water also recognizes the potential for spills and other contamination threats in the source water due to several industries located near the river banks upstream of the drinking water intake. Thus, the utility is interested in using SWM data to provide timely detection of contamination incidents. Additionally, the utility wants to monitor long-term trends in source water quality to inform the selection of source water protection strategies and evaluate the efficacy of those strategies that are implemented.

Based on these considerations, the utility is designing SWM to support optimization of treatment processes, detection of contamination incidents, and monitoring threats to long-term water quality. Performance objectives were established for operational reliability, information reliability, and sustainability, which serve as metrics for evaluating the effectiveness of SWM implementation.

To inform the design of SWM for the purposes of detecting contamination incidents and monitoring threats to long-term water quality, the project team used DWMAPS to identify stationary threats and consulted with the United States Coast Guard to identify potential mobile threats on the river source. Through these resources, more than two dozen potential SW threats were identified, and the characteristics described in Section 2.3 were gathered and documented for each threat. The project team conducted a risk assessment that considered short-term risks due to contamination incidents and threats to long-term water quality. The results of the risk assessment produced a list of prioritized SW threats that could cause (1) a short-term contamination incident and (2) a long-term degradation in source water quality. The assessment identified a total of five high-priority SW threats, three near the river and two near the reservoir, as shown in **Figure 8-1**. Summaries of the risk assessment results for high-priority SW threats of source water contamination and long-term source water quality are presented in **Tables 8-1** and **8-2**, respectively.

Figure 8-1. Location of High-Priority SW Threats for Anytown Water

Table 8-1. High-Priority SW Threats of Source Water Contamination for Anytown Water

ID	SW Threat	Potential Contaminants	Rationale for Risk Assessment Scoring	Risk Score
A	Commercial Barges (Mobile Threat - River)	• Hydrocarbons • Unknown Organics • Unknown Inorganics	Large volumes of fuel and unknown cargo are stored on commercial barges and transported along the river. **Likelihood.** High: While a limited number of accidental spills have been reported along the river upstream of the utility intake over the past decade, commercial barge traffic has doubled over the past two years, increasing the probability of accidents and spills. **Vulnerability.** High: The treatment plant can remove hydrocarbons at concentrations in the sub mg/L range, however, higher concentrations would likely overwhelm and pass through treatment. Furthermore, the ability of the treatment plant to remove unknown contaminants that could be in the cargo is unknown. **Consequence.** High: A high probability exists that at least some of these contaminants could damage utility infrastructure or pass through to the customer and create a potential public health issue. Furthermore, hydrocarbons would be very difficult to clean from the distribution system and premise plumbing systems, and remediation would likely be difficult, expensive, and lengthy.	35

ID	SW Threat	Potential Contaminants	Rationale for Risk Assessment Scoring	Risk Score
B	Petrochemical Facility (Stationary Threat - River)	• Hydrocarbons • Unknown Organics	Large volumes of fuel oil, diesel fuel, and smaller quantities of unknown organic compounds are stored in tanks at the facility. **Likelihood.** Low: Effective secondary containment surrounding the tanks should contain a spill from a leaking tank. However, there is still a slight chance that spilled chemicals could make their way into the river, just one mile upstream of the intake. **Vulnerability.** Moderate: The treatment plant could remove the hydrocarbons at concentrations in the sub mg/L range; higher concentrations would likely overwhelm and pass through treatment. **Consequence.** High: A high probability exists that at least some of these contaminants could damage utility infrastructure or pass through to the customer and create a potential aesthetic problem. Furthermore, hydrocarbons would be very difficult to clean from the distribution system and premise plumbing systems, and remediation would likely be difficult, expensive, and lengthy.	25
C	Wastewater Outfall (Stationary Threat - River)	• Pathogens • Unknown Organics • Unknown Inorganics	A failure at the wastewater treatment plant could result in large volumes of untreated wastewater entering the river. **Likelihood.** Low: Wastewater treatment failures are infrequent and safeguards that prevent discharge of untreated wastewater are in place. **Vulnerability.** Moderate: The existing treatment processes are not equipped to handle the high contaminant loads that would result from a large discharge of untreated wastewater. **Consequence.** Moderate: While contaminant concentrations would be reduced through treatment, it is likely that some potentially harmful contaminants would pass through the drinking water treatment plant and create a potential public health issue.	20
D	Pesticide Storage Tank (Stationary Threat - Reservoir)	• Pesticides	A significant volume (100-1,000 gallons) of pesticide is stored onsite at an agricultural facility near the reservoir. **Likelihood.** Low: The agricultural facility has secondary containment around the storage tanks, and the tanks are rarely full. **Vulnerability.** Low: The treatment plant may have the capacity to handle the increased contaminant load, depending on the concentration of pesticide in the source water at the intake. **Consequence.** Moderate: Pesticides passing through the drinking water treatment plant could create a potential public health issue.	15

Table 8-2. High-Priority SW Threats to Long-Term Source Water Quality for Anytown Water

ID	SW Threat	Potential Contaminants	Rationale for Risk Assessment Scoring	Risk Score
C	Wastewater Outfall (Stationary Threat - River)	• Pathogens • Unknown Organics • Unknown Inorganics	Increasing volumes of treated wastewater effluent are projected due to increased residential and industrial growth over the next five years. **Likelihood.** High: Models project that these increased discharge volumes will degrade water quality in the river, leading to increased loading of pathogens, unknown organics, and unknown inorganics. **Vulnerability.** Low: The treatment plant may have the capacity to treat the degraded source water, although some contaminants may present a challenge. Also, the flow in the river, and thus the potential for dilution of the treated wastewater effluent, may change due to the effects of climate change. **Consequence.** Moderate: Failure to effectively respond to the degraded water quality could result in Safe Drinking Water Act (SDWA) violations and water that is unacceptable to customers.	30
E	Agricultural Runoff (Stationary Threat - Reservoir)	• Ammonia • Nitrates and Nitrites • Phosphorous • Pesticides	The cumulative effects of agricultural runoff could irreversibly degrade water quality in the reservoir. **Likelihood.** Low: The reservoir has been engineered to minimize runoff into the reservoir. **Vulnerability.** Moderate: It would be difficult to restore the reservoir to acceptable quality if accumulated contaminants from runoff started eutrophication. **Consequence.** Moderate: Impaired source water would likely increase the occurrence of harmful algal blooms and other serious water quality problems. Modifications to the treatment plan may be necessary to maintain acceptable finished water quality.	20

Due to constraints on available resources, both financial and personnel, Anytown Water recognized that its SWM program would need to be implemented in phases over several years. However, the utility wanted to realize benefits as soon as possible while building toward a long-term vision for SWM, so it ensured that the system would be capable of supporting all three design goals, to some degree, in the first phase. SWM stations installed in latter phases would expand the ability of SWM to support contamination incident detection and monitoring of threats to long-term water quality.

8.2 SWM Location Selection

The SWM locations selected to meet the design goals are shown in **Figure 8-2.**

Figure 8-2. SWM Locations for Anytown Water

The utility's blending facility, shown in Figure 8-2, was evaluated as a potential SWM location to support treatment process optimization. To ensure that this location would provide SWM data in sufficient time to make treatment process adjustments, the project team compared the hydraulic travel time between the blending facility and the pretreatment contact basin with the time required to change pretreatment operations. Under typical production, the hydraulic travel time between the blending facility and the pretreatment process basin was calculated to be 13 minutes. It was also determined that operators can investigate and validate an SWM alert and adjust pretreatment in 10 minutes or less. Thus, monitoring at the blending facility provides sufficient time to make a process change and was selected as SWM Location 1 to support treatment process optimization.

The project team evaluated additional SWM locations to support detection of contamination incidents. The critical detection point on the river was determined to be 0.25 miles upstream of the river intake structure, which would provide sufficient time to close the intake should a contamination incident be detected upstream of this point. To provide additional response time, the utility placed SWM Location 2 approximately 0.75 miles upstream of the river intake, which is both upstream of the critical detection point and downstream of SW Threats B and C (petrochemical facility and wastewater outfall). SWM Location 3 was located inside the river intake structure to provide monitoring for SW Threat A, which represents mobile threats that could cause a contamination incident between SWM Location 2 and the river intake. While a detection at Location 3 does not provide sufficient time for an optimal response, consequences could still be mitigated if a response is implemented following a detection at this location.

The project team placed SWM Location 4 at the reservoir intake structure, as shown in Figure 8-2, to monitor SW Threat D (pesticide storage tank). The flow from the reservoir to the intake structure is low enough such that monitoring at SWM Location 4 provides adequate time to close the reservoir intake if a contamination incident was detected at that location.

SWM Locations 2, 3, and 4 can also be used to monitor threats to long-term water quality. Locations 2 and 3 monitor SW Threat C (wastewater outfall), while Location 4 monitors SW Threat D (agricultural runoff).

8.3 SWM Parameter Selection

SWM parameters were selected based on the design goals established by Anytown Water. For the treatment optimization design goal, the project team determined it would be necessary to monitor the parameters shown in **Table 8-3** to meet the treatment targets.

Table 8-3. Parameters Selected to Support Treatment Process Optimization for Anytown Water

SWM Location 1 (Blending Facility)	
SWM Parameter	**Rationale for Parameter Selection**
DOC/TOC	Source water DOC/TOC concentration data is needed to determine the coagulant dose necessary to achieve the turbidity and TOC removal targets.
Turbidity	Source water turbidity concentration data is needed to determine the coagulant dose necessary to achieve the turbidity and TOC removal targets.
pH	Source water pH data is needed to determine the acid dose required to reach the pH necessary to achieve the turbidity and TOC removal targets.
Temperature	Temperature impacts the equilibrium and kinetics of the chemical processes that drive coagulation, with higher temperatures generally increasing the effectiveness of coagulation.

To detect contamination incidents and monitor threats to long-term water quality, parameter selection was driven by the high-priority SW threats identified during the risk assessment. Parameters were selected based on the contaminants associated with each SW threat and are listed in **Table 8-4**.

Table 8-4. Parameter Selected to Detect Contamination Incidents and Monitor Threats to Long-Term Water Quality for Anytown Water

SWM Location 2 (River)		
SWM Parameter	**Threat ID**	**Rationale for Parameter Selection**
Hydrocarbons	A, B	Hydrocarbon monitoring can provide a direct measure of hydrocarbon concentrations in the source water.
Spectral Absorbance	A, B, C	Many chemicals absorb in the spectral range of 250-450 nm. A change in spectral absorbance can indicate an increase in the concentration of chemical contaminants in the source water.
DOC/TOC	A, B, C	An increase in DOC/TOC can indicate contamination with an organic chemical.
Specific Conductance	A, C	Some chemicals have charged functional groups that can dissociate and form ionic species when dissolved in water. A change in specific conductance could be an indicator of the presence of unknown chemicals in the source water.
Turbidity	C	An increase in turbidity results from an increase in the concentration of suspended solids, which can be an indicator of potential microbiological contamination.
Ammonia	C	Ammonia can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Nitrates and Nitrites	C	Nitrates and nitrites can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Ortho-phosphates	C	Orthophosphates can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Photosynthetic Pigments	C	Photosynthetic pigments can provide a direct indication of algal activity in the source water.
SWM Location 3 (River Intake)		
SWM Parameter	**Threat ID**	**Rationale for Parameter Selection**
Hydrocarbons	A, B	Hydrocarbon monitoring can provide a direct measure of hydrocarbon concentrations in the source water.
Spectral Absorbance	A, B, C	Many chemicals absorb in the spectral range of 250-450 nm. A change in spectral absorbance can indicate an increase in the concentration of chemical contaminants in the source water.
DOC/TOC	A, B, C	An increase in DOC/TOC can indicate contamination with an organic chemical.
Specific Conductance	A, C	Some chemicals have charged functional groups that can dissociate and form ionic species when dissolved in water. A change in specific conductance could be an indicator of the presence of unknown chemicals in the source water.
Turbidity	C	An increase in turbidity results from an increase in the concentration of suspended solids, which can be an indicator of potential microbiological contamination.
Ammonia	C	Ammonia can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Nitrates and Nitrites	C	Nitrates and nitrites can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Ortho-phosphates	C	Orthophosphates can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Photosynthetic Pigments	C	Photosynthetic pigments can provide a direct indication of algal activity in the source water.

SWM Location 4 (Reservoir)		
SWM Parameter	**Threat ID**	**Rationale for Parameter Selection**
Spectral Absorbance	D	Many organic chemicals, including pesticides, absorb in the spectral range of 250-450 nm. A change in spectral absorbance can indicate an increase in the concentration of organic contaminants that could result from fuel or cargo spills in the source water.
DOC/TOC	D	An increase in DOC/TOC can indicate contamination with an organic chemical, including pesticides.
Ammonia	E	Ammonia can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Nitrates and Nitrites	E	Nitrates and nitrites can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Ortho-phosphates	E	Ortho-phosphates can provide a direct measure of nutrients that can trigger an algal bloom if in sufficient concentration.
Photosynthetic Pigments	E	Photosynthetic pigments can provide a direct indication of algal activity in the source water.

8.4 SWM Station Design

SWM station design involved the selection of sensor technologies, a sampling approach, power distribution, a communications solution, and packaging for the SWM locations. Station design was informed by the locations and parameters selected in previous steps, as well as the performance objectives established for SWM.

A key aspect of SWM station design is the selection of sensor technologies to measure the selected parameters. The comparison methodology presented in *Framework for Comparing Alternative Water Quality Surveillance and Response Systems* (EPA, 2015d) was used to evaluate candidate sensor technology options for the selected parameters at each location. This comparison considered both lifecycle costs and the capability of each alternative. The lifecycle costs included capital, maintenance, and replacement costs over an established period of time to enable technology comparison on an equal basis. To objectively assess the capability of each alternative, the following evaluation criteria were developed:

- **Ability to measure a parameter and provide reliable data.** This criterion included a review of existing information and an evaluation of sensor performance in the installed environment. It also considered the ability of sensors to reliably measure the expected range of parameter values. Other performance indicators that were considered include accuracy, precision, resolution, measurement frequency, fouling potential, and interference.
- **Integration within current systems.** The degree to which a particular technology fits with existing systems and within current training, quality assurance, maintenance, and procurement programs.
- **Potential for future applications.** This criterion includes a technology's ability to monitor parameters that can be leveraged for future phases of SWM implementation or other water quality monitoring applications.

The project team compared sampling, power distribution, communication, and packaging options for each station design. The station designs for SWM Locations 2, 3, and 4 were more complex compared to SWM Location 1 due to the number of parameters selected to support the design goals and the lack of existing infrastructure at the installation sites (e.g., SWM Location 2 is positioned on the bank of the river where grid power and wired communications are unavailable).

A summary of the station designs for each SWM location is provided in **Table 8-4**. The summary includes the selected parameters, instrumentation, sampling, power distribution, communication, and packaging for each station. To facilitate procurement, fabrication, and maintenance, a common suite of instruments was used across the four SWM stations. A local computer was also installed within each station to manage operation of sensors and station equipment and allow operators to perform remote diagnostics on the spectral absorbance instruments.

Table 8-5. Final SWM Station Designs for Anytown Water

SWM Station Element	SWM Location 1 (Blending facility)	SWM Location 2 (Bank of river)	SWM Location 3 (River intake)	SWM Location 4 (Reservoir intake)
Instrumentation • **Parameters**	Absorption Spectrometry • DOC/TOC • Turbidity ISE • pH • Temperature	Absorption Spectrometry • DOC/TOC • Turbidity • Nitrogen species • Spectral absorbance • Hydrocarbons ISE • pH • Temperature • Ammonia Colorimetry • Ortho-phosphates Fluorometry • Photosynthetic pigments Conductivity Cell • Specific conductance	Absorption Spectrometry • DOC/TOC • Turbidity • Nitrogen species • Spectral absorbance • Hydrocarbons ISE • pH • Temperature • Ammonia Colorimetry • Ortho-phosphates Fluorometry • Photosynthetic pigments Conductivity Cell • Specific conductance	Absorption Spectrometry • DOC/TOC • Nitrogen species • Spectral absorbance ISE • pH • Temperature • Ammonia Colorimetry • Ortho-phosphates Fluorometry • Photosynthetic pigments
Sampling	Sample line fitted with a pressure regulator to carry water from the effluent pipe from the blending facility to a flow-cell at the SWM station	Pump used to transfer water from the river to a flow-cell, and a drain line to collect the waste stream (which contained reagents from the colorimeter)	Sample line fitted with a pressure regulator to carry water from effluent pipe from the intake facility to a flow-cell, and a drain line to collect the waste stream (which contained reagents from the colorimeter)	Sample line fitted with a pressure regulator to carry water from effluent pipe from the intake facility to a flow-cell, and a drain line to collect the waste stream (which contained reagents from the colorimeter)
Power Supply and Distribution	Existing grid power	Solar power	Existing grid power	Existing grid power
Communications	Fiber optics	Wireless	Fiber optics	Fiber optics
Packaging	Wall-mounted rack	Enclosed station	Enclosed station	Enclosed station

8.5 Information Management and Analysis

Anytown Water decided to use a dedicated SWM information management system rather than leverage its existing SCADA system. A key driver behind this decision was that the SCADA historian could not provide appropriate storage for spectral array data, which will be collected by three of the four SWM stations, as shown in Table 8-5. This dedicated system provides storage using a PostgreSQL database and three displays: one dedicated to treatment plant optimization, one dedicated to detection of contamination incidents, and the third for monitoring threats to long-term water quality.

For the treatment process optimization design goal, the display shows time-series plots of TOC, turbidity, pH, and temperature data, as well as their associated treatment optimization thresholds. Threshold values for DOC/TOC, turbidity, pH, and temperature were determined by analyzing one year of historic data to characterize normal variability in these parameters, the results of jar tests, and full-scale experience to determine treatment process settings necessary to achieve optimal performance for different source water quality types. Once a threshold is exceeded, the SWM information management system generates an alert to notify the operator that treatment process settings may need to be adjusted to maintain optimal treatment process performance.

For detection of contamination incidents, an ADS operates on the local computer at each SWM station to analyze the station water quality data in real time and generate alerts if an anomaly is detected. These alerts, along with the sensor data, are transmitted to the SWM information management system for presentation on the display and storage in the PostgreSQL database. The alerts are also transmitted to mobile communication devices assigned to key personnel.

For monitoring of threats to long-term water quality, SWM data is pulled quarterly from the PostgreSQL database and analyzed using statistical analysis tools available through the SWM information management system. Each quarter, a dedicated group of utility personnel with expertise in water quality, source water management, and statistics meet to review the data. A variety of analysis techniques, such as those listed in Table 6-1, are used to investigate trends and correlations in the data. The analysis is cumulative, building an understanding of long-term changes and trends over multiple years.

8.6 Investigation and Response Procedures

To support SWM operations, Anytown Water developed two procedures: (1) SWM Alert Investigation and Response Procedure and (2) Investigation and Response Procedure for Long-Term Water Quality Changes.

The SWM Investigation and Response Procedure supports treatment process optimization and detection of contamination incidents, and includes the following elements:

- An alert investigation process flow diagram, which presents the steps to identify the most likely cause of an alert and decide whether response actions are necessary
- An alert investigation checklist, which documents the information resources that should be checked and actions that should be taken over the course of an alert investigation
- A treatment roadmap, which prescribes adjustments to chemical dosing and loading rates to maintain optimal performance from pretreatment through disinfection
- A source water contamination incident response decision tree, that summarizes the decision logic and criteria for implementing various response actions if source water contamination is possible
- A list of key personnel and their contact information along with a description of their responsibilities under this procedure

The Investigation and Response Procedure for Long-Term Water Quality Changes supports monitoring of threats to long-term water quality and development of mitigation strategies, and includes the following elements:

- A framework for investigating the cause of a long-term change in source water quality, including the statistical methods, visualization techniques, analysis methods, and information resources used to understand trends in source water quality by location and by parameter
- A framework for making decisions and strategic plans to respond to a significant change in source water quality, including resources to help establish the cost, feasibility, and efficacy of various mitigation strategies
- A list of key personnel and their contact information along with a description of their responsibilities under this procedure

Section 9: Case Studies

Various organizations across the world have implemented SWM systems in response to threats to source water quality such as shale oil and gas drilling in watersheds, harmful algal blooms, spills, or other forms of source water contamination. This section provides case studies of existing SWM systems that have been implemented to address the three design goals described in Section 2. These case studies include SWM systems designed by individual drinking water utilities as well as watershed-scale systems.

9.1 Greenville Water

Greenville Water supplies drinking water to almost 500,000 customers in the Upstate region of South Carolina, drawing water from Table Rock Reservoir, North Saluda Reservoir, and Lake Keowee. The design goal for Greenville's SWM system is to detect contamination incidents.

> **AT A GLANCE**
>
> **Design goals:** To detect contamination incidents
>
> **Monitoring locations:** 3
>
> **Parameters:** pH, specific conductance, and turbidity

The water quality in each of Greenville's sources is relatively constant, which simplifies the process of identifying a potential contamination incident. To achieve real-time monitoring of the sources, an SWM station was installed at the treatment plant intake located on each source water. **Figure 9-1** provides an overview of Greenville's SWM locations. Each station monitors pH, specific conductance, and turbidity.

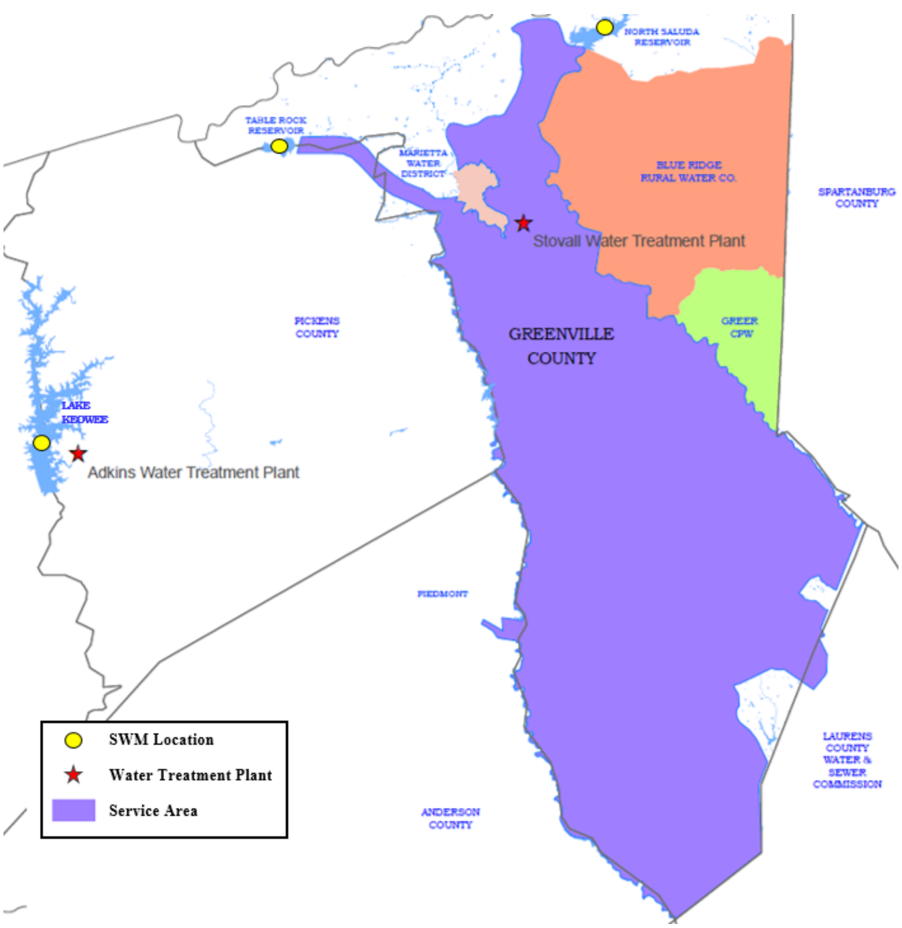


Figure 9-1. Greenville Water SWM Locations

SWM data is sent via radio to Greenville's control room where it is stored and can be accessed by utility personnel. The data is reviewed daily on SCADA system screens. **Figure 9-2** is an example of a SCADA screen that displays data from one of the SWM stations. The SCADA system can generate an alert if one or more of the parameter values crosses established thresholds. However, no significant water quality incidents have been detected in any of Greenville's source waters as of the date of publication.

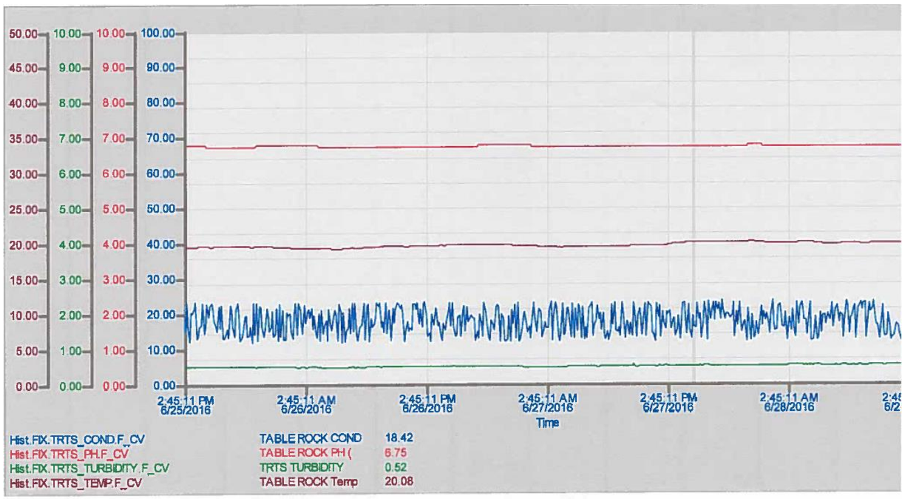


Figure 9-2. Example of Greenville Water SCADA System Screen for SWM Data

9.2 City of Fort Collins Utilities

The City of Fort Collins Utilities in Colorado supplies water to a population of 161,000, treating water from the Cache la Poudre River (Poudre River) and Horsetooth Reservoir. The design goals for the Fort Collins' SWM system are to optimize treatment processes and detect contamination incidents.

The Poudre River water quality is subject to large fluctuations due to a number of different influences (e.g., spring runoff, floods, fires), which may impact the ability to use the source. Fort Collins' SWM system includes five stations to monitor the two sources, as shown in **Table 9-1**. Emphasis is placed on monitoring the Poudre River due to recent issues with turbidity caused by wildfires in 2012.

AT A GLANCE

Design goals: To optimize treatment processes and detect contamination incidents

Monitoring locations: 3 remote, 2 in plant

Parameters: alkalinity, hydrocarbons, pH, specific conductance, temperature, TOC, turbidity, and UV-254

Table 9-1. Fort Collins Utilities SWM Stations

Location	Parameters	Role	Utilization
In Poudre River, four miles upstream of intake	• Specific conductance • Turbidity	Detection of contamination incidents	Only March/April through November, as the river is otherwise too low or frozen
In Poudre River, just upstream of the intake	• Turbidity	Detection of contamination incidents	Monitors the river turbidity continuously, even when the flow to the plant is shut off
In pipeline between the Poudre River intake and the treatment plant	• Alkalinity • Hydrocarbons • pH • Specific conductance • Temperature • Turbidity • UV-254	Treatment process optimization and detection of contamination incidents	Only online when the Poudre River intake is in use
Poudre River raw water at the treatment plant	• Alkalinity • pH • Specific conductance • Temperature • TOC • Turbidity	Treatment process optimization and detection of contamination incidents	Only online when the Poudre River intake is in use. TOC is only online during spring runoff
Horsetooth Reservoir raw water at the treatment plant	• Alkalinity • Hydrocarbons • pH • Specific conductance • Temperature • Turbidity	Treatment process optimization and detection of contamination incidents	Only online when the Horsetooth Reservoir intake is in use

All monitoring stations transmit data to a SCADA system where it is stored and can be accessed. Alerts are based on thresholds for specific parameters. Operators respond to alerts by reviewing the SWM data, which informs decisions for treatment process operations. Operators have the ability to isolate or blend the two sources, as necessary, in response to source water quality changes.

EXAMPLE INCIDENT

In 2012, wildfires created ash in the watershed, which caused significant turbidity in the Poudre River. Turbidity measurement in the river just upstream of the intake provides warning of high turbidity. The Poudre River is not used as a source when the turbidity reaches a pre-defined threshold.

Case Study References

- http://www.fcgov.com/utilities/what-we-do/water/water-quality/source-water-monitoring
- http://www.fcgov.com/utilities/what-we-do/water/water-quality/source-water-monitoring/upper-poudre-quality-monitoring
- http://www.fcgov.com/utilities/img/site_specific/uploads/December_2015_Watershed_Newsletter_Template.pdf
- http://www.fcgov.com/utilities/img/site_specific/uploads/2013HT_report_final.pdf

9.3 Clermont County Water Resources Division

The Clermont County Water Resources Department supplies water to over 43,000 customers in southwest Ohio, drawing water from Harsha Lake, the Little Miami River Valley Aquifer, and the Ohio River Valley Aquifer. The design goals for this SWM system are to detect contamination incidents and monitor threats to long-term water quality.

AT A GLANCE

Design goals: To detect contamination incidents and monitor threats to long-term water quality

Monitoring locations: 3

Parameters: DO, ORP, pH, photosynthetic pigments, specific conductance, spectral absorbance, temperature, toxicity, and turbidity

Harsha Lake has a history of cyanotoxin producing HAB events, which have typically occurred in early summer. The high risk of cyanotoxin formation in the lake and the difficulty in removing it through existing drinking water treatment processes forced Clermont County to add advanced, expensive treatment techniques. To control the formation of DBPs, granular activated carbon (GAC) contactors were installed, which provide the added benefit of removing several cyanotoxins. Managing loading rates of multiple GAC contactors has become an important tool in cyanotoxin treatment. As a result, the utility wanted to develop empirical relationships between algal community composition, toxicity, and cyanotoxin concentrations to better detect and respond to cyanobacterial blooms and their toxins. To accomplish this objective, the utility established a partnership with EPA's Office of Research and Development to convert three historical water quality sampling sites to SWM stations, as described in **Table 9-2**. Grab sampling for a range of water quality parameters occurs at various frequencies to supplement data produced by SWM stations.

Table 9-2. Clermont County Water Resources Division SWM Stations

Location	Parameters	Role
Surface of Harsha Lake near the intake of the Bob McEwen Water Treatment Plant	• DO • ORP • pH • Photosynthetic pigments • Specific conductance • Spectral absorbance • Temperature • Toxicity • Turbidity	Detection of contamination incidents and monitoring of threats to long-term water quality
Harsha Lake intake to the Bob McEwen Water Treatment Plant	• DO • ORP • pH • Photosynthetic pigments • Specific conductance • Spectral absorbance • Temperature • TOC • Toxicity • Turbidity	Detection of contamination incidents and monitoring threats to long-term water quality
Floating Platform on Harsha Lake	• DO • ORP • pH • Photosynthetic pigments • Specific conductance • Temperature • TOC • Turbidity	Detection of contamination incidents and monitoring of threats to long-term water quality

Data produced by SWM stations is sent via a cellular internet connection to a central workstation. All data is analyzed visually, using time-series plots to determine parameter relationships and identify data outliers and instances of instrument failure. Spectral absorbance and toxicity data is also analyzed by an ADS that is integrated with instrument software. Utility personnel can access SWM data through a central workstation and externally, in “read-only mode,” through other secured methods. The system creates weekly reports that include QA metrics, for personnel to review on a weekly basis.

9.4 West Virginia American Water

West Virginia American Water (WVAW) serves approximately 550,000 customers in around 300 communities across West Virginia, drawing water from various surface water sources across the state. The primary design goals of WVAW's SWM system are to optimize treatment processes and detect contamination incidents.

AT A GLANCE

Design goals: To optimize treatment processes and detect contamination incidents

Monitoring locations: 8

Parameters: DO, DOC (via UV-254), ORP, pH, specific conductance, temperature, and turbidity

WVAW has implemented an SWM system that goes above and beyond state regulatory requirements established in 2014 to proactively monitor their source waters. An SWM station was installed at each of WVAW's eight water treatment plants to monitor water from the associated intakes. These stations continuously monitor the following parameters: DO, DOC (via UV-254), ORP, pH, specific conductance, temperature, and turbidity. A photograph of one of the SWM stations is shown in **Figure 9-3**.

Figure 9-3. West Virginia American Water Source Water Monitoring Station

SWM data is recorded every two minutes and sent, via fiber optic cable, to a server that securely transmits data to a cloud-based web platform. Personnel with their own login credentials can view current parameter values as well as time-series plots of historical data using a secure Internet connection. A screenshot of a time-series plot showing a data subset generated at an SWM location is shown in **Figure 9-4**. SWM data is currently analyzed using visual and statistical techniques to establish baseline water quality at each of the SWM locations. WVAW is in the process of implementing an ADS to analyze data from multiple sensors in real-time and provide alerting based on a "rare combination" comparison to baseline data.

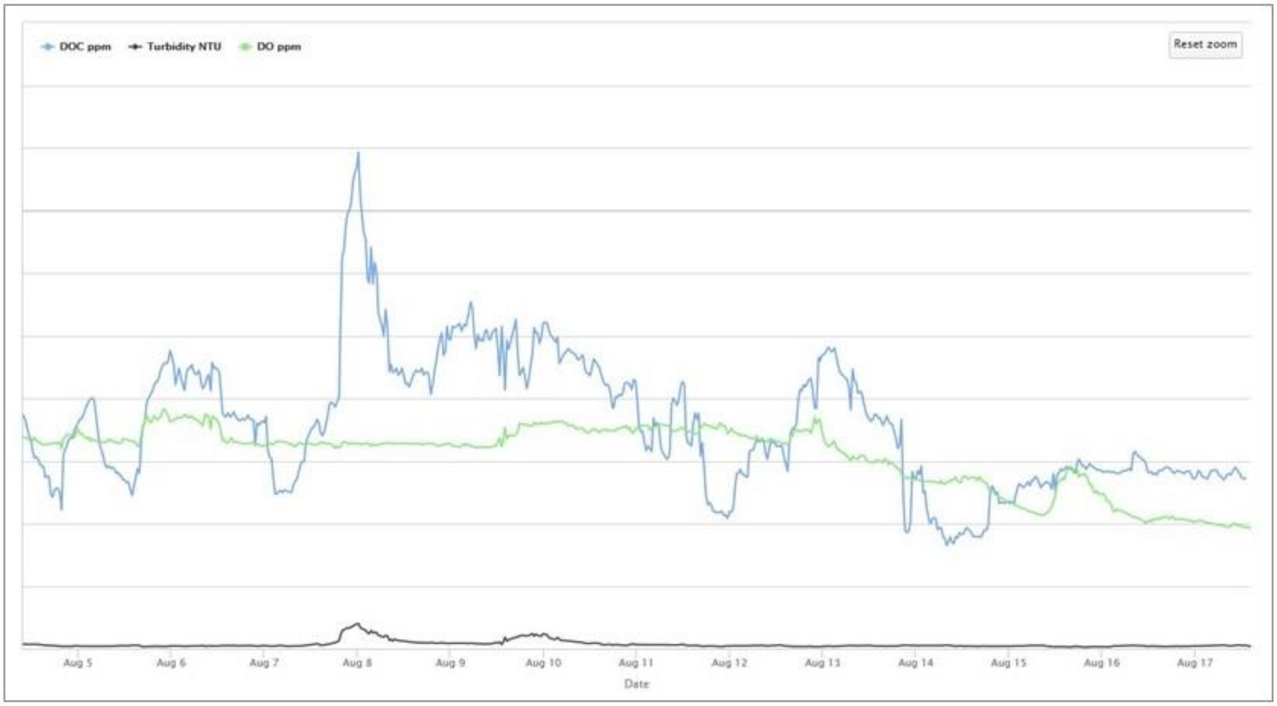


Figure 9-4. Screenshot of West Virginia American Water Source Water Monitoring Data

Case Study References

- http://www.amwater.com/wvaw/water-quality-and-stewardship/source-water-protection/index.html
- Data Quality Management for Continuous Source Water Monitoring, Presented at NEMC, August 2016 http://www.nemc.us/meeting/2016/load_abstract.php?id=91

9.5 Bratislava Water Company

The Bratislava Water Company in Slovakia uses groundwater from a deep aquifer as its main source to supply a population of greater than 600,000. Over 144 MGD of drinking water is produced in seven central water treatment facilities that extract water from 176 wells. The only treatment performed is chlorination to prevent microbiological regrowth during distribution. The design goal for Bratislava's SWM system is to detect contamination incidents.

AT A GLANCE

Design goals: To detect contamination incidents

Monitoring locations: 176

Parameters: NO_3, specific conductance, spectral absorbance, temperature, and TOC

Water quality is consistently high in most of Bratislava's 176 groundwater wells. However, the utility is concerned about the possibility of contamination with pesticides, water soluble components of oil, and chemical warfare agents. As a result, SWM stations were installed at each of the sources to monitor NO_3, TOC, specific conductance, temperature, and spectral absorbance. A photograph of an SWM station is shown in **Figure 9-5**.

Figure 9-5. Bratislava Water Company SWM Station

Each of the SWM stations is equipped with an ADS that sends an alert to plant operators when a potential water quality anomaly is detected, as illustrated in **Figure 9-6**. When an alert is received, operators shut down the well in which the anomaly was detected. Water samples are then collected and analyzed to determine whether contamination has occurred before bringing the well back online.

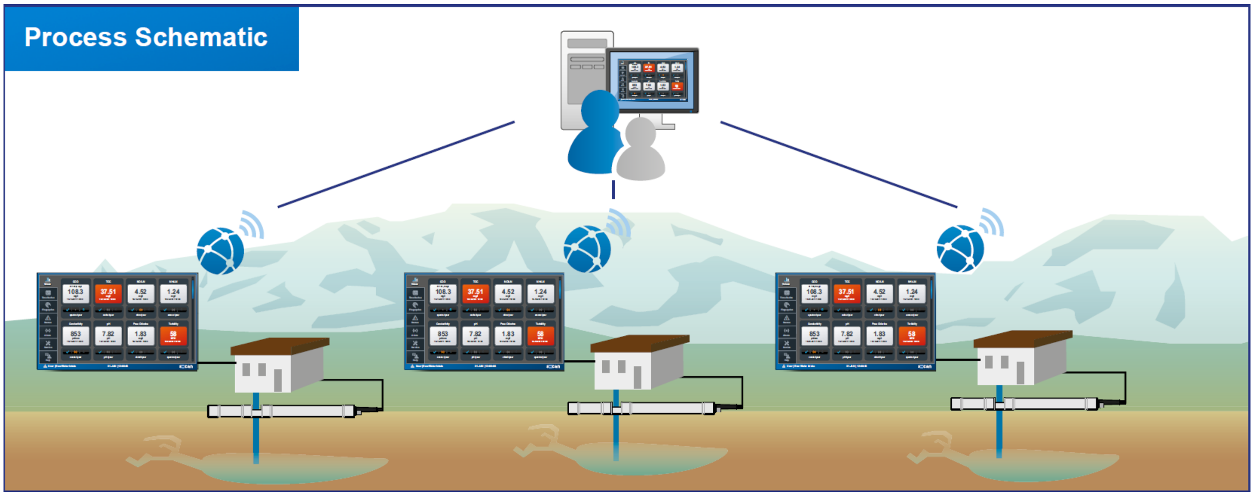


Figure 9-6. Bratislava Water Company SWM Alert Notification

Case Study References

- http://www.s-can.at/medialibrary/references/Reference_Bratislava_web.pdf
- http://www.s-can.at/medialibrary/pdf/bratislava_publication.pdf
- http://www.s-can.at/medialibrary/pdf/bratislava_poster.pdf

9.6 Susquehanna River Basin Commission Early Warning System

The Susquehanna River Basin Commission (SRBC) Early Warning System is an SWM program for the lower Susquehanna River region which provides water to parts of Pennsylvania, New York, and Maryland. The system provides information to help protect public drinking water supplies serving about 850,000 people. A stakeholder group guides implementation of the SWM program and includes participating public water suppliers and representatives from various environmental protection and emergency response agencies. The design goals of SRBC's system are to optimize treatment processes and detect contamination incidents.

AT A GLANCE

Design goals: To optimize treatment processes and detect contamination incidents

Monitoring locations: 55

Parameters: pH, temperature, and turbidity

SRBC operates 55 SWM stations that monitor a minimum of pH, temperature, and turbidity at critical locations along the major rivers of the Susquehanna Basin. The monitored area is shown in **Figure 9-7**. The system was set up as an early warning system for contamination incidents and includes SWM stations that monitor water quality downstream of oil and gas industry facilities. A photo of an SWM station is shown in **Figure 9-8**.

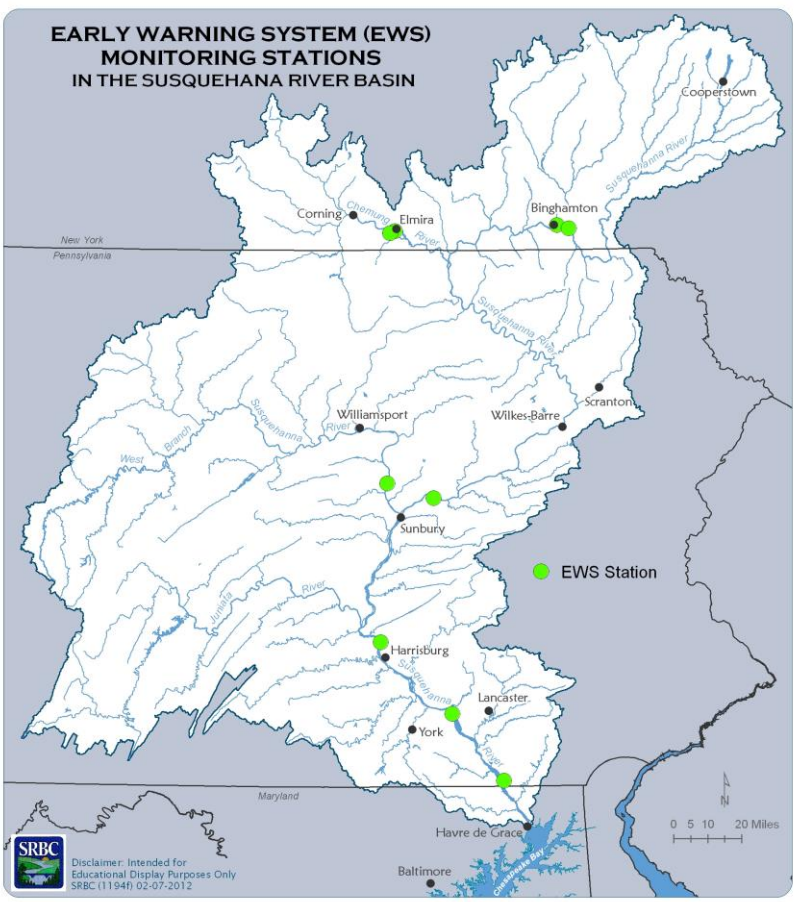


Figure 9-7. Susquehanna River Basin Region

Figure 9-8. Susquehanna River Basin Commission SWM Station

SWM data is transmitted in real-time to water treatment plants and the SRBC. A secure database and website interface provide access to the data and tools for investigating, or responding to, contamination incidents. The website interface provides user-friendly access to information and tools, including a time-of-travel tool to help estimate contaminant dispersal times that enable downstream users to respond to adverse changes in water quality. Data associated with the stations specifically monitoring the oil and gas industry are published to a public website every five minutes.

Case Study References

- http://www.sourcewaterpa.org/?page_id=1806
- http://www.srbc.net/drinkingwater/
- http://www.srbc.net/pubinfo/docs/infosheets/SRB%20_Early_Warning_System_136411_1.pdf
- http://www.srbc.net/programs/docs/09SRBCEWS.pdf

9.7 River Alert Information Network

The River Alert Information Network (RAIN) is a regional SWM system dedicated to protecting shared drinking water resources in western Pennsylvania and northern West Virginia. RAIN is a collaboration of 51 water utilities, the Pennsylvania Department of Environment Protection, the West Virginia Department of Health and Human Resources, the California University of Pennsylvania, Carnegie Mellon University, and the University of Pittsburgh. The design goal for RAIN's SWM system is to detect contamination incidents.

AT A GLANCE

Design goals: To detect contamination incidents

Monitoring locations: 29

Parameters: DO, NH_3, pH, specific conductance, temperature, and turbidity

RAIN currently monitors water quality in the Monongahela, Allegheny, and Ohio rivers. A total of 29 SWM stations are installed along these rivers to monitor DO, NH_3, pH, specific conductance, temperature, and turbidity. A photo of a RAIN SWM station is shown in **Figure 9-9**. An overview of SWM locations is shown in **Figure 9-10**.

Figure 9-9. RAIN SWM Station

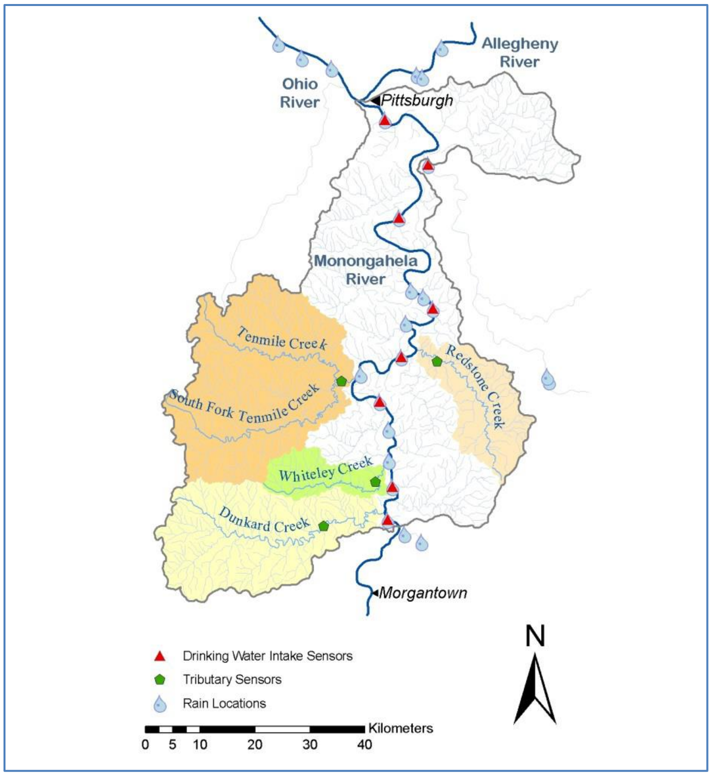


Figure 9-10. Overview of RAIN SWM Locations

SWM data is transmitted from SWM stations in the field to a data center at the California University of Pennsylvania for analysis. Electronic updates are periodically forwarded to RAIN headquarters in Pittsburgh. If one or more parameters fall outside of established threshold values, automated notifications are sent to impacted drinking water treatment plants. SWM data is also made available to the public via the USGS RAIN website. A screenshot of the website, which displays an interactive map and data from one of the RAIN SWM stations, is shown in **Figure 9-11**.

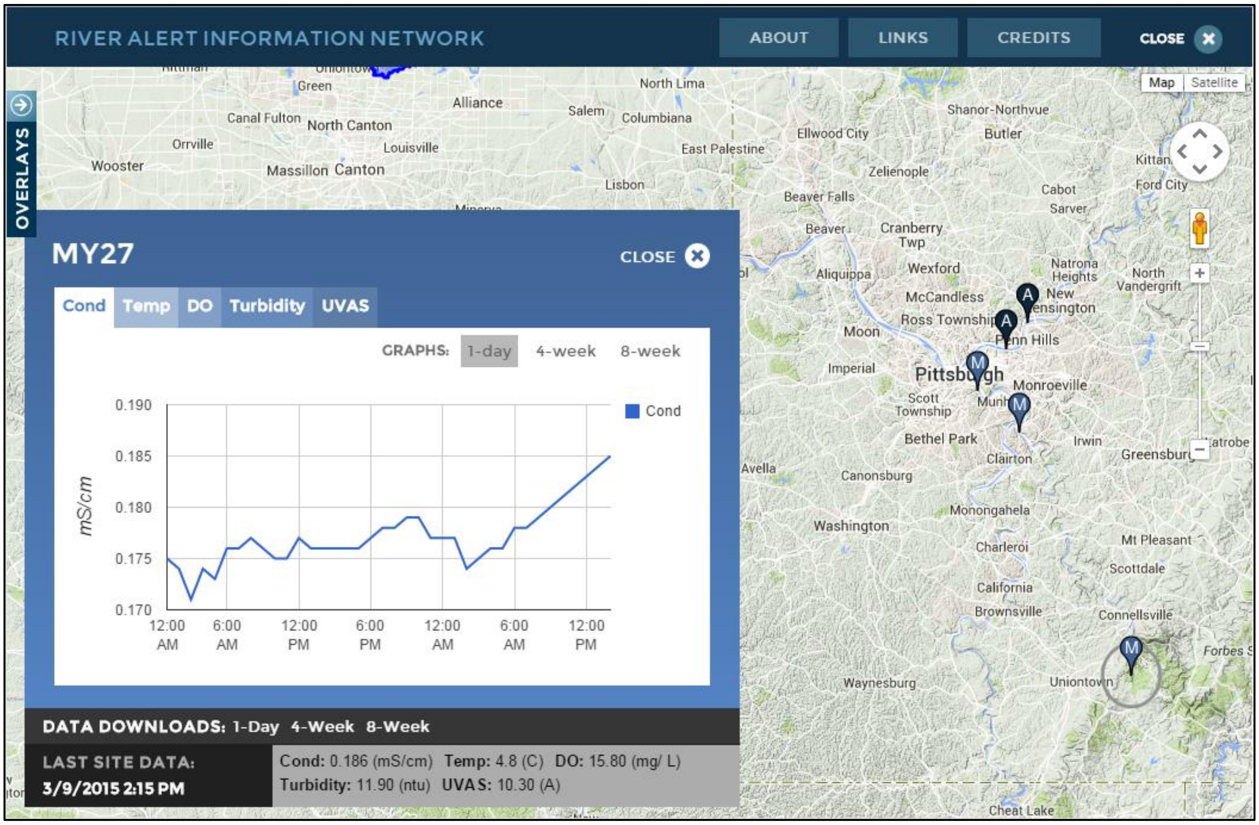


Figure 9-11. RAIN Interactive Display

EXAMPLE INCIDENT

In 2010, SWM stations detected an increase of bromide levels in the Monongahela River. While a single source for the increased levels was never identified, it was suspected that the increase was caused by wastewater discharges from Marcellus Shale drilling or electric power plants. The combined effect of controls that were placed on some discharges along the river as well as significantly more rainfall resulted in lower bromide concentrations and more stable water quality in the river in 2011.

Case Study References

- http://www.rainmatters.org/
- http://www.sourcewaterpa.org/wp-content/uploads/2013/04/Part-2-SWP-Coalitions-vs-DIY-Gina-Cyprych-RAIN-3-9-13-Schuylkill-Watershed-Congress.pdf
- http://usgs.dailyinvention.com/rain.php

9.8 Philadelphia Water Department

Philadelphia Water Department (PWD) is a combined urban utility located in Philadelphia, Pennsylvania, that delivers approximately 250 MGD of high-quality drinking water to 1.6 million residents in Philadelphia and its surrounding suburbs. PWD operates three conventional drinking water treatment plants located on two densely populated and industrialized rivers with distinct water quality characteristics. The Schuylkill River hosts two treatment plants that supply a total of roughly 40 percent of the city's demand. The balance of the demand is met by the utility's largest plant located on the tidal Delaware River. Philadelphia is located at the confluence of these two rivers in a vast watershed of more than 10,000 square miles. **Figure 9-12** provides an overview of the utility's source watersheds and drinking water intakes. Less than 1 percent of the total source watershed area is within city boundaries, necessitating a partnership-based approach to meet source water protection objectives.

PWD has taken proactive steps towards being an industry and regional leader in source water protection by creating mechanisms for regional coordination to implement source water protection measures. Recognizing the many benefits of online water quality monitoring, the utility has incorporated SWM components into regional, local, and utility-specific systems. Two SWM systems are described in this case study: the Delaware Valley Early Warning System and the Philadelphia Water Resources Monitoring Program.

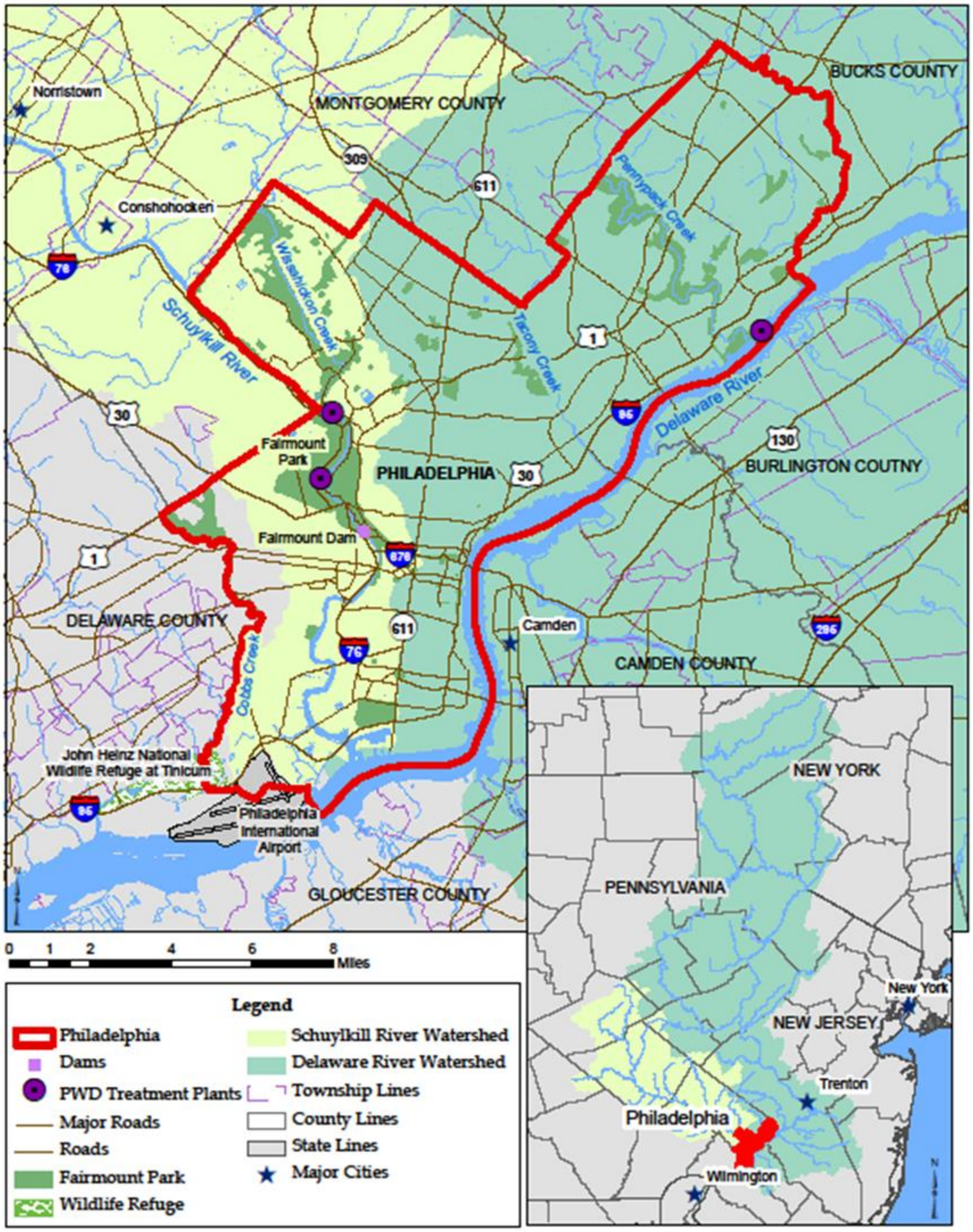


Figure 9-12. Overview of PWD's Source Watersheds and Drinking Water Intakes

Delaware Valley Early Warning System

The Delaware Valley Early Warning System (EWS) is a private, web-based water quality event communication system. The EWS is designed to monitor the safety of the drinking water supply by providing data and analysis tools to aid planning and response for potential source water contamination incidents. Technological components of the EWS, such as a sophisticated notification system, secure database portal, user-friendly website, and comprehensive water quality and flow monitoring network, create the advanced functionality and unique capabilities that make the EWS an industry model for surface water notification and monitoring systems.

AT A GLANCE

Design goals: To detect contamination incidents and monitor threats to long-term water quality

Monitoring locations: 88

Parameters: DO, pH, specific conductance, temperature, and turbidity

The system is owned and managed by PWD, although the system covers an area well outside of the city's boundaries. The system's user base consists of more than 300 individual users from 50 different organizations that include water utilities, industries, and representatives from government agencies in Pennsylvania, New Jersey, and Delaware. EWS technical and analytical capabilities cover both the Schuylkill and Delaware Watersheds with the exception of tributaries downstream of Philadelphia and the New York City water supply.

Water quality incidents are reported through a telephone hotline or the EWS website, and email and telephone notifications to the entire user base are processed within minutes. Users can log in to the secure website to see additional event details and supplemental information, including an interactive ArcGIS map of the projected spill trajectory and time of travel estimations for tidal and non-tidal intakes. In addition to providing a user interface, the website supports SWM system users by providing:

- Secure means of accessing and analyzing information
- Tools for determining appropriate incident response
- Interface for updating incident reports
- List of contacts for incident follow-up
- Animation of modeled spill trajectory for events on tidal waters

The SWM stations are fully integrated with the EWS website and database portal. The monitoring network consists of four SWM stations at drinking water intakes and 84 supplemental USGS water monitoring stations on the lower Delaware River and its tributaries. These stations monitor parameters such as DO, flow, pH, specific conductance, temperature, and turbidity. The system is designed to allow EWS users to easily track water quality changes and potential impacts from contamination incidents through automatically generated graphical displays and user-friendly data query tools available on the system's secure website. An example of real-time flow and turbidity data visualization from the EWS homepage is shown in **Figure 9-13**. The graph displays readings from the last 15 days from multiple SWM stations on the main stem of the Schuylkill and Delaware Rivers.

Another objective of the system is to provide users with access to historic water quality data through query functions. Both real-time and historic data can be queried and viewed in charts online or downloaded to a file that can be further analyzed by the EWS subscriber using data analysis software. Additionally, both real-time and historic flow data can be used to produce conservative time of travel estimations for each reported event.

PWD supports ongoing system upgrades and enhancements to ensure that the EWS remains the most advanced and robust system possible, helping to protect the drinking water supply for over 3 million people in the watershed.

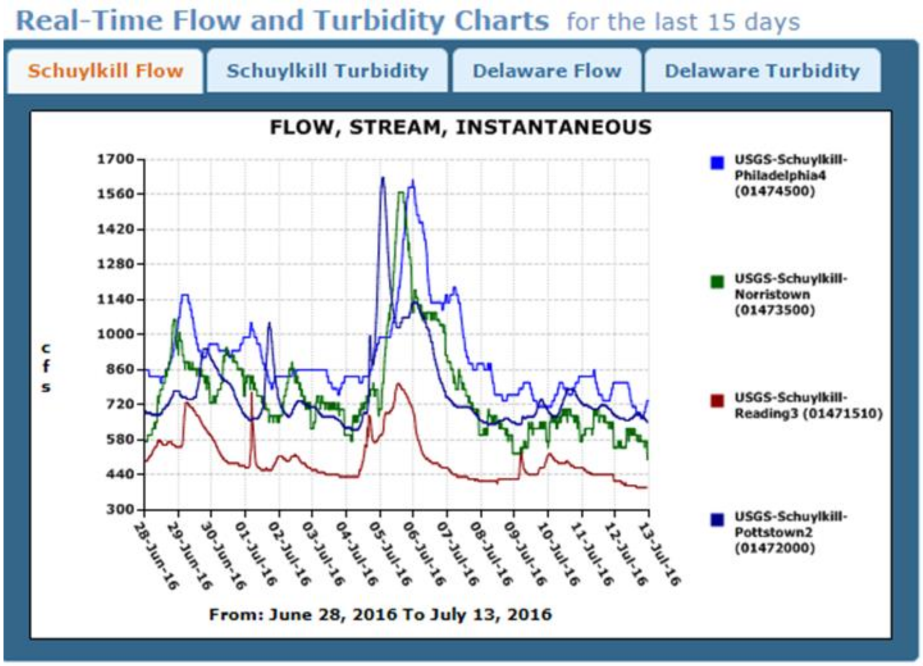


Figure 9-13. Example of SWM Data Visualization on EWS Homepage

> **EXAMPLE INCIDENTS**
>
> Past significant contamination incidents reported to the Delaware Valley EWS include a spill of 275,000 gallons of crude oil in the tidal Delaware River in 2004, a spill of 100 million gallons of fly ash into the Delaware River from an industrial lagoon in 2005, a cyanide release through a wastewater treatment plant into a tributary to the Schuylkill River in 2006, and a train derailment release of 25,000 gallons of vinyl chloride into a tributary to the Delaware River in 2012.

Philadelphia Water Resources Monitoring Program

As a combined utility, PWD uses online water quality monitoring data to support both Safe Drinking Water Act and Clean Water Act objectives. PWD works cooperatively with USGS to maintain an extensive monitoring network within the City of Philadelphia. The objective of the system is to characterize the quality of the City's waterways and detect water quality changes that may warrant further investigation. Ten strategically positioned stream flow monitoring stations augmented with SWM instruments characterize water quality entering and exiting Philadelphia's sub-watersheds.

> **AT A GLANCE**
>
> **Design goals:** To detect contamination incidents and monitor threats to long-term water quality
>
> **Monitoring locations:** 10
>
> **Parameters:** DO, pH, specific conductance, temperature, and turbidity

Monitored water quality parameters include DO, pH, specific conductance, temperature, and, at select locations, turbidity. Hydrological parameters such as flow and gauge height are also measured.

SWM data is automatically uploaded to databases in the USGS computer network, and a web server transfers the data to the USGS National Water Information System (NWIS) website. A separate utility website automatically retrieves data from the USGS NWIS at regular intervals and geospatially displays the results on a publicly accessible website shown in **Figure 9-14**. A traffic light color scheme is applied to each parameter at each station to denote good water quality (green), undesirable changes in water quality (yellow), and poor water quality (red). Rating thresholds are based on stream use designations and established water quality criteria. Users can select a station on the map to see the most recent instantaneous readings.

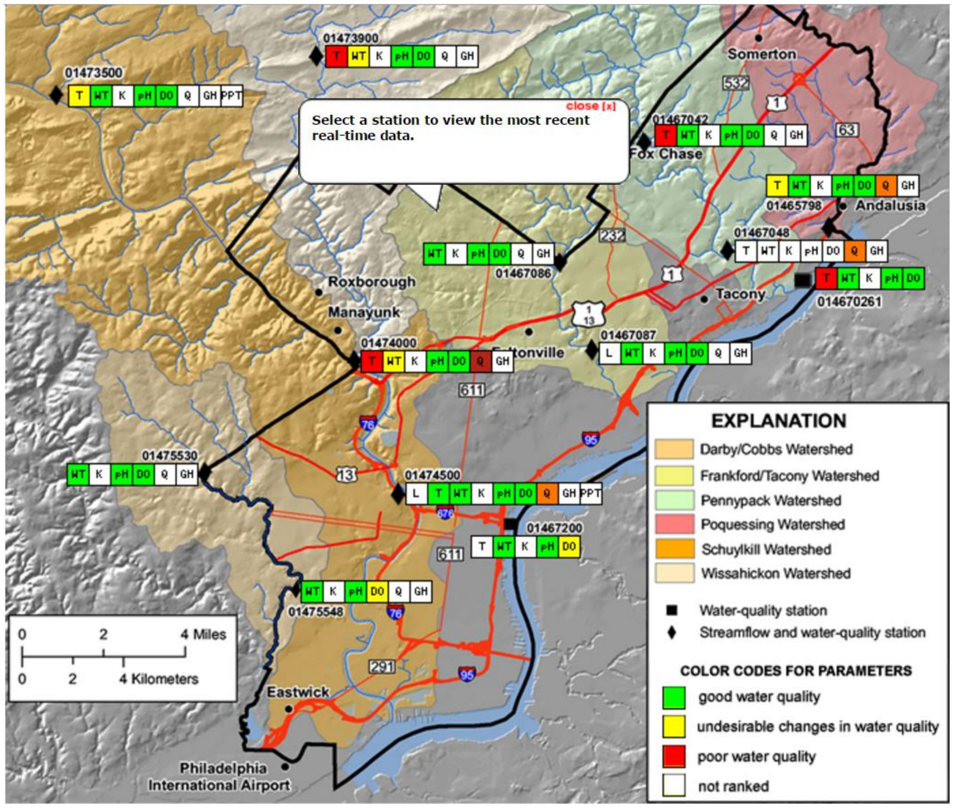


Figure 9-14. Philadelphia Water Resources Monitoring Program Website User Interface

The user interface and data visualization allows PWD personnel to simultaneously monitor spatial and temporal quality and quantity trends. This information is used to assess aquatic ecosystem health, evaluate source water quality, and inform decision-making surrounding watershed restoration initiatives. Additionally, these stations serve as Philadelphia's long-term, wet-weather monitoring stations. Additional quality assurance and data analysis is performed on data from each SWM station.

Case Study Reference

- http://www.phila.gov/water/wu/Water%20Quality%20Reports/2015WaterQuality.pdf

Resources

Introduction

Water Quality Surveillance and Response System Primer (EPA, 2015a)

https://www.epa.gov/sites/production/files/2015-06/documents/water_quality_sureveillance_and_response_system_primer.pdf

This document provides an overview of Water Quality Surveillance and Response Systems, and serves as a foundation for the application of technical guidance and products used to implement an SRS. EPA 817-B-15-002, May 2015.

Framework for Designing a Source Water Monitoring System

Guidance for Developing Integrated Water Quality Surveillance and Response Systems (EPA, 2015b)

https://www.epa.gov/sites/production/files/2015-12/documents/guidance_for_developing_integrated_wq_srss_110415.pdf

This document provides guidance for applying system engineering principles to the design and implementation of an SRS to ensure that the SRS functions as an integrated whole and is designed to effectively perform its intended function. Section 2 provides guidance on project management and coordination. Section 3 provides guidance on master planning for a multi-component SRS. EPA 817-B-15-006, October 2015.

Quality Assurance (ACRR) Matrix (ASW, 2010)

http://www.watersensors.org/pdfs/ASW_QA_Matrix_web.pdf

A series of tables that provide guidance on quality control and record-keeping practices for common water quality parameters monitored online.

J100 Standard (AWWA, 2010)

http://www.awwa.org/store/productdetail.aspx?productid=21625

The J100 Standard was developed collaboratively by the American National Standards Institute (ANSI), American Society of Mechanical Engineers Innovative Technologies Institute (ASME-ITI), and American Water Works Association (AWWA). J100 sets the requirements for all-hazards risk and resilience analysis for the water sector, ensuring a consistent framework for conducting risk assessments. The J100 documents a seven-step process for evaluating risks presented by man-made threats, natural hazards, dependencies, and proximity to hazardous sites.

Vulnerability Self-Assessment Tool (EPA, 2015c)

https://yosemite.epa.gov/ow/SReg.nsf/description/VSAT

The Vulnerability Self-Assessment Tool (VSAT) is an electronic resource designed to help water and wastewater utilities of all sizes to identify vulnerabilities to both man-made and natural hazards, and evaluate potential improvements to enhance their security and resiliency. Version VSAT 6.0, released in 2015, is consistent with the J100 Standard.

State Primacy Agency Source Water Assessments (EPA, 2016a)

https://www.epa.gov/sourcewaterprotection/conducting-source-water-assessments

State drinking water primacy agencies are required to conduct source water assessments that include an inventory of known and potential sources of contamination. Source water assessments provide information about sources of drinking water used by public water systems. They are developed by state primacy agencies to help local governments, water utilities, and others protect drinking water sources. While the assessment programs are tailored to each state's specific issues, they all generally follow these three steps: (1) delineate the source water protection area, (2) conduct an inventory of potential sources of contamination, and (3) determine the vulnerability of the water supply to contamination. Contact your state drinking water primacy agency for more information.

DWMAPS (EPA, 2016b)

https://www.epa.gov/sourcewaterprotection/dwmaps

This GIS-based tool was developed by EPA to help states and utilities update their source water assessments. It provides layers of spatially referenced data using information from databases such as National Pollutant Discharge Elimination System (NPDES); Toxic Release Inventory (TRI); Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS); Resource Conservation and Recovery Act Information (RCRAInfo); and Toxic Substances Control Act (TSCA). DWMAPS also provides meta-data that can be useful for characterizing potential SW threats. A secure version of DWMAPS, which shows the location of drinking water intakes relative to the location of source water threats, is available to drinking water utilities and state primacy agencies.

Template for Conducting a Risk Assessment for Source Water Threats (Word File)

Click this link to open the template

This Word template can be used to document a risk assessment for SW threats. It provides tables for summarizing the attributes of SW threats and associated contaminants, example definitions of the risk assessment parameters, and tables for documenting the results of the risk assessment. September 2016.

Framework for Comparing Alternatives for Water Quality Surveillance and Response Systems (EPA, 2015d)

https://www.epa.gov/sites/production/files/2015-07/documents/framework_for_comparing_alternatives_for_water_quality_surveillance_and_response_systems.pdf

This document provides guidance for selecting the most appropriate SRS design for a utility from a set of viable alternatives. It guides the user through an objective, stepwise analysis for ranking multiple alternatives and describes, in general terms, the types of information necessary to compare the alternatives. EPA 817-B-15-003, June 2015.

Template for Developing an SWM Preliminary Design Document (Word File)

Click this link to open the template

This Word template can be used to document the preliminary design of an SWM system, including: SWM implementation team, design goals, performance objectives, SW threats, SWM locations, SWM parameters, preliminary information management requirements, initial training plan, budget, and schedule. September 2016.

Source Water Monitoring Locations

Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting (USGS, 2006)

http://pubs.usgs.gov/tm/2006/tm1D3/pdf/TM1D3.pdf
Provides guidelines for equipment and monitor selection, placement of online water quality monitoring equipment in an aquatic environment, sensor inspection and calibration methods, data evaluation, record review, and data reporting.

Source Water Monitoring Parameters

Guidance for Selecting Online Water Quality Monitoring Parameters and Evaluating Sensor Technologies for Source Water and Distribution System Monitoring (EPA, 2016c)

https://www.epa.gov/waterqualitysurveillance/online-water-quality-monitoring-resources
This document provides detailed information about commonly monitored water quality parameters and guidance on selecting appropriate parameters to monitor for a given application. It also provides a summary of available technologies for monitoring each parameter.

Distribution System Water Quality Monitoring: Sensor Technology Evaluation Methodology and Results A Guide for Sensor Manufacturers and Water Utilities (EPA, 2009)

http://www.epa.gov/sites/production/files/2015-06/documents/distribution_system_water_quality_monitoring_sensor_technology_evaluation_methodology_results.pdf
This document presents the methodology and findings from several studies evaluating the ability of common water quality parameters to detect a variety of contaminants in finished drinking water. EPA 600/R-09/076, October 2009.

Source Water Monitoring Stations

Guidance for Building Online Water Quality Monitoring Stations (EPA, 2016d)

https://www.epa.gov/waterqualitysurveillance/online-water-quality-monitoring-resources
This document provides guidance for designing water quality monitoring stations for both source water and distribution system applications. It describes different station designs and provides detailed design schematics, describes basic station equipment and station accessories, and provides considerations for fabricating and installing online water quality monitoring stations.

Guidance for Designing Communications Systems for Water Quality Surveillance and Response Systems (EPA, 2016e)

https://www.epa.gov/waterqualitysurveillance/system-design-resources
This document provides guidance and information to help utilities select an appropriate communications system to support operation of a Water Quality Surveillance and Response System. It provides rigorous criteria for evaluation communications system options, evaluates common technologies with respect to these criteria, describes the process for establishing requirements for a communications system, and provides guidance on selecting and implementing a system. EPA 817-B-16-002, September 2016.

Information Management and Analysis

Guidance for Developing Integrated Water Quality Surveillance and Response Systems (EPA, 2015b)

https://www.epa.gov/sites/production/files/2015-12/documents/guidance_for_developing_integrated_wq_srss_110415.pdf

This document provides guidance for applying system engineering principles to the design and implementation of an SRS to ensure that the SRS functions as an integrated whole and is designed to effectively perform its intended function. Section 4 provides guidance on developing information management system requirements, selecting an information management system, and IT master planning. Appendix B provides an example outline for an IT operations and maintenance plan. EPA 817-B-15-006, October 2015.

Exploratory Analysis of Time-series Data to Prepare for Real-time Online Water Quality Monitoring (EPA, 2016f)

https://www.epa.gov/waterqualitysurveillance/online-water-quality-monitoring-resources

This document describes methods for analyzing time-series water quality data to establish normal variability for water quality at unique monitoring locations. It also describes how the results of this exploratory analysis can be used to develop tools and training to prepare utility personnel for real-time analysis of online water quality data.

Treatment process selection for particle removal (McEwen, 1998)

http://www.waterrf.org/executivesummarylibrary/90701_423_profile.pdf

This document provides guidance on the evaluation, testing, implementation, and optimization of drinking water treatment processes for particle removal. McEwen, J. B. (ed.). Denver, CO: AWWA/International Water Supply Association.

Parameter set points: an effective solution for real-time data analysis (Umberg and Allgeier, 2016)

http://dx.doi.org/10.5942/jawwa.2016.108.0009

This paper presents the results from an evaluation of the application of thresholds to anomaly detection in online water quality data collected from a drinking water distribution system. Umberg, K. and Allgeier, S. *JAWWA, 108*, E60-E66.

Event Detection System Challenge (EPA, 2013a)

https://www.epa.gov/sites/production/files/2015-07/documents/water_quality_event_detection_system_challenge_methodology_and_findings.pdf

This report describes the methodology and results from a study designed to evaluate five anomaly detection systems used for the analysis of online water quality data for finished water. EPA 817-R-13-002, April 2013.

Dashboard Design Guidance for Water Quality Surveillance and Response Systems (EPA, 2015e)

https://www.epa.gov/sites/production/files/2015-12/documents/srs_dashboard_guidance_112015.pdf

This document provides information about useful features and functions that can be incorporated into an SRS dashboard. It also provides guidance on a systematic approach that can be used by utility managers and IT personnel to define requirements for a dashboard. EPA 817-B-15-007, November 2015.

Statistical Methods in Water Resources (USGS, 2002)

http://water.usgs.gov/pubs/twri/twri4a3/

This document provides a comprehensive and detailed description of statistical techniques that can be used to analyze water quality data. It is particularly useful for evaluating correlations and long-term trends in source water quality. Helsel, D. R. and Hirsch, R. M. In Techniques of water-resources investigation of the United States Geological Survey, Book 4, Hydrologic analysis and interpretation.

Information Management Requirements Development Tool (EPA, 2015f)

http://www.epa.gov/waterqualitysurveillance/surveillance-and-response-system-resources

This tool is intended to help users develop requirements for an SRS information management system, thereby preparing them to select and implement an information management solution. Specifically, this tool (1) assists SRS component teams with development of component functional requirements, (2) assists IT personnel with development of technical requirements, and (3) allows the IT design team to efficiently consolidate and review all requirements. EPA 817-B-15-004, October 2015.

Investigation and Response Procedures

Template for Developing SWM Investigation and Response Procedures (Word File)

Click this link to open the template

This Word template can be used to develop investigation and response procedures, including: an SWM alert investigation procedure, a treatment process optimization procedure, and a source water contamination incident response procedure. The template includes editable procedure flowcharts with supporting tables and an editable investigation checklist. September 2016.

Guidance for Developing Integrated Water Quality Surveillance and Response Systems (EPA, 2015b)

https://www.epa.gov/sites/production/files/2015-12/documents/guidance_for_developing_integrated_wq_srss_110415.pdf

This document provides guidance for applying system engineering principles to the design and implementation of an SRS to ensure that the SRS functions as an integrated whole and is designed to effectively perform its intended function. Section 5 provides guidance on developing alert investigation procedures, and includes examples of alert investigation tools such as an alert investigation record and quick reference guides. Section 6 provides guidance on developing a training program to support SRS operations. EPA 817-B-15-006, October 2015.

Guidance for Building Laboratory Capabilities to Respond to Drinking Water Contamination (EPA, 2013b)

https://www.epa.gov/sites/production/files/2015-06/documents/guidance_for_building_laboratory_capabilities_to_respond_to_drinking_water_contamination.pdf

This document provides guidance to assist drinking water utilities with building laboratory capabilities for responding to water contamination incidents, including those occurring in source waters. It presents contaminant classes of concern, lists analytical methods for those classes, and provides information on the role of national laboratory networks in responding to drinking water contamination incidents. EPA 817-R-13-001, March 2013.

Cyanobacterial Harmful Algal Blooms (EPA, 2016g)
https://www.epa.gov/nutrient-policy-data/cyanohabs
This website provides information and numerous resources for understanding, preventing, and managing harmful algal blooms in surface water. Topics covered include: causes and prevention, detection, health and ecological effects, control and treatment, guidance and recommendations, and a listing of stat resources.

Water Contaminant Information Tool (EPA, 2016h)
https://www.epa.gov/waterlabnetwork/access-water-contaminant-information-tool
This database provides information on over 800 drinking water and wastewater contaminants, including pathogens, pesticides, and toxic industrial chemicals. It can serve as a useful resource for investigating the properties of contaminants associated with SW threats during a risk assessment. It can also be a valuable resource during response to a source water contamination incident once the identity of the contaminant is known or suspected. Note that users must register with EPA to obtain access to this database. EPA 817-F-15-026, November 2015.

Treatability Database (EPA, 2016i)
https://iaspub.epa.gov/tdb/pages/general/home.do
This database provides referenced information on the control of contaminants in drinking water. It allows users to access information gathered from thousands of literature sources from a single database. It can serve as a useful resource for investigating the treatability of contaminants when planning a response to a source water contamination incident.

Guide for Developing a Distribution System Contamination Response Plan (EPA, 2016j)
https://www.epa.gov/waterqualitysurveillance/consequence-management-resources
This resource provides an editable template for developing a utility-specific Distribution System Contamination Response Plan. Elements of this plan include investigation of a possible distribution system contamination incident, planning for site characterization, implementing operational response actions, issuing public notification, and planning for remediation and recovery. An accompanying guide helps the user populate the template to customize the plan to a specific utility.

Developing Risk Communication Plans for Drinking Water Contamination Incidents (EPA, 2013c)
https://www.epa.gov/sites/production/files/2015-07/documents/developing_risk_communication_plans_for_drinking_water_contamination_incidents.pdf
This resource provides guidance on developing an effective risk communication plan to guide communications with response partners and the public during a drinking water contamination incident. EPA 817-F-13-003, April 2013.

Climate Ready Water Utilities (EPA, 2012)
https://www.epa.gov/crwu
This EPA program provides the water sector with practical tools, training, and technical assistance needed to adapt to climate change by promoting a clear understanding of climate science and adaptation strategies. One tool provided through this program is the Climate Resilience Evaluation and Awareness Tool (CREAT), which is a risk assessment tool that allows a water utility to evaluate potential impacts of climate change under different time periods and scenarios. CREAT complements other tools and resources, including hydrology and water quality models.

Source Water Protection (EPA, 2016k)

https://www.epa.gov/sourcewaterprotection

This EPA program provides guidance and links to a variety of tools and resources to support source water protection activities.

Source Water Collaborative (SWC, 2016)

http://sourcewatercollaborative.org/

The Source Water Collaborative (SWC) is a group consisting of 26 national organization and state and local partners with a mission to foster protection of drinking water resources. The SWC hosts a website with links to a number of tools and resources to support source water protection.

SRS Exercise Development Toolbox (EPA, 2016l)

https://www.epa.gov/waterqualitysurveillance/water-quality-surveillance-and-response-system-exercise-development-toolbox

The Exercise Development Toolbox helps utilities and response partner agencies to design, conduct, and evaluate exercises around contamination scenarios. These exercises can be used to develop and refine investigation and response procedures, and train personnel in the proper implementation of those procedures. The toolbox guides users through the process of developing realistic scenarios, designing discussion-based and operations-based exercises, and creating exercise documents. March 2016.

Glossary

accuracy. The degree to which a measured value represents the true value.

alert. An indication from an SRS surveillance component that an anomaly has been detected in a datastream monitored by that component. Alerts may be visual or audible, and may initiate automatic notifications such as pager, text, or email messages.

alert investigation process. A documented process that guides the investigation of an SRS alert. A typical procedure defines roles and responsibilities for alert investigations, includes an investigation process diagram, and provides one or more checklists to guide investigators through their role in the process.

anomaly. A deviation from an established baseline in a monitored datastream. Detection of an anomaly by an SRS surveillance component generates an alert.

anomaly detection system (ADS). A data analysis tool designed to detect deviations from an established baseline. An ADS may take a variety of forms, ranging from thresholds to complex computer algorithms.

architecture. The fundamental organization of a system embodied in its components, their relationships to each other and the environment, and the principles guiding its design and evolution. The architecture of an information management system is conceptualized as three tiers: source data systems, analytical infrastructure, and presentation.

baseline. Values for a datastream that include the variability observed during typical system conditions.

completeness. The percentage of data that is of sufficient quality to support its intended use.

component. One of the primary functional areas of an SRS. There are four surveillance components: Online Water Quality Monitoring (including source water and distribution system monitoring), Enhanced Security Monitoring, Customer Complaint Surveillance, and Public Health Surveillance. There are two response components: Consequence Management and Sampling and Analysis.

consequence. The adverse effects of an incident experienced by a utility (e.g., damaged infrastructure) or its customers (e.g., illness). In the context of a source water risk assessment, consequences result when a threat contaminates or degrades the quality of a source water. The value for consequence in the risk assessment equation can be based on quantitative factors such as economic damage, duration of lost services, number of illnesses, or number of fatalities. The consequence value can also be based on semi-quantitative measures and normalized such that the SW threat that would result in the greatest consequences has a consequence value of 100, and the values for all other SW threats being less than 100.

Consequence Management (CM). One of the response components of an SRS. This component encompasses actions taken to plan for and respond to possible drinking water contamination incidents to minimize the response and recovery timeframe, and ultimately minimize consequences to a utility and the public.

contamination incident. The presence of a contaminant in a source water or drinking water distribution system that has the potential to cause harm to a utility or the community served by the utility. Contamination incidents may have natural (e.g., toxins produced by a harmful algal bloom), accidental (e.g., chemicals spilled into a source water), or intentional (e.g., purposeful injection of a contaminant into a source water) causes.

control center. A utility facility that houses operators who monitor and control treatment plant and system operations, as well as other personnel with monitoring or control responsibilities. Control centers often receive system alerts related to operations, water quality, security, and some of the SRS surveillance components.

control point. A location where a treatment process can be modified (e.g., addition of pretreatment chemicals) or a response action can be implemented (e.g., closing an intake).

critical detection point. The location upstream of a drinking water intake from which the hydraulic travel time to the intake equals the time required to implement a response action, such as closing an intake structure. The location of the critical detection point is a function of the flow rate used to calculate the hydraulic travel time.

dashboard. A visually oriented user interface that integrates data from multiple SRS components to provide a holistic view of system water quality. The integrated display of information in a dashboard allows for more efficient and effective management of water quality and the timely investigation of water quality anomalies.

data analysis. The process of analyzing data to support routine system operation, rapid identification of water quality anomalies, and generation of alert notifications.

data quality objectives. Qualitative and quantitative statements that clarify study objectives, define the appropriate types of data, and specify the tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

design goal. The specific benefits to be realized through deployment of an SRS and each of its components. For source water monitoring, the following three design goals are applicable: to optimize treatment processes, detect contamination incidents, and monitor threats to long-term water quality.

Distribution System Contamination Response Plan. A planned decision-making framework that establishes roles and responsibilities and guides the investigative and response actions following a determination that distribution system contamination is possible.

emergency response plan (ERP). A document that describes the actions a drinking water utility would take in response to a variety of emergencies such as contamination incidents, natural disasters, or loss of a critical asset.

functional requirement. A type of information management requirement that defines key features and attributes of an information management system that are visible to the end user. Examples of functional requirements include the manner in which data is accessed, the types of tables and plots that can be produced through the user interface, the manner in which component alerts are transmitted to investigators, and the ability to generate custom reports.

geographic information system (GIS). Hardware and software used to store, manage, and display geographically referenced information. Typical information layers used by water utilities include utility infrastructure, hydrants, service lines, streets, and hydraulic zones. GIS can also be used to display information generated by an SRS.

information management system. The combination of hardware, software, tools, and processes that collectively support an SRS and provide users with information needed to monitor real-time system conditions. The system allows users to efficiently identify, investigate, and respond to water quality incidents.

invalid alert. An alert from an SWM system that is not due to a true water quality anomaly or a contamination incident.

lifecycle cost. The total cost of a system, component, or asset over its useful life. Lifecycle cost includes the cost of implementation, operation and maintenance, and renewal.

likelihood. In the context of a source water risk assessment, the probability that an SW threat will contaminate the source water. The value for likelihood in the risk assessment equation can range from 0 (contamination won't occur) to 1 (contamination is certain to occur).

Online Water Quality Monitoring (OWQM). One of the surveillance components of an SRS. OWQM utilizes data collected from monitoring stations that are deployed at strategic locations in a source water or a distribution system. Monitored parameters can include common water quality parameters (e.g., pH, specific conductance, turbidity) and advanced parameters (e.g., total organic carbon, spectral absorbance). Data from monitoring stations is transferred to a central location and analyzed.

percentile. In statistics, a value on a scale of 100 that indicates the percent of a distribution that is equal to or below it.

performance objectives. Measurable indicators of how well an SRS or its components meet established design goals.

possible. In the context of the threat level determination process, water contamination is considered possible if the cause of an alert from one of the surveillance components cannot be identified or determined to be benign.

preliminary operation. A period of SRS component operation during which all equipment and IT systems are operational, but data analysis and investigations are not performed in real time. The purpose of preliminary operations is to evaluate the performance of the SRS component, address problems, and allow personnel to become familiar with SRS component procedures.

real-time. A mode of operation in which data describing the current state of a system is available in sufficient time for analysis and subsequent use to support assessment, control, and decision functions related to the monitored system.

risk assessment. A method of assigning risk values to a threat based on likelihood, vulnerability, and consequence. The current standard risk methodology for the water sector is the J100 standard.

risk communication plan. A plan developed by a utility to guide communications with the public and coordination with response partners and the media during an emergency.

Sampling and Analysis (S&A). One of the response components of an SRS. S&A is activated during Consequence Management to help confirm or rule out possible water contamination through field and laboratory analyses of water samples. In addition to laboratory analyses, S&A includes all the activities associated with site characterization. S&A continues to be active throughout remediation and recovery if contamination is confirmed.

source water. Water from natural resources that is generally treated in order to produce drinking water for a community. Source water is usually classified as either groundwater (drawn from aquifers) or surface water (drawn from rivers, streams, lakes, ponds, etc.). Prior to being removed for the purpose of drinking water production, surface water may have other uses such as recreation (e.g., boating, swimming, fishing), aquaculture, and transportation route.

source water threat (SW threat). A facility, land use, weather event, or environmental condition with the potential to degrade source water quality.

spectral fingerprint. The spectral absorbance of a sample over a range of wavelengths (typically in the visible and ultraviolet spectrum). Spectral fingerprints can be measured for specific compounds or complex mixtures, and can be a means of identifying the presence of a specific compound or a change in the characteristics of a complex mixture.

SWM location. The specific location in a source water or watershed where water is sampled for measurement by an SWM station. Note that an SWM station may be installed away from the SWM location (i.e., if the water sample is transported from the waterbody to the SWM station through piping).

SWM station. A configuration of one or more water quality instruments and associated support systems, such as plumbing, electric, and communications that is installed to monitor water quality in real time at an SWM location.

technical requirement. A type of information management requirement that defines system attributes and design features that are often not readily apparent to the end user, but are essential to meeting functional requirements or other design constraints. Examples include attributes such as system availability, information security and privacy, backup and recovery, data storage needs, and inter-system integration requirements.

threshold. Minimum and/or maximum acceptable values for individual datastreams that are compared against current or recent data to determine whether conditions are anomalous or atypical of normal operations.

treatment process model. A conceptual representation of the operation and performance of a drinking water treatment unit process. The model typically captures the relationship among influent water quality, treatment process settings, and effluent water quality. Treatment process models can be categorized as mechanistic, statistical, or knowledge-based.

treatment roadmap. A set of instructions for adjusting treatment processes to achieve treatment targets based on information from influent water quality data, process monitoring feedback, or process effluent water quality data.

valid alert. An alert due to water contamination, a verified water quality incident, an intrusion at a utility facility, or a public health incident.

vulnerability. In the context of a source water risk assessment, the probability that a utility or its customers would be impacted by an SW threat. The value for vulnerability in the risk assessment equation can range from 0 (no adverse impact will occur) to 1 (adverse impact is certain to occur). The vulnerability value is generally based on the ability of the utility to effectively respond to an SW threat, preventing or mitigating consequences to utility infrastructure, operations, and customers.

water quality instrument. A unit that includes one or more sensors, electronics, internal plumbing, displays, and software that is necessary to take a water quality measurement and generate data in a format that can be communicated, stored, and displayed. Some instruments also includes diagnostic tools.

water quality sensor. The part of a water quality instrument that performs the physical measurement of a water quality parameter in a sample.

Water Quality Surveillance and Response System (SRS). A system that employs one or more surveillance components to monitor and manage source water and distribution system water quality in real time. An SRS utilizes a variety of data analysis techniques to detect water quality anomalies and generate alerts. Procedures guide the investigation of alerts and the response to validated water quality incidents that might impact operations, public health, or utility infrastructure.