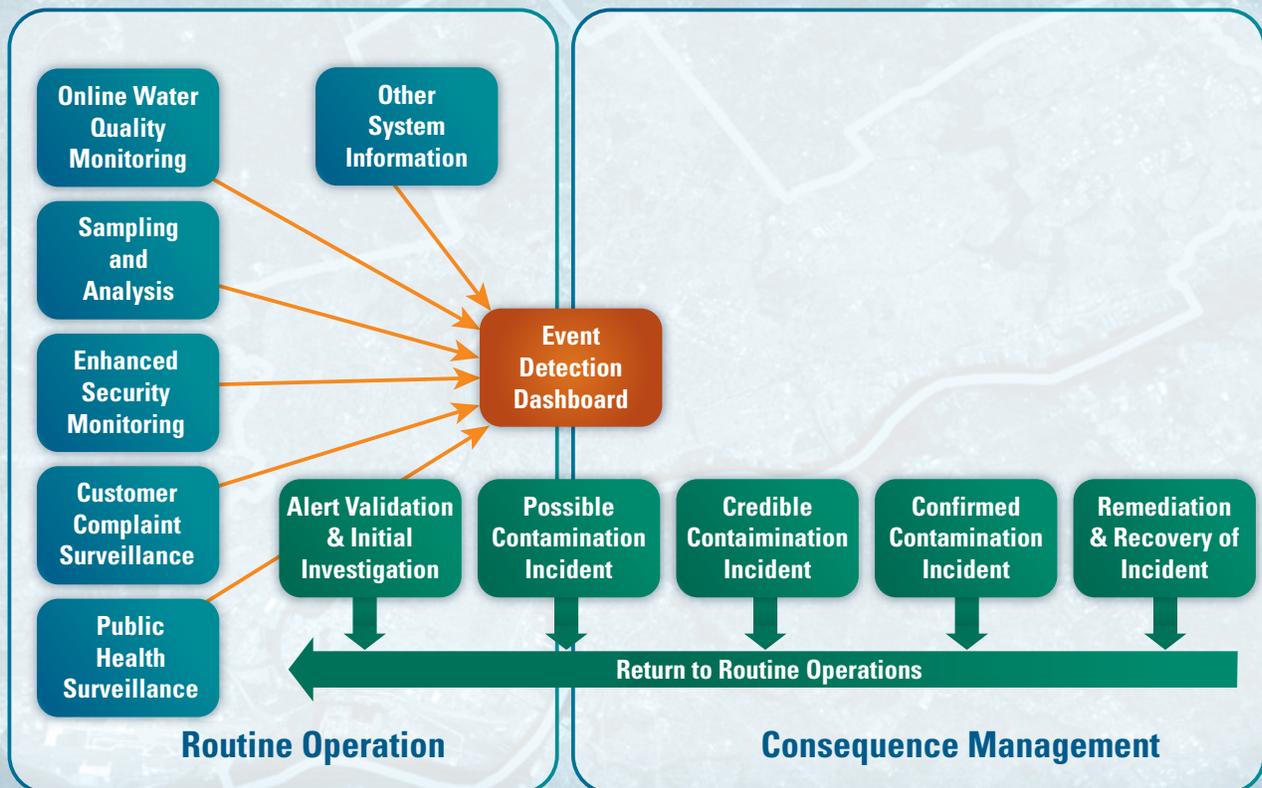


Philadelphia Water Department
 Contamination Warning System Demonstration Pilot Project:

Selection of Online Water Quality Monitoring Technologies and Station Design



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Abstract

The Philadelphia Water Department (PWD) developed a comprehensive contamination warning system (CWS) for its drinking water system under a U.S. Environmental Protection Agency (EPA) Water Security (WS) initiative grant. One of the online water quality monitoring (OWQM) component objectives was to design the OWQM sensors and stations to continuously monitor the distribution system. The sensor data is used to identify abnormal water quality, including possible water contamination and to generate an alert.

This paper describes the justification used by PWD in selecting the water quality parameters it included at the monitoring stations. It also present the approach used in selecting the various sensors located in the OWQM standard station. Lastly, it describes additional analytical instrument evaluation conducted at superstations to gain experience with alternate instruments and technologies.

Project Background

PWD developed a comprehensive CWS for its drinking water system under an EPA 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 OWQM component objectives is to identify the parameters and sensors that will be used to monitor, detect, and alert staff to abnormal distribution system water quality, including a potential contamination event. Achievement of this objective requires an evaluation of the various water quality parameters to determine the appropriate ones for inclusion in the OWQM stations. The various available sensors for these parameters are then compared and the final OWQM station design determined.

CH2M HILL served as the project contractor and supported PWD in development of its CWS. CH2M HILL supported PWD in the evaluation and selection of water quality instruments, determination of requirements and characteristics of selected monitoring locations, and design of OWQM stations.

Water Contaminants and Their Characteristics

EPA has defined 12 classes of potential water contaminants. The 12 categories of contaminants can be consolidated into five general groups (2007):

- Industrial chemicals
- Chemical warfare agents
- Microbial agents
- Biochemical agents
- Radioactive materials

Because the number of potential contaminants is large, many cannot be specifically identified through conventional OWQM monitoring. Thus, it is typically more practical to use sensors that measure indicator or *surrogate* parameters to detect abnormal water quality for possible contamination evaluation.

Early OWQM research demonstrated that changes in 10 of the 12 classes of contaminants can be detected by measuring three common surrogate parameters: chlorine residual, conductivity, and total organic carbon (TOC) (EPA 2009). The two classes of contaminants potentially not sensed by these parameters include chemical warfare agents and plant toxins, which fall under the general group of biochemical agents. Other surrogate water quality parameters which respond at differing levels of sensitivity to various contaminant classes include pH, oxidation-reduction potential (ORP), and turbidity. These six parameters constitute the most common set of surrogates typically included in an OWQM sensor station. For water utilities with particular identified vulnerabilities or concerns, other surrogate or contaminant-specific analyzers may be included in the OWQM system. Volatile organic carbon (VOC) analyzers can detect and identify specific compounds from two of the 12 contaminant classes (chemical warfare agents and plant toxins) and located in the industrial chemicals group.

Rather than measuring surrogate parameters, other sensors detect potential contamination through monitoring of bioactivity. These systems monitor for chemical contaminants by examining the responsiveness of small organisms, such as fish, mussels, daphnia, and algae, to changes in their environment. Fluctuations in the organisms' responses, such as behavior, productivity, or respiration, may indirectly indicate the presence of a chemical contaminant. These systems can be extremely sensitive to detecting water quality anomalies, but as with any surrogate system, additional testing is required to identify the specific contaminant present.

Water quality sensors can monitor parameters that can be present in water due to its source characteristics or resulting from treatment rather than from contamination. For example, nitrification may occur in drinking water when excess ammonia is available from the chloramination process or from the breakdown of chloramines. Nitrification is not considered to be a water contaminant, but early detection of impending nitrification is a worthwhile *operational benefit*, and monitoring for nitrification generally is included in OWQM systems for utilities that use chloramination as a secondary disinfectant in the distribution system. The potential and degree of nitrification can be determined by evaluating nitrite, nitrate, ammonia, and assimilable organic carbon levels in the distribution system.

Selection of Parameters for Contamination Monitoring

PWD and CH2M HILL conducted a workshop during which numerous water quality parameters available for OWQM application were considered, as well as various instruments and technologies available for sensing these parameters. PWD ultimately decided that the standard OWQM station would include instruments to measure:

- Conductivity
- Chlorine (combined)
- pH
- ORP
- Temperature
- Turbidity
- Ultraviolet light absorption (narrow band at the 254-nanometer wavelength)

The following parameters were also considered but were not selected:

- Nitrification was not included based on a decision to focus initially on detection of possible water contamination. If desired, instruments for nitrification monitoring may be added in the future. The spectrolyzers installed at the OWQM superstations, which are discussed below, have the capability to be configured to measure nitrate.
- Use of biomonitors was briefly considered but eliminated because of the high level of maintenance required, and the requirement for sample stream dechlorination before introduction into the biomonitor chamber.

- Traditional electrochemical analysis of TOC was considered but not selected. These analyzers are typically mechanically complex and have a steep learning curve before achieving stable, long-term operation. PWD evaluated this type of TOC analyzer in the past and found them to require high levels of maintenance and calibration to produce acceptable results. Instead, PWD decided to measure ultraviolet light absorbance as a general indication of TOC.
- PWD also considered monitoring for fluoride concentration. However, because fluoride is stable in water, once concentrations are determined at any location, they are unlikely to change, so continuous monitoring was not considered beneficial.

In addition to the standard OWQM stations, two OWQM “superstations” were configured to provide a test bed for alternate analyzers, operating in parallel to standard stations located at the same sites. For these systems, the parameters monitored included:

- Ultraviolet/visible light absorption (continuous broad band spectral analysis from 200 to 770 nanometers)
- Nitrate
- TOC
- Volatile organic carbon (one station only)
- A multi-parameter sonde which included
 - Chlorine (free and total)
 - pH
 - Conductivity
 - Turbidity

Standard OWQM Station Analyzer Selection

Once the water quality parameters to be measured were selected, analyzers from numerous manufacturers were considered for use in the OWQM stations. The following analyzers were selected for installation.

Analytical Technologies Water Quality Panel

The Analytical Technologies Inc. (ATI) suite of surrogate parameter sensors was selected for use in the OWQM standard stations to match the manufacturer and model of instruments widely used elsewhere in the PWD system. This avoided the need to maintain a separate supply of spare parts and the training and expertise needed to maintain instruments that otherwise would differ from the utility’s standard. The following instruments were included in the ATI pre-fabricated water quality panel:

- Combined chlorine – model Q45H
 - This analyzer operates without the use of reagents that require periodic replenishment and therefore minimizes expendables and required maintenance activities.
 - Two chlorine sensors are included at each OWQM station to provide redundancy for this critical process measurement, ensuring that data will not be lost.
- pH – model Q45P. The pH sensor, in addition to providing a measurement for contaminant monitoring, also provides pH compensation to the chlorine analyzer for enhanced accuracy.
- ORP – model Q45R.
- Conductivity – model Q45C4.
- Turbidity – model A17-76.
- Temperature – incorporated into the chlorine, pH, and ORP sensors for signal compensation and secondary indication of the sample water temperature.

Real Tech Security Monitor

Measurement of ultraviolet (UV) 254 absorbance was a new parameter for PWD and was included in the OWQM standard station to provide a general indication of TOC. The Real Tech Security Monitor was selected for use based on its simplicity of design and operation, and low capital cost.

Water is largely transparent to ultraviolet and visible light. The Real Tech Security Monitor measures the absorbance of ultraviolet light, specifically at the 254-nanometer wavelength. Organic content of the sample stream absorbs UV light, and so measurement of UV absorbance provides an indication of the organic concentration. The Real Tech absorbance signal can be correlated to TOC by applying a mathematical slope adjustment to the measured value. Accuracy of this reading is highly dependent on the consistency of the sample water. If the water source changes, the correlation slope may change, and accuracy of the TOC indication would suffer. UV absorbance can be affected by the turbidity content of the water, which the Real Tech analyzer does not compensate for. Therefore, PWD monitors only the UV absorbance signal and does not use the TOC correlation or apply a separate turbidity correction. The Real Tech analyzer takes regular readings of the UV lamp output through free air, and applies a correction to the water reading which addresses lamp aging.

The rate of fouling of the optical windows in the sensor, attributed to iron deposits, proved to be a significant problem throughout the project. This resulted in an inconsistent determination of true UV absorbance, and therefore prevented the Real Tech measurements from being used in the contaminant detection system.

Flow Measurement

At each OWQM station, an electromagnetic flowmeter was installed to provide remote indication of the flow to the measuring instruments. Use of a flow transmitter is beneficial to ensure that sensor measurements are valid and not based on a stagnant sample resulting from disruption of sample flow. A flow transmitter is more costly than a simple flow switch, but less prone to failure than a switch. A measurement of flow confirms that analysis values are based on manufacturer's stated minimum flow rates and therefore helps to confirm accuracy.

Street-side OWQM Station Analyzer Selection

The standard OWQM station is enclosed in a panel approximately 6-feet high, 6-feet wide and 2-feet deep. To test a design which may be installed on a typical city sidewalk, a variant of the standard OWQM station was fabricated in a smaller physical size, approximately 5-feet high, 3-feet wide and 2-feet deep.

This "street-side" or "sidewalk" OWQM station included the same ATI suite of surrogate parameters, but did not have sufficient physical space for installation of the Real Tech Security Monitor. To measure UV absorbance, an instrument manufactured by HV Scientific, the AccUView Online UV% Transmission Analyzer was installed.

HF Scientific AccUView Online UV % Transmittance Analyzer

The AccUView analyzer measures UV absorbance at the 254 nm wavelength.

The analyzer is fabricated in a compact size, which facilitates installation in limited spaces such as the Sidewalk OWQM station. An installed pressure regulator is used to adjust the pressure supplied to the flow measurement cell. A manual valve is provided on the discharge of the flow cell and is used to regulate sample flow and also to maintain system pressure, thereby eliminating small bubbles which may form at low pressure and impact analyzer readings. An integral flow regulator limits sample flow to approximately 1 liter/minute.

An optional ultrasonic cleaning system operates continuously to reduce accumulation of deposits on the walls of the measuring cuvette. Manual cleaning of the cell is still periodically required, as with all of the other UV instruments. PWD's experience was that the cleaning system may have had some effect on deposition of iron, but did not eliminate it entirely. After a period of operation, the difference between UV absorbance readings for the HF Scientific analyzer and a measured grab sample was less than the difference for the Real Tech or standard analyzers.

OWQM “Superstation” Analyzer Selection

For the two “superstations,” additional analytical instruments were selected to gain experience with alternate instruments and technologies that may be selected by PWD for use in future OWQM activities or other water utility applications. These additional analyzers are discussed below.

s::can spectro::lyser™

The s::can spectro::lyser™ is a UV absorbance instrument that measures absorbance at 256 discrete wavelengths ranging from 200 to 700 nm. Each absorbance values is assembled in a broad-band spectral absorption curve for the sample water, which results in greater analytical capability compared to single wavelength UV254 instruments. Analysis of the absorption curve can provide equivalent measurements of several water surrogate parameters including TOC, dissolved organic carbon (DOC), nitrate, and turbidity, among others. The broad band spectral curve itself can be analyzed to identify general water quality changes. Use of special software within the spectro::lyser™ controller can provide a *spectral alarm* indicating changing water conditions.

The PWD-installed system includes measurement and reporting of the surrogate parameters TOC, DOC, nitrate, and turbidity. The event detection system (EDS) selected for use in the project (Bluebox) did not have the capability to evaluate the broad spectral curves generated by the spectro::lyser™, so those data are not included in the EDS analysis or for remote viewing in the PWD system.

Operation of the analyzer was simple and straightforward. Vendor support was available from the US product manager; however, spare parts and factory service were not always available in a timely manner. Product software was updated frequently to resolve operational issues or to provide enhanced functionality which required relatively frequent upgrades of the analyzer operating system. Parts and service availability and software stability had improved substantially by the end of the project.

As with the Real Tech analyzer, fouling of the optical windows due to iron deposition caused substantial difficulties throughout the project. The automated cleaning brushes were set for frequent operation, up to 10 percent of the analyzer monitoring cycle, with limited benefit. This problem prevented the use of the broad spectral data from the spectro::lyser™ from being used in the contamination event detection system.

Intellitect Intellisonde™

The Intellisonde™ is a multi-parameter sonde with sensors for chlorine, pH, conductivity, turbidity, and temperature. The Intellisonde™ chlorine sensor uses new technology consisting of a gold-traced electronic chip that takes measurements based on voltage differences induced in the circuitry. The analyzer is configured so that it can be inserted into a water main through a 1½-inch pipe tee, enabling its use in locations where physically larger instruments cannot fit.

The Intellisonde™ was inserted in a sample port rather than directly into a water main. The objective was to evaluate the device’s operational characteristics and maintenance requirements. As a new technology device, the Intellisonde™ was found to be unstable in operation. Additionally, it did not provide the accuracy and precision of measurement required for long-term use. Its use was discontinued at the end of the project. PWD is having a conversation with Intellitect regarding the performance concerns and the manufacturer has responded positively. Intellitect has revamped the sonde to mitigate the performance issues. Currently, PWD is deliberating whether to evaluate the updated technology.

Inficon CMS-5000

The CMS-5000 is a volatile organic carbon analyzer. PWD owned an earlier version of the analyzer, which was upgraded for inclusion at the OWQM superstations. The analyzer required custom programming to report the concentration of several specific compounds selected from a list of available organic compounds. It was also possible to program the unit to report in a general, nonspecific manner regarding the presence of organic compounds.

The analyzer bubbles inert argon through a water sample to strip organic compounds and entrain them in the gas flow. The gaseous sample flows through a diffusion column contained in the analyzer that separates the various components contained within the flow stream and provides a report.

The analyzer is complex in construction but fairly simple in operation. The user interface is complicated, requiring a high degree of analytical chemistry knowledge for configuration, setup, and data evaluation. Maintenance of the unit requires a high level of technical skills. Based on its operation in the CWS pilot project, the analyzer was regarded as unsuited to continuous monitoring in field OWQM stations. It may be appropriate for use in a laboratory setting, by qualified individuals, to provide a more detailed analysis of water samples that have been highlighted by surrogate parameter monitoring.

Recommendations and Conclusions

PWD selected the surrogate water quality parameters chlorine, conductivity, pH, ORP, and turbidity for online water quality monitoring. It was decided to monitor absorbance of UV254 as an indication of the water's TOC content. Previous research demonstrated that monitoring the chlorine residual, conductivity, and TOC may indicate the potential presence of 10 of the 12 EPA contaminant categories. PWD included pH, ORP, and turbidity sensors because they respond at differing levels of sensitivity to various contaminant classes.

For monitoring the selected parameters, instruments manufactured by ATI and Real Tech were selected for the standard OWQM station. Other instruments were selected for pilot testing at the superstations to monitor the identified water quality parameters and DOC, nitrate, and VOCs. The selected instruments were manufactured by s::can, Intellitect, and Inficon.

Selection of the ATI instruments for use in the OWQM stations provided the following benefits:

- No learning curve for operation or maintenance as PWD uses the same instruments.
- No additional spare parts or components to be maintained in stock.

The only drawback of using ATI instruments was that the physical space required to accommodate the sensors and transmitters was greater than may be achieved with other manufacturers' sensors. However, since physical space was not a limiting factor at the monitoring sites, this did not pose a problem.

The advantages of the Real Tech Security Monitor for the system included:

- Simple instrument to operate and maintain
- Fairly reliable UV 254 absorbance measurement

Drawbacks included:

- No reliable TOC correlation or turbidity compensation
- Poor product documentation that made full use of analyzer diagnostics difficult

For the Streetside stations, the HF Scientific AccUView analyzer provided the following benefits:

- Accurate operation
- Small footprint that enables installation in limited spaces
- Ultrasonic cleaning reduced the degree of iron deposition compared with other UV analyzers

No drawbacks were noted.

For the Superstations, the s::can spectro::lyser™ provided the following benefits:

- Simple and reliable TOC measurement without reagents or the mechanical complexity of conventional TOC analyzers
- Compact form, enabling installation in a fairly small space
- Ability to obtain additional process measurements (DOC, turbidity, and nitrate) from the same analyzer

Drawbacks included:

- Parts and service availability were less than desired during most of the project.
- Frequent software updates resulted in an ever-changing product that was difficult to evaluate.

The benefits of the Intellitect Intellisonde™ included:

- A small footprint that allows the analyzer to be installed in restrictive spaces
- An easy-to-use, browser-based user interface

However, drawbacks for the instrument were significant:

- Several measured parameter readings, most notably chlorine and turbidity, were not stable to the point that the data was unusable.
- No U.S.-based vendor support.
- Spare part procurement in Euros and export/import documentation requirements made maintenance complicated.

The Inficon CMS-5000 provides the benefit of specific identification of organic contaminants. However, PWD found that highly trained technical staff is required for maintenance of the analyzer, so the complexity of configuration and maintenance renders it impractical for field installations. Use in a laboratory for specialized analysis is a more appropriate use for the device. Furthermore, data communication from the analyzer to a traditional SCADA system or contaminant monitoring system is complex and difficult to achieve.

Abbreviations and Acronyms

ATI	Analytical Technologies, Inc.
CWS	Contamination Warning System
DOC	Dissolved organic carbon
EDS	Event detection system
EPA	United States Environmental Protection Agency
nm	Nanometer
ORP	Oxidation reduction potential
OWQM	On-line Water Quality Monitoring
PWD	Philadelphia Water Department
TOC	Total organic carbon
UV	Ultraviolet
VOC	Volatile organic compound
WS	Water Security

References

- EPA. 2007. *Water Security Initiative: Interim Guidance on Planning for Contamination Warning System Deployment*. Revision 1. July.
- EPA. 2009. *Distribution System Water Quality Monitoring: Sensor Technology Evaluation Methodology and Results*. October.

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