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technical BRIEF

Detecting Contamination Events in Water Distribution Systems, Using Multi-Parameter Sensors

Five water-monitoring sensors evaluated for detecting contamination events

U.S. EPA's Homeland Security Research Program (HSRP) develops products based on scientific research and technology evaluations. Our products and expertise are widely used in preventing, preparing for, and recovering from public health and environmental emergencies that arise from terrorist attacks. Our research and products address biological, radiological, or chemical contaminants that could affect indoor areas, outdoor areas, or water infrastructure. HSRP provides these products, technical assistance, and expertise to support EPA's roles and responsibilities under the National Response Framework, statutory requirements, and Homeland Security Presidential Directives.

In the past, people in the United States have largely taken for granted the convenience of potable municipal water. However, the threat of intentional contamination of our water supplies is becoming a concern because of a rise in the number of terrorist acts around the world.

As a result, there is much interest in technologies that can be used to detect a contamination event either as it is occurring or immediately after. Such technologies include multi-parameter water monitors that are integrated into sensor units.

These sensor units can be deployed at multiple locations in water distribution systems and collect general water quality data that can be transmitted to various locations, including remote locations, thereby giving water utilities access to real-time or near real-time data from their overall system. These units can also be customized for users' needs to include various monitoring devices for pH, conductivity, alkalinity, total organic carbon (TOC), oxidation reduction potential (ORP), temperature, turbidity, and chlorine.

Residual chlorine is particularly important because changes in its concentration can indicate the presence of low levels of contamination within a distribution system. Chlorination is a very common form of water treatment used by water utilities.

During 2004, EPA evaluated five multi-parameter water sensors:

- Q45WQ Series (Analytical Technology, Inc.)
- Sentinal™ 500 Series (Clarion Sensing Systems, Inc.)
- Water Distribution Monitoring Panel (WDMP) and Event Monitor™ Trigger System (Hach Company)
- TitraSip™ SA (Man-Tech Associates Inc.)
- Model WQS (Rosemount Analytical)

Each unit was evaluated for:

- Accuracy
- Response to injected contaminants
- Inter-unit reproducibility
- Ease of use

Chlorine was measured using amperometric, colorimetric, or potentiometric titration methods. Turbidity was measured by nephelometry, and conductivity, pH, and ORP were measured using the applicable electrodes/meters. TOC analysis combined chemical and ultraviolet oxidation techniques and alkalinity was measured using titration. Data were collected from each sensor unit using a data logger or memory stick. Data were then imported into a database. Some sensors were equipped with alarms that would signal when a threshold was exceeded.

Test Design

The sensors were evaluated in three stages, using the recirculating pipe loop at the EPA Test and Evaluation Facility in Cincinnati, OH:

- Stage 1 tested accuracy.
- Stage 2 tested responsiveness to water quality changes.
- Stage 3 tested performance, including inter-unit reproducibility and ease of use.

Stage 1 (Accuracy):

Water quality conditions were simulated by changing pH and temperature variables. Seven four-hour test periods of unique pH and temperature conditions with reference method sampling and analysis every hour were used to evaluate the accuracy of the units:

- pH at approximately 7, 8, and 9, with water temperatures between 21 and 23 ºC
- pH at approximately 7 and 8, with water temperatures between 12 and 14 ºC
- pH at approximately 7 and 8, with water temperatures of approximately 27 ºC

Monitor measurements from two sensor units were evaluated by comparing each measurement to the hourly result from standard laboratory reference methods and then calculating the percent difference.

Stage 2 (Responsiveness):

Six runs were performed to evaluate responsiveness of each unit's monitors. Specifically, contaminants (nicotine, arsenic trioxide, and aldicarb) were injected at two separate times into the recirculating pipe loop. Upon injection, contaminant concentrations within the pipe loop were approximately 10 milligrams per liter (mg/L).

This concentration level was chosen since it is of sufficient magnitude that it could be detected by the sensor units. After contaminant injection, the response of each water quality parameter (increase, decrease, or no change) was then documented

Stage 3 (Performance):

This stage consisted of two phases. The first phase evaluated the performance of the sensor during an extended deployment of 52 continuous-operation days. References samples were collected once daily throughout this time period.

The second phase, which lasted approximately one week, consisted of a two-step evaluation: 1) to determine whether extended operation negatively impacts the accuracy of the sensor unit and 2) to determine how well the sensor units respond to the injection of a contaminant.

For the second phase of Stage 3, a reference grab sample was collected every hour during a 4-hour time period. The sample results from the sensor unit monitors were then compared to results from the standard laboratory reference method. Next, aldicarb and *E. coli* were injected at two different times (duplicates for each contaminant) into the recirculating pipe loop to evaluate the sensor's response to contaminant injections after extended deployment. In most cases, the differences between the results before and after extended deployment were nominal.

In addition to analysis of the accuracy and contaminant injection data, inter-unit reproducibility was assessed by comparing the results of two identical sensor units operating simultaneously. Overall ease of the sensor unit use was also documented by the technicians who operated and maintained them.

The multi-parameter water monitoring sensor (Hach WDMP), equipped with event detection and contaminant identification software, was separately evaluated from the other units.

An additional stage (Stage 4) was included as part of this unit's testing to determine:

1) whether the software detected the injection of selected contaminants

2) whether it correctly identified each contaminant.

Testing involved two separate injections of 13 contaminants (aldicarb, arsenic trioxide, colchicine, dichlorvos, dicamba, *E. coli*, bacteria, glyphosate, lead nitrate, mercuric chloride, methanol, nicotine, potassium ferricyanide, and sodium fluoroacetate).

Performance and Results

Table 1 provides the sensor units' range of percent differences and median percent differences for various water quality parameters.

Table 1. Stage 1- Accuracy Evaluation Range of % Difference (Median % Difference)

Sensor Unit	Free Chlorine	Turbidity	Conductivity	pH	TOC	Alkalinity
Q45WQ Series	-41.5 to 54.3 (-15.7)	-47.2 to -16.9 (-24.9)	-19.7 to -2.6 (-12.7)	-11.8 to -0.9 (-5.0)	NM	NM
WQS	-11.1 to 96.7 (14.5)	NM	2.9 to 5.3 (4.2)	-7.4 to -1.1 (-3.0)	NM	NM
Sentinal™ 500	3.4 to 117.1 (26.2)	NM	-26.8 to -22.4 (-24.6)	-6.1 to 0.5 (-1.9)	NM	NM
TitraSip™	-13.2 to 20.6 (7.5)	-65.2 to 0.6 (-45.2)	37.9 to 94.3 (57.5)	-2.2 to 5.4 (0.6)	NM	3.2 to 30.4 (11.5)
WDMP	-47.4 to 4.5 (-3.9)	-53.9 to -1.3 (-34.1)	-15.5 to 8.1 (2.2)	-6.6 to 3.1 (0.9)	-64.7 to 147.5 (-14.8)	NM

NM = Parameter was not measured by this sensor unit.

The ranges of percent difference for free and total chlorine, turbidity, and TOC were large, which indicates the sensors were not very accurate for these water quality parameters.

The ranges of percent difference for conductivity, pH and alkalinity were generally within ±30% difference from the reference results, which indicates the sensors were more accurate for these water quality parameters.

The median percent difference (in parentheses in Table 1) identifies the central value across all measurements for the water quality parameter of interest. This evaluation for accuracy was repeated after extended deployment, and the results were very similar.

Table 2 summarizes the responses to injected contaminants. Results are reported as either no change (NC), not measured (NM), an increase (+), or a decrease (-).

Table 2. Stage 2- Response to Injected Contaminants

Contaminant	Sensor Unit	Free & Total Chlorine	Turbidity	Conductivity	pH	ORP	TOC	Alkalinity
Nicotine	Q45WQ	-	+	NC	NC	-	NM	NM
	WQS	-	NM	NC	NC	-	NM	NM
	Sentinal™ 500	-	NM	NC	NC	-	NM	NM
	TitraSip™	-	(a)	NC	NC	NM	NM	NC
	WDMP	-	+	NC	NC	NM	+	NM
Arsenic trioxide	Q45WQ	-	+	+	+	-	NM	NM
	WQS	(b)	NM	+	+	-	NM	NM
	Sentinal™ 500	-	NM	+	+	-	NM	NM
	TitraSip™	-	(a)	+(b)	+	NM	NM	+
	WDMP	-	+	+	+	NM	NC	NM
Aldicarb	Q45WQ	-	+	NC	NC	-	NM	NM
	WQS	-	NM	NC	NC	-	NM	NM
	Sentinal™ 500	-	NM	NC	NC	-	NM	NM
	TitraSip™	-	(b)	NC	NC	NM	NM	NC
	WDMP	-	+	NC	NC	NM	+	NM

(a) =Relatively large uncertainties occurred in the reference and continuous measurements that made it difficult to determine a significant change.
(b) = Duplicate injection results did not agree.
+ or - = Parameter measurement increased or decreased, respectively, upon injection.
NC = No obvious change was noted through visual inspection of the data.
NM = Parameter was not measured by this sensor unit.

The following can be concluded regarding the injection of the three contaminants (nicotine, arsenic trioxide, and aldicarb):

- All sensor units showed decreases in free chlorine concentrations after the three contaminants were injected.
- All sensor units showed decreases in ORP measurements concentrations after the three contaminants were injected.
- No sensor unit showed a change in pH and conductivity readings when nicotine and aldicarb were injected; however, they showed an increase in pH and conductivity readings after arsenic trioxide was injected.

This evaluation was repeated after the extended deployment using aldicarb and E. coli.:

- Injection of aldicarb yielded similar results to those in Table 2.

- Injection of *E. coli.* showed decreases in free chlorine and increases in ORP, alkalinity, and conductivity.

For the Stage 4 testing of the Hach WDMP:

- All contaminant events (22 contaminant events – two separate injections of 13 contaminants) were identified as they occurred.
- Eleven of the 13 contaminants injected were correctly identified during the testing.
- Two of the 13 contaminants injected (potassium ferricyanide and lead nitrate) were correctly identified during the entire testing (i.e., injection) time period.

CONTACT INFORMATION

For more information, visit the EPA Web site at www.epa.gov/nhsrc.

Technical Contact: Eric Koglin (koglin.eric@epa.gov)

General Feedback/Questions: Kathy Nickel (nickel.kathy@epa.gov)

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