

# Laboratory and Flow Loop Validation and Testing of the Operational Effectiveness of an On-Line Security Platform for the Water Distribution System

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## Abstract

The drinking water distribution system is vulnerable to deliberate or accidental back flow events. The large number of agents that could be potential threats and the innumerable access points make this a difficult scenario to defend against. This was clearly stated in a GAO report to Congress that listed the vulnerability of the distribution system to attack as the largest security risk to water supplies. A system designed to address the problem of distribution system monitoring is described here. The developed system employs an array of common analytical instrumentation, such as pH and chlorine monitors, coupled with advanced interpretive algorithms housed in an event monitor to provide detection/identification-response networks that are capable of enhancing system security.

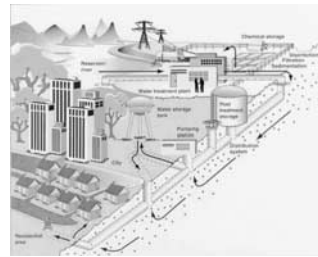
### #1 Are Our Water Supplies Vulnerable?

As early as 1941, after America had suffered another devastating surprise attack, FBI Director J. Edgar Hoover wrote, "Among public utilities, water supply facilities offer a particularly vulnerable point of attack to the foreign agent, due to the strategic position they occupy in keeping the wheels of industry turning and in preserving the health and morale of the American populace. Obviously, it is essential that our water supplies be afforded the utmost protection."



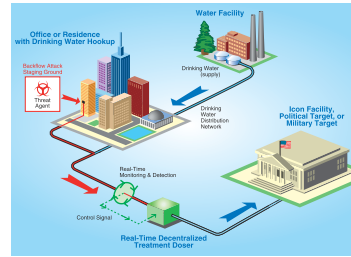
### #2 How Could an Attack Occur?

When observing a typical municipal water supply system it is natural to assume that the main point of vulnerability to a CBR attack would be the introduction of an agent into the system at the source water (reservoir) or treatment plant. However, in order to create widespread casualties from an attack on the source water, the amount of contaminant required would, after taking dilution into account, be either too large to handle easily or be more expensive than other readily available terrorist weapons.



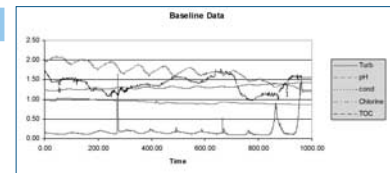
### #3 What is a Backflow Attack?

A backflow attack occurs when a pump is used to overcome the pressure gradient that is present in the distribution system's pipes. Currently, monitoring of drinking water supplies in the distribution system is limited. Previous to the terrorist threat, it was not a priority. The ability to detect an event in the distribution system and then identify it would be of incomparable value in responding to an incident in a timely and proper manner.



### #4 Water Analysis Presents Many Challenges

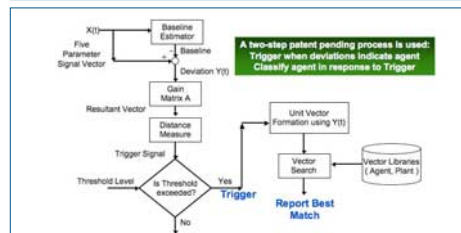
Security monitoring in the distribution system is a difficult proposition. The sheer number and diversity of potential threat agents that could be utilized in an attack against the system makes monitoring for them on an individual basis an effort that is doomed to failure from the start. What is needed is a broad-spectrum analyzer that can respond to any possible threat and even unknown or unanticipated events. This need to detect such a large number of diverse contaminants requires a realignment of thinking from the traditional development of a sensor for a given compound or agent. Sensor arrays on a chip or the use of analytical instrumentation capable of detecting this variety is a definite challenge. Another approach is to use chemometrics to detect and characterize changes in basic water quality parameters and correlates them with threat agent introduction. This is the approach chosen by Hach HST.



### #5 The HST Approach

Rather than attempting to develop individual sensors to detect contaminants or classes of contaminants, the Hach HST approach is to utilize a sensor suite of commonly available off-the-shelf water quality monitors such as pH, electrolytic conductivity, turbidity, chlorine residual and total organic carbon (TOC) linked together in an intelligent network. The developed system has been subjected to strenuous testing in both laboratory and field scenarios as detailed in the remainder of this paper and has been found to be an effective tool for surveillance of the distribution system.

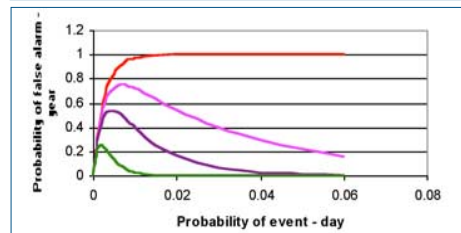
The use of intelligent algorithms with standard bulk parameter monitoring equipment allows for a robust system that is capable of triggering on and classifying a wide diversity of threat agents



Percent of LD-50 that the system requires to be present for triggering and classification

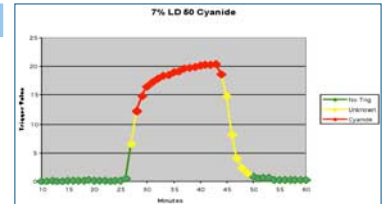
AGENT	TRIGGER	CLASSIFY
Aflatoxin	0.37	1
Aldicarb	0.66	0.7
Cyanide	0.5	0.15
Nicotine	0.8	3.3
Oxamyl	2.5	2.6
Sodium Fluoroacetate	1	4.8
Strichnine	0.7	1.5

Reduction of Unknown Alarms via Hach Learning Algorithm  
 Learning period = 0, 30, 90, 365 days  
 $P(\text{unknown alarm}) = P(\text{not learned}) * P(\text{event})$



### #6 Single Pass, Flow Testing at Hach

single pass flow system was set up in the laboratory to determine if responses generated from the beaker derived testing were adequate to alarm and classify when extrapolated to a flowing system. In some cases chemical simulants were used due to waste disposal concerns to exercise the instruments in the laboratory. In all cases, the system was able to correctly identify the compound in question at very low concentrations. Numerous agents were tested in this manner. The data for 7% of the LD-50 for cyanide is shown at the right. As the line is green the system has not yet triggered or identified. When the line is yellow the system has triggered but has not as yet identified the compound. When the line is red the system has both triggered and identified the compound.



### #7 Battelle EPA ETV Verification Testing

In the fall of 2004, the developed technology was submitted for testing to the EPA Environmental Technology Verification (ETV) testing program run by Battelle. The ETV Program develops testing protocols and verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment. ETV was created to accelerate the entrance of new environmental technologies into the domestic and international marketplace. The category being tested was Multi-parameter Water Monitors for Distribution.

ACCURACY					
Evaluation Parameter	Cl	Turb	Cond.	pH	TOC
Stage 1 Units 1 & 2, Accuracy range of %D (median)	-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)

INTER-UNIT REPRODUCIBILITY						
Parameter	Cl	Turb	Cond.	pH	TOC	
Inter-unit Reproducibility	Slope (intercept)	0.98 (0.03)	0.97 (0.005)	0.92 (4.19)	1.06 (-0.40)	0.97 (0.31)
	r <sup>2</sup>	0.994	0.881	0.961	0.919	0.991
	p-value	0.779	0.884	0.006	0.517	0.374

CONTAMINANT INJECTION							
Parameter	Nicotine	Ref	Cl	Turb	Cond.	pH	TOC
Initial response to injected contaminants	Nicotine	Ref	-	(a)	NC	NC	+
	Arsenic Trichloride	Ref	-	(a)	+	+	NC
	Aldicarb	Ref	-	(a)	NC	NC	+
Response after extended deployment	E. coli	Ref	-	(a)	+	+	+
	Aldicarb	Ref	-	(a)	NC	-	+
	Nicotine	Ref	-	(a)	NC	+	+

LONG-TERM DEPLOYMENT					
Parameter	Average (SD)	Average (SD)	%D	Average (SD)	%D
Free Chlorine	1.03 (0.03)	0.98 (0.02)	-4.9	0.98 (0.02)	-4.9
Turbidity	0.17 (0.02)	0.16 (0.03)	-5.9	0.15 (0.04)	-11.8
Temperature	22.66 (0.16)	22.61 (0.03)	-0.2	23.70 (0.06)	4.6
Conductivity	356 (1)	360 (1)	6.7	357 (1)	0.3
pH	8.59 (0.01)	8.40 (0.01)	-2.2	8.61 (0.00)	0.2
TOC	0.88 (0.01)	0.70 (0.01)	-20.5	0.91 (0.01)	3.4

INTER-UNIT REPRODUCEABILITY				
Parameter	Slope	Intercept	r <sup>2</sup>	t-test p-value
Free Chlorine	0.98	0.03	0.994	0.779
Turbidity (outlier removed)	0.97	0.005	0.881	0.884
Temperature	0.72	7.88	0.758	5.5 x 10 <sup>-6</sup>
Conductivity	0.92	4.19	0.961	0.006
pH	1.06	-4.40	0.919	0.517
TOC	0.97	0.31	0.991	0.374

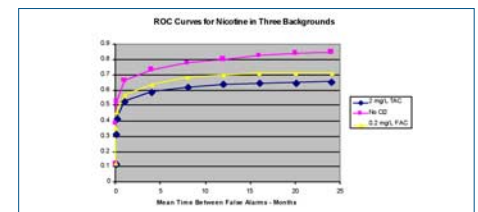
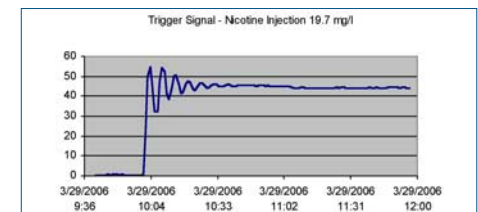
CONTAMINANT CLASSIFICATION				
Contaminant	INJECTION 1		INJECTION 2	
	Unit 1	Unit 2	Unit 1	Unit 2
Aldicarb	4	4	4	4
Arsenic Trichloride	2	2	2	2
Colchicine	4	4	4	4
Dicamba	4	5	5	5
Dichlorvos	4	3	4	2
E. coli	3	2	4	2
Ferricyanide	5	5	5	5
Fluoroacetate	5	5	4	4
Glyphosate	4	3	2	2
Lead Nitrate	5	5	5	5
Mercuric Chloride	4	4	4	4
Methanol	4	4	4	3
Nicotine	2	2	2	2

CONTAMINANT CLASSIFICATION (Algorithm Version 3)				
Contaminant	INJECTION 1		INJECTION 2	
	Unit 1	Unit 2	Unit 1	Unit 2
Aldicarb	4	4	4	4
Arsenic Trichloride	4	5	4	5
Colchicine	4	4	4	4
Dicamba	4	3	5	5
Dichlorvos	2	2	3	3
E. coli	4	3	4	3
Ferricyanide	5	5	5	5
Fluoroacetate	5	5	5	5
Glyphosate	4	4	4	4
Lead Nitrate	5	5	5	5
Mercuric Chloride	5	5	5	5
Methanol	4	4	4	3
Nicotine	4	4	4	4

Level 5 - greater than 70%  
 Level 4 - between 31% and 69%  
 Level 3 - between 1% and 30%  
 Level 2 - injected contaminant not identified but other contaminants were identified  
 Level 1 - no injections detected

### #8 Beaker Testing and Flow Loop Testing at Edgewood Chemical and Biological Command (ECBC)

The purpose of this effort was to challenge water distribution systems and sensors, with agent simulants and real threat agents, in order to characterize the response of the distribution system and Early Warning System to agents. Agent concentrations and water solutions were varied to allow for the development and demonstration of distribution methodologies and performance data acquisition. In addition, this work evaluates the effectiveness of Hach Homeland Security Technologies real-time detection technology and provides important information necessary for the U.S. Army to perfect its theories of operation and response mechanisms.



## Conclusion

The system described has made use of robust off-the-shelf sensor technologies by placing them together in an array and using intelligent algorithms in a new and powerful manner to extract data that is of interest in devising an early warning system for water security. The system has been shown to be effective versus a wide variety of threat agents in a laboratory setting. The use of a unique system for estimating the baseline in real world systems allows for the identification of small deviations from normal readings in water analysis parameters. This in turn leads to a system capable of triggering on these deviations.