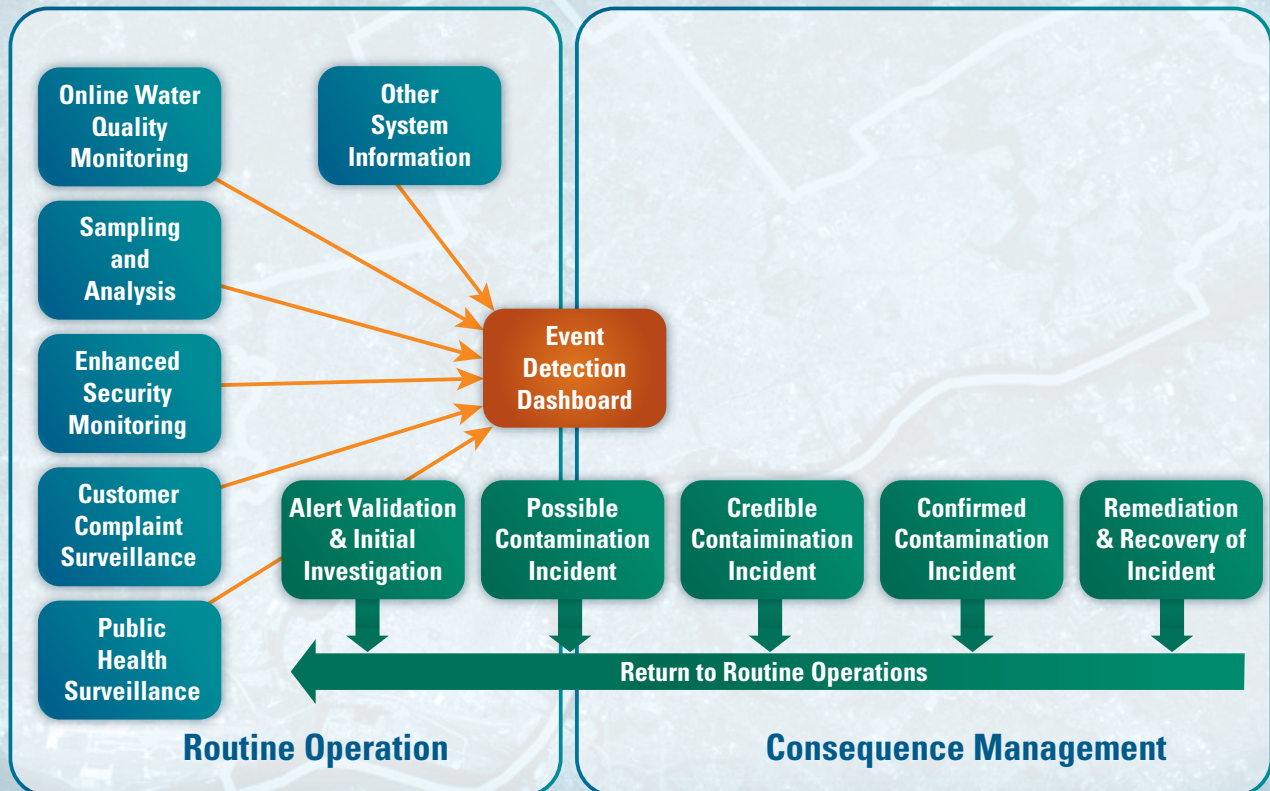


Philadelphia Water Department
 Contamination Warning System Demonstration Pilot Project:

Developing and Maintaining a Baseline for Water Quality



EPA Disclaimer

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Abstract

The Philadelphia Water Department (PWD) developed a comprehensive contamination warning system (CWS) for its drinking water system under a Water Security (WS) initiative grant from the U.S. Environmental Protection Agency (EPA). One of the sampling and analysis (S&A) objectives is to provide and characterize water quality data for specific contaminants and contaminant classes under normal operating conditions. The water quality data are obtained as part of baseline monitoring through sample collection in the distribution system and sample analysis, or mining historical data. These data are then used to develop a baseline water quality profile. After a baseline water quality profile has been established, maintenance monitoring is performed indefinitely to update the baseline water quality profile and maintain S&A response capabilities.

This paper provides general information on establishing procedures to ensure data quality, develop baseline and maintenance monitoring programs, and analyze and manage the water quality data obtained through these programs. In general, PWD leveraged existing monitoring programs and historical data and added monitoring locations to obtain needed information to complete the baseline database. The maintenance monitoring sampling parameters, locations and frequencies, and laboratory analyses were selected based on the results of the baseline monitoring program. The maintenance monitoring sampling parameters, methods, locations and frequencies are largely based on the existing routine monitoring program because PWD's routine monitoring program provides (1) adequate coverage of the detectable contaminants, (2) continuous water quality data, and (3) the maintenance of sampling and laboratory analysis capabilities.

Project Background

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

The project has six major components:

1. Online water quality monitoring
2. Sampling and analysis
3. Enhanced security monitoring
4. Consumer complaint surveillance
5. Public health surveillance
6. Consequence management

One of the S&A component objectives is to provide and characterize water quality data for specific contaminants and contaminant classes under normal operating conditions. The data are obtained through distribution system sample collection and analysis, or mining historical data. These data are then used to develop a baseline water quality profile. This data collection effort is referred to as baseline monitoring. The EPA defines baseline monitoring, in the context of a CWS, as a sampling and analysis activity of specified duration with the object of establishing EPA priority contaminant occurrence (contaminants, levels, and frequency of detection) and method performance (precision, recovery, and interferences) in utility system water samples. This characterization of the water extends to identification (but not necessarily quantification) of non-priority contaminants and tentatively identified compounds. The PWD baseline monitoring program was a 1-year program that was initiated in July 2010.

After a baseline water quality profile has been established, maintenance monitoring is performed indefinitely to update the baseline water quality profile and maintain S&A response capabilities.

CH2M HILL served as the project contractor and supported PWD in development of its CWS. CH2M HILL supported PWD in the design and implementation of the baseline and maintenance monitoring programs and water quality data analysis.

Description of PWD and Routine Water Quality Monitoring

PWD is a municipal utility providing integrated water, wastewater, and storm water services to the greater Philadelphia region. PWD delivers reliable and safe drinking water to more than 1.6 million people in Philadelphia and its suburbs. Source water is obtained from the Delaware and Schuylkill Rivers.

PWD maintains 84 drinking water sampling stations for routine water quality monitoring and regulatory compliance purposes. The monitoring sites include PWD facilities and various other sites (such as police and fire stations) spread throughout the distribution system. PWD also conducts optimized corrosion control sampling at 13 locations throughout the distribution system and at the entry points to the distribution system to comply with Pennsylvania Department of Environmental Protection permit requirements under EPA's Lead and Copper Rule. The 13 locations throughout the distribution system are monitored quarterly. Entry points to distribution are sampled weekly. Each parameter has a designated monitoring schedule that may require analysis at Bureau of Laboratory Services (BLS) daily, weekly, monthly, quarterly or annually. PWD routinely analyzes for general water quality, metals, and biologicals. Volatile and semi-volatile organics are analyzed quarterly.

Baseline and Maintenance Monitoring Program Objectives

Baseline monitoring is a special purpose monitoring program that is not intended to fulfill any regulatory compliance monitoring requirements, nor is baseline monitoring an early detection component in the CWS. The frequency of sample collection and the limited number of samples collected make it unlikely that baseline monitoring will detect a transient, localized event (EPA 2007).

Baseline monitoring defines analytical method performance, determines background or "baseline" levels of targeted and nontargeted contaminants, and analyzes, stores, retrieves, and interprets data in a manner that supports threat evaluation during the CWS event response process. It is recognized that active baseline monitoring at any feasible frequency is unlikely to capture episodic contaminant occurrence, though it would capture occurrence of contaminants often found in the water and identify method performance issues. For that reason, analysis of historical data is yet another means of establishing baseline data. PWD's baseline monitoring program was designed considering the following objectives (EPA 2005):

- Establish field and laboratory preparedness for rapid response during a CWS event.
- Practice event response under low-stress conditions.
- Determine contaminant occurrence, frequency, and concentration under various seasonal and spatial water conditions.
- Determine analytical method performance.
- Establish data management and analysis tools to analyze, store, retrieve, and interpret data in a manner that supports the threat evaluation process.
- Establish or maintain relationships with external support labs.
- Develop recommendations for a long-term maintenance monitoring program.

Ongoing maintenance monitoring is conducted to ensure the usability of the baseline water quality data as a reference for data interpretation and to retain the ability to effectively conduct sampling and analysis activities. The maintenance monitoring program was designed considering the following objectives (EPA 2005):

- Maintain Proficiency with Sampling and Analysis Processes – Sampling frequencies will be established to allow personnel to maintain proficiency in laboratory and field processes that may otherwise be employed only during rare water quality incidents.
- Maintain a Baseline Water Quality Profile – The baseline water quality profile is used to determine whether incident sample test results are outside the range defined as normal. Maintenance monitoring should

maintain the water quality profile to account for changes such as source water characteristics and treatment process changes to ensure that all baseline data are reliable enough to make such determinations.

- Maintain Equipment and Supplies – Routine inspection of equipment and supplies will help to ensure response readiness. Examples include charging/replacing field equipment batteries, performing instrument response checks, and verifying laboratory analytical equipment readiness.
- Keep Current with the Advancements in Equipment and Processes – As the science of sampling and analysis advances, it will be crucial for PWD to keep current.
- Maintain a Laboratory Support Network – A strong laboratory support system will be important if samples require specialty analysis or overflow analytical support is needed. Having current contracts or letters of understanding and current contact information in place will expedite the analysis process.
- Maintain an Agency Support Network – A strong agency support network will be important if specialty testing, hazardous substance, or law enforcement response is required.

The maintenance monitoring plan should be reviewed periodically and compared to the objectives described above. If outcomes fall short of the objectives, the process should be refined to ensure the quality of the baseline water quality profile and the sampling and analysis capabilities. The maintenance monitoring sampling design should be modified during maintenance monitoring to take advantage of any identified dual benefit.

Data Quality

Data Quality Assurance and Control

To assure data quality throughout the CWS project, PWD developed and established a formal quality system. The quality system is a structured and documented management approach describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan to ensure quality of work processes, products, and services (EPA 2001, 2002). It provides the framework for planning, implementing, and assessing quality assurance/quality control (QA/QC) activities on the project. The quality system was documented in the project Quality Management Plan and Quality Assurance Project Plans (QAPPs).

All S&A component activities were planned at both management and technical levels to ensure that applicable quality objectives are adequately identified and relevant quality-related activities are specified. The S&A QAPP documented planning activities to ensure that each person was informed of and understood the requirements of the QA/QC program. The S&A QAPP described how quality objectives will be met for the various tasks in the S&A component, including sampling, laboratory analysis, baseline and maintenance monitoring, and response to CWS events. For this project, PWD leveraged existing processes and procedures from various supporting documents and included them as part of the S&A QAPP. The BLS Quality Manual and standard operating procedures (SOPs) were included as appendices. These documents collectively formed the core of the quality system for the S&A component.

Data Quality Objectives

The data quality objectives process is a systematic procedure for establishing the criteria that a data collection design should satisfy, and it determines the type, quantity, and quality of data needed for effective decision-making and planning (EPA 2006). The S&A data quality objectives were selected to provide the ability to compare a result with baseline or “normal” water quality. The laboratory and field data quality objectives were presented in the S&A QAPP and in each SOP.

Quality Control Check Samples

QC check samples provide a means to monitor analytical precision and accuracy. QC samples are analyzed and compared to established acceptance criteria. The QC check sample types and analysis frequency were presented in each SOP and typically include the following:

- Blank samples
- Duplicate samples

- Secondary source standards
- Matrix spikes/matrix spike duplicates

Data Quality Indicators

Data quality indicators are the qualitative and quantitative descriptors used to interpret the degree of acceptability or utility of data for the end user. The principal data quality indicators are bias, precision, accuracy, comparability, completeness, representativeness, and sensitivity. The data quality indicator requirements for each analytical method were specified in the SOP and presented in the S&A QAPP.

Demonstration of Capability

Each analyst conducting the testing performed an initial demonstration of capability for each analytical procedure. A training checklist form and initial demonstration of capability certification form should be contained in the S&A QAPP. Continuing demonstration of capability should also be performed periodically. The initial and continuing demonstration of capability is detailed in the analytical method SOPs.

Standard Operating Procedures

SOPs were developed for both field and analytical testing. They describe the specific processes and requirements and may be used as both operational and training tools. PWD already had most SOPs developed before the project, but some laboratory SOPs needed to be updated and some field SOPs needed to be developed for new equipment and processes. The component leader, quality assurance officer, and laboratory management team should ensure that SOPs are followed and that appropriate updates are made as needed. The SOPs were provided in the S&A QAPP.

Data Review, Validation, and Management

The data review, validation, and management processes were detailed in the QAPP and in each Sampling and Analysis Plan. This process ensures that the quality objectives and performance criteria established are met during data collection and evaluation.

Data verification is the process of evaluating the completeness, correctness, and conformance of a specific data set against method, procedure, or contract specifications. Under the BLS quality system, all laboratory data follows a review process to ensure that the reported data are free from transcription and calculation errors. Data completeness, technical acceptance, and verification of method requirements are reviewed by each analyst and the laboratory supervisor or other authorized personnel. Data calculations and formulas for each test method are presented in their respective SOPs.

Once the data have been verified, they go through a data validation process to evaluate whether the data quality goals established in the quality plans have been achieved. To the extent possible, data are reported only if all QC measures are acceptable. Data that meet the data quality objectives, data quality indicators, and method-specific QA requirements are considered acceptable for reporting and signed off by a laboratory supervisor or other authorized personnel. When data quality objectives or method-specific QA requirements are not met, the affected samples are reanalyzed, or the results are reported to the user with a qualifying note.

Assessment and Oversight

The QAPP and each Sampling and Analysis Plan detail the assessment and oversight processes. As work for the baseline and maintenance monitoring program progresses, each element is evaluated to ensure that adequate levels of quality are being achieved and that the component is functioning as intended for the CWS project. Project assessments include review of baseline data, field operations, and analytical methods.

Self-assessment procedures, such as internal audits and management system reviews, are conducted throughout the project. Management system reviews are qualitative assessments of a data collection and validation operation to determine whether the prevailing quality management structure, policies, practices, and procedures are

adequate for ensuring that the type and quality of data needed are obtained. For the CWS project, the PWD component leader and the BLS quality assurance officer conducted the management system reviews.

Developing Sampling Designs

Baseline Sampling Design Information

EPA provided guidance in the development of the baseline monitoring design and identification of monitoring locations and frequency in the *Interim Guidance on Planning for Contamination Warning System Deployment* (2007). The guidance document recommends that the baseline monitoring program proceed through six phases of activity, culminating in the development of a maintenance monitoring program (EPA 2007). The first five phases are designed to establish laboratory capabilities and QC practices and to perform survey studies of the distribution system to determine if system variability influences contaminant occurrence or method performance. Phase 6 analyzes the results from the first five phases and establishes control charts and tools for use during a triggered sampling and analysis event. The following describes the phases of the baseline monitoring as provided in the EPA guidance document.

Phase 1 – SOPs and necessary resource document development for critical activities related to baseline monitoring should be developed. Initial demonstrations of capability (IDC) and minimum reporting limits for each method and contaminant should be established, as well as data reporting requirements and protocols.

Phase 2 – Following the development of SOPs and the completion and review of IDC data, finished water at the treatment plants should be analyzed with respect to contaminant occurrence (contaminants detected, levels detected, and frequency of detection) and method performance. Finished water results from the treatment plant serve as a benchmark for comparison of contaminant occurrence and method performance on distribution system water results. All future baseline and triggered sampling events may include the water treatment plant's effluent as a control.

Phase 3 – Regular surveillance monitoring of strategic/priority locations should be initiated and conducted at regular intervals to establish baselines for these locations and to determine whether there are seasonal or spatial trends.

Phase 4 – A survey study should be performed to determine contaminant occurrence and method performance in the distribution system. Sample collection locations should be selected with the goal of achieving spatial coverage of the distribution system and to capture a wide range of conditions in source water, water age in different pressure zones, and pipe material. Phase 4 is designed to survey the distribution system for contaminant occurrence and method performance. The results from this survey study may result in the design of Phase 5 (focused studies).

Phase 5 – Based on the results of Phases 2 through 4, short-term, focused studies may be conducted to look more closely at possible differences in contaminant occurrence or method performance within the distribution system. If significant differences are found, these findings may influence the selection of locations for maintenance monitoring.

Phase 6 – The final phase analyzes the results from Phases 1 through 5 to establish the management, interpretation, and use of baseline data and to establish a maintenance monitoring program. Emphasis should be placed on access and interpretation of baseline data during a triggered sampling and analysis event.

The guidance document provides information on the selection of baseline monitoring locations and frequency. A primary goal of location selection for baseline monitoring is to collect water from locations that are representative of the distribution system. Key locations throughout the distribution system should be selected so that data from those locations can be compared to finished water data collected at the treatment plants. Water treatment plant effluent should be used as a control for comparison of all data from baseline monitoring and triggered sampling events. The purpose of baseline monitoring from multiple and diverse locations is to determine whether the water is homogeneous with respect to contaminants detected, levels detected, frequency of detection, and

method performance. Other factors that should be considered in selecting potential sampling locations for baseline monitoring include the following (EPA 2007):

- Proximity of location to utility (a sampling location situated farther from the utility may have greater vulnerability, such as potentially decreased chlorine residual).
- Accessibility of location (ease of access for samplers to collect large samples and to gain access to sample collection location).
- Percentage of treated supply from each plant into the system (consider increased sampling of key locations that receive finished water from plants that contribute a higher percentage).
- Age of the water being sampled (extremely aged water could have a decreased chlorine residual or increased potential for the presence of bacterial regrowth compared to water that is less than 1 day old).
- Condition and composition of piping that finished water has passed through before being sampled.
- Finished water storage facility (vulnerability, condition, mixing of water).
- High-risk locations where backflow into the system could pose a significant threat.
- Other key locations, such as pump stations.
- Other key locations as identified through assessments for online water quality and enhanced security monitoring.

Sampling frequency for baseline monitoring should consider the following factors (EPA 2007):

- Size of the utility's distribution system and service community
- Flow rates through various parts of distribution system
- High pressure points within the system
- Seasonal affects (e.g., increased intake of surface water into plant due to rainy season or snow/ice melts)
- Changes in water source (if different sources are used during different times of the year)
- Frequency of customer complaints (e.g., increased customer complaints during stagnant, hot seasons)

Baseline Monitoring Design at PWD

The baseline monitoring program at PWD was designed to leverage data from existing monitoring programs and add monitoring locations to fill needed information to complete the baseline database to meet CWS objectives. Baseline monitoring was divided into three phases of activity and was conducted for 1 year. Phase 1 was the same as Phase 1 of the EPA guidance document. Phase 2 combined Phases 2 through 5 of the EPA guidance document as monitoring studies were not implemented over time but conducted concurrently. Phase 3 was the same as Phase 6 of the EPA guidance document. Details of each phase for each contaminant class were described in the baseline monitoring Sampling and Analysis Plan. Contaminant classes or methodologies proceeded at a different pace and level of effort because of practical limitations in sample collection, analysis, costs, and personnel limitations, and to achieve sustainability and dual benefits. The following describes the phases of the baseline monitoring at PWD.

Phase 1 – SOPs and necessary resource documents for critical activities related to baseline monitoring were assembled or developed, as appropriate. These SOPs were compiled and provided in the QAPP. IDC and minimum reporting limits for each method and contaminant were compiled. Data reporting requirements and protocols were reviewed.

Phase 2 – Finished water at the treatment plants (entry points to the distribution system) and specific routine monitoring locations in the distribution system were analyzed to determine contaminant occurrence (contaminants detected, levels detected, and frequency of detection), method performance and seasonal and spatial trends.

Phase 2 of baseline monitoring consisted of field data collection and laboratory analysis. Field operations data collected during the baseline monitoring period included the use of field safety screening equipment and rapid field screening. Field safety screening equipment, HAPSITE® (volatile organic compounds [VOCs]) and HazMat

Smart-Strips, were used and assessed for sustainability during an exercise. Radioactivity screening using the Ludlum instrument was conducted four times at numerous locations at BLS. Rapid field testing was conducted as part of the hydrant flushing studies. Hydrant flushing studies were conducted four times during the baseline monitoring period to evaluate possible matrix effects on analytical methods and to determine whether the variations in field parameter concentrations were due to high turbidity and iron resulting from the hydrant flush. The field measurements included pH, specific conductance, turbidity, total chlorine residual, free cyanide, and UV-254 using the portable scan instrument.

Laboratory analysis during the 1-year baseline monitoring period included inorganic and indicator parameters, metals, biological, radiologicals, and volatile and semi-volatile organic compounds. Most of the inorganic and indicator parameters were analyzed under existing monitoring programs for compliance purposes. Additional monitoring/measurements for inorganic and indicator parameters conducted under the CWS include the following:

- Quarterly analysis of turbidity, apparent color, total chlorine, and total organic carbon at 12 locations during the hydrant flushing focused study
- Quarterly analysis of total organic carbon at specific distribution taps
- Quarterly analysis of relative acute toxicity using Eclox methods at the entry points to distribution and specific distribution taps

Toxicity testing using the Eclox test kit was performed in the laboratory on 336 samples collected at 8 locations collected from June 2010 to April 2011. It should be noted that based upon its use during baseline monitoring and input from other utilities, Eclox provides highly variable results, requires significant time for sample analysis, can have unusable reagents, and is costly. Furthermore, studies have shown that the presence of some contaminants at concentrations considered toxic to human health were not detected.

The majority of the metals were analyzed under existing monitoring programs for compliance purposes. Additional monitoring/measurements for metals conducted under the CWS include the following:

- Analysis of metals quarterly at specific distribution taps
- Quarterly analysis of metals at 12 hydrants during the hydrant flushing study
- Analysis of a larger suite of metals using full- and semi-quantification methods during the hydrant flushing study

Four hydrant flushing studies were conducted during the baseline monitoring period to evaluate the usefulness of hydrant samples for contamination detection and tracking for security and distribution operations in an aging water distribution system. The samples collected as part of the hydrant flushing study were also analyzed for a larger suite of metals using full- and semi-quantification methods.

Three site characterization emergency response sampling exercises were conducted to practice the process of collecting samples, contacting the laboratory, getting samples to the laboratory, and testing the laboratory response and data communication processes. Although the samples were collected as part of site characterization, the laboratory results for the samples are considered a part of the baseline monitoring program. PWD and a contract laboratory developed ready-to-go Water Quality Response Kits to provide 24-hour turnaround for all possible water contaminants that the contract laboratory could manage. These included general water quality parameters, metals (EPA 200.7 and 200.8), biologicals (SM20 9223 B), VOCs (EPA 524.2), SVOCs (EPA 525.2), carbamates (EPA 531.1 rev 3.1), herbicides (EPA 515.1 and SM-846 8151 A), pesticides (EPA 508, 509 and SW 846 8141 A), and petroleum products (SW 846 8015B). Finished water samples using the Water Quality Response Kits were collected at the three WTPs during three site characterization emergency response exercises and sent to the contract laboratory for analysis. Nine samples were collected and analyzed for each parameter.

A review was conducted on how the online water quality monitoring overlapped with S&A and where the overlap could be streamlined for sustainability and dual purposes.

Phase 3: The final phase included the analysis of the results from Phases 1 and 2 to establish the management, interpretation and use of baseline data and to establish a maintenance monitoring program. Emphasis was placed on access and interpretation of baseline data during a triggered sampling and analysis incident.

Maintenance Monitoring Design at PWD

The maintenance monitoring sampling parameters, locations, frequencies, and laboratory analyses were selected based on the results of the baseline monitoring program. The maintenance monitoring sampling parameters, methods, locations, and frequencies were largely based on the existing routine monitoring program because PWD's routine monitoring program provides (1) adequate coverage of the detectable contaminants, (2) continuous water quality data, and (3) the maintenance of the sampling and laboratory analysis capabilities. Therefore, modifications to the routine sampling program could result in modifications to the maintenance monitoring design. Any modification to the routine monitoring program will consider the maintenance monitoring design objectives.

Data Analysis and Management

Baseline Data Analysis and Control Limits

Phase 3 of baseline monitoring included the development of a baseline database, and the analysis of the results to evaluate and interpret the baseline data to establish the maintenance monitoring program. Existing data and data collected under baseline monitoring were evaluated by developing basic summary statistics, determining statistically significant spatial or temporal differences in parameter concentrations, and developing control limits that could differentiate normal from abnormal test results during maintenance monitoring. Control limit types (regulatory, reporting, system operational, and statistically generated upper bound limits) for a given parameter were evaluated by calculating the frequency at which the detectable concentrations were greater than or less than the associated limit. The most appropriate control limit was then selected based on the parameter's frequency of detection, behavior in the distribution system and source water, the availability and representativeness of predetermined and statistically derived limits and the ability of the control limit to identify abnormal water quality without increasing the number of false positives.

To have confidence in the control limits over time, PWD plans to continually update the baseline water quality database. A new laboratory information management system (LIMS)(WinLIMS™) was installed after the CWS project was completed. This new system will have the capability to update dynamic control limits based on maintenance monitoring data and then compare analyte concentrations to both embedded static control limits and the recalculated dynamic control limits to identify any exceedance. Control limits will be re-evaluated and updated on either a systematic (every 2 to 3 years) or as-needed (changes in source water or treatment goals) basis.

Data Management

All finalized laboratory results and relevant QA/QC data will be stored in the current BLS LIMS (Microsoft SQL Server 6.5) until the new LIMS system is implemented. The new software will improve data entry and reporting capabilities, enhance information management, and accommodate important metadata related to QA/QC and analytical methods. QA/QC data will also be available in hard copy form.

Recommendations and Conclusions

To assure data quality during the baseline and maintenance monitoring programs, a formal quality system should be developed and documented in the QAPP. The S&A QAPP documents planning activities to ensure that each person is informed of and understands the requirements of the QA/QC program. Existing data quality processes and procedures should be leveraged to form the core of the quality system for the S&A component.

The baseline monitoring program should be designed in phases to establish laboratory capabilities and QC practices, and perform survey studies of the distribution system to determine whether system variability influences contaminant occurrence or method performance. An analysis of these results will help to establish tools for use during a triggered sampling and analysis incident. To the extent possible, water utilities should leverage their existing laboratory and field capabilities and monitoring programs to develop baseline and maintenance monitoring programs that are cost-effective and sustainable. Water utilities have various reasons to monitor water quality: from regulatory requirements, to process control, to avoidance of customer complaints. In general, developing baseline and maintenance monitoring is appropriate for each water quality parameter for which a water utility collects data.

Abbreviations and Acronyms

BLS	Bureau of Laboratory Services
CWS	Contamination Warning System
EPA	United States Environmental Protection Agency
IDC	Initial demonstration of capability
PWD	Philadelphia Water Department
LIMS	Laboratory Information Management System
QAPP	Quality Assurance Project Plans
QA/QC	Quality assurance/quality control
S&A	Sampling and Analysis
SOP	Standard operating procedure
SVOC	Semivolatile organic compound
UV	Ultraviolet
VOC	Volatile organic compound
WS	Water Security

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