

Trigger and Detection Method for Threat Agents in Drinking Water

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ABSTRACT

Distribution system monitoring has typically included a minimal set of water quality parameters, acquired at low frequency.

The parameter set, and frequency of data acquisition are insufficient for the surveillance of typical distribution systems' water quality in the event of agent introduction.

An improved methodology is discussed. The method includes a more complete set of water quality parameters acquired at higher frequency, mathematical processing to alarm on deviations from operational baseline, pattern recognition of deviations, statistical analysis of recurring events, and a learning function which allows recurring events to be recognized and categorized as normal operation or unknown. Examples of events from distribution systems are presented and discussed.

Keywords: monitoring, distribution system, water quality, pattern recognition, statistical analysis

1. INTRODUCTION

Most water plants and distribution systems have historically monitored chlorine levels, turbidity, flow and pressure. Some have included parameters such as pH and conductivity to gain a better understanding of their water quality within the distribution system. It is commonly believed that these parameters change very slowly as they travel through the distribution system, and that frequent reporting of the parameters is not necessary.

The assumption of slow variations is generally reasonable given the physical nature of the systems. However, consideration of possible terrorist attack on a distribution system shows that the previous assumptions are invalid.

A backflow or injection attack could quickly introduce harmful substances into a system¹. In that case, models and physical testing show that water quality readings could change rapidly, and over a short time frame².

There is now a serious need for real-time monitoring that can quickly respond to an attack. Failure to respond for long periods of time could delay an appropriate response to an attack. The difference between long and short response time could be measured in thousands of lives.

A system with real-time monitoring and reporting also has the capability to provide information for optimization of daily plant and system operation.

2. APPROACH TO THE PROBLEM

The analysis of this problem involves a number of steps:

Selection of possible threat agents against a distribution system

Consideration of parameters to measure and sensors that could be used

Selection of sensors

Testing agents for response on the sensor set

Analysis of the obtained responses

Development of an algorithm to Trigger on abnormal conditions
Testing of the Algorithm
Development of an algorithm to attempt classification of the response
Testing of a classification algorithm

3. EXAMINATION OF AGENTS

To understand the monitoring requirements, one must understand the chemical characteristics of a large set of potential threat agents that could be used in a water distribution system. A list of 65 agents (chemicals, toxins, biologicals) was made and analyzed for their characteristics and possible detection.

4. CONSIDERATION OF PARAMETERS AND SENSORS FOR THE APPLICATION

It is not practical with current technology to have a specific sensor for each agent. Further, that approach would be finite in scope and always vulnerable to the agent left out, or one modified to avoid detection by a specific sensor. Our approach turned to using a set of bulk water quality sensors, and chemometric methods to extract information from their responses.

5. SELECTION OF SENSORS

The characteristics of the agents suggested a particular set of bulk water quality parameters that should be measured in order to sense the presence of such agents.

Sensor	Characteristics
pH	acid/base relationships
Chlorine	presence of oxidizing or reducing agents
Conductivity	ionized species
Turbidity	undissolved particulate matter
TOC	total organic carbon content of the agent

Also of consideration was selection of parameters/sensors that would provide unrelated, orthogonal measurements. For that reason, parameters such as Oxidation Reduction Potential (ORP) and dissolved oxygen were not chosen for this initial development.

Given the requirement for rapid response, we elected to do an analysis every minute. This set of sensors easily allows for that to be done.

A further advantage of these sensors is that most of them have been used in water plants and the personnel are generally familiar with their operation and maintenance.

6. TESTING SENSORS FOR RESPONSE TO AGENTS

A large battery of tests were run with agents and the sensors selected to verify that the sensors would indeed respond to the agents in concentrations that would be harmful to people. The benchmark used was 1 Lethal Dose 50% (LD-50) concentration, the amount calculated to cause 50% mortality to those exposed, in a liter of water based on the LD-50 extrapolated for a 70 Kg male subject. Testing showed that the instruments were responsive at that concentration, and much lower, depending on the agent. The approach to use bulk sensors was validated, and justified further testing and development.

The agents tested included such items as:

- Chemical warfare agents,
- Commercially available herbicides, pesticides and rodenticides
- Street drugs such as LSD and heroin;
- Heavy metals
- Toxic Industrial Chemicals such as cyanide
- Biological agent cultures
- Biotoxins

7. SENSOR RESPONSE ANALYSIS

All those tested showed useful responses in the concentrations that could harm people. Many showed responses at levels lower than harmful in the short term. Of course, not all sensors responded to all agents.

The responses showed that the set of parameters selected was an adequate choice. Not all agents of interest could be obtained or legally tested in our labs. External parties are currently testing those agents.

8. TRIGGER ALGORITHM (PATENT PENDING)

Analysis of the set of responses showed that agents could be found at low levels of concentration. A proprietary algorithm was developed to provide a real-time scalar Trigger Signal that triggers an alarm when conditions in the water depart from the expected baseline parameter values. When the scalar Trigger Signal exceeds a selected threshold, an alarm is triggered.

This algorithm was developed with the realization that sensor technology will improve over time, and that there will be a need to add additional sensors in the future. The algorithm permits the inclusion of additional sensors if and when such measurements prove effective.

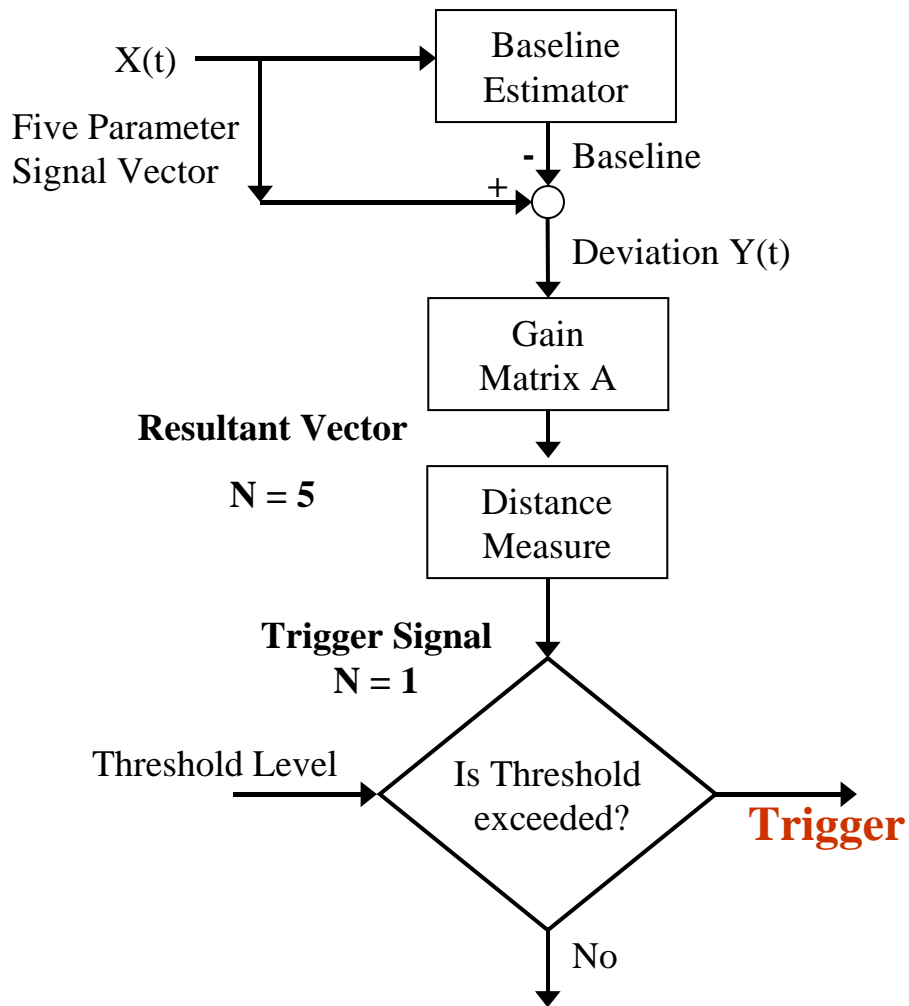


Figure 1.

9. TRIGGER ALGORITHM TESTING

Testing was first done with mathematical models. Models were derived using data from installations where real water data were collected to define typical, and worst-case conditions. Common hydraulic models were used to define the response curve versus time for agent introduction².

When those predicted good results, laboratory tests with real agents and simulants were done. Testing was done with various types and levels of disinfectants used in drinking water.

The graph below shows the Trigger Signal for real process data where no threat agent was present. The threshold value of 1.0 is not exceeded and no alarm is given.

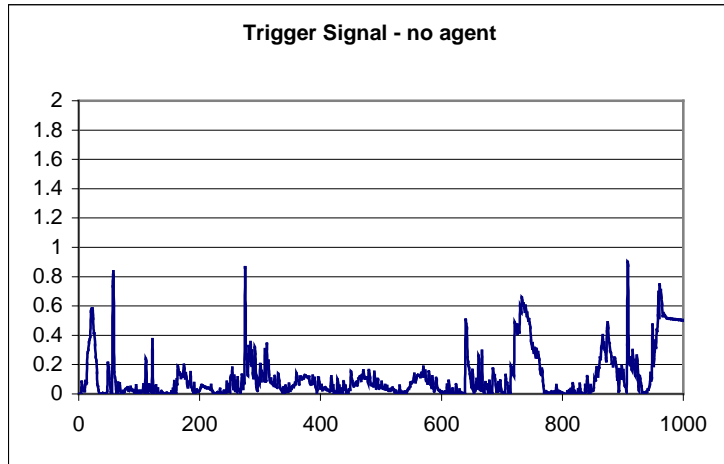


Figure 2.

This graph shows the Trigger Signal when a small dose of cyanide is added. The Trigger Signal exceeds the threshold when the cyanide is present, and an alarm is given.

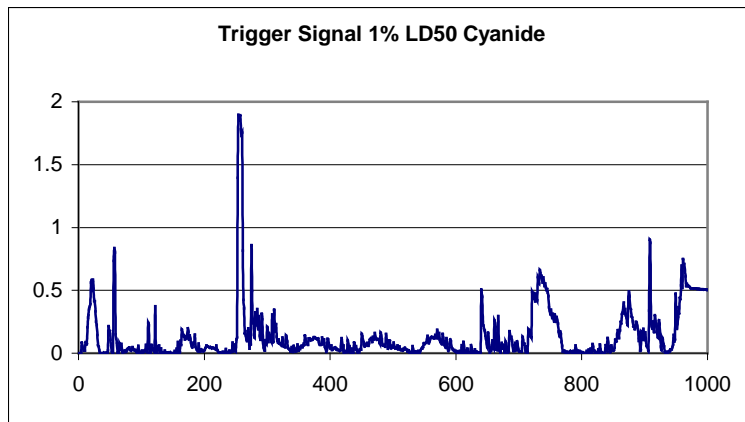


Figure 3.

The multiple methods of testing show that the algorithm is robust and sensitive, triggering on the presence of abnormal events, including those caused by system operational changes. The monitoring system thus is useful for both security and plant/system operation.

ROC curve presentation

Receiver Operating Characteristic curves are commonly used to gauge the performance of military triggering/detection systems. They are particularly useful to describe system performance at different alarm threshold levels.

The ROC curves shown here are adapted from the classical format to be more useful for selecting threshold levels for on-line instrumentation.

The curve describes the sensitivity of the trigger, in terms of the detection level in % LD50, versus the Mean Time between False Positives caused by process noise. The markers on the trace are different threshold level settings. These curves provide the information necessary for plant operators to make the tradeoff between trigger sensitivity and false alarm rate.

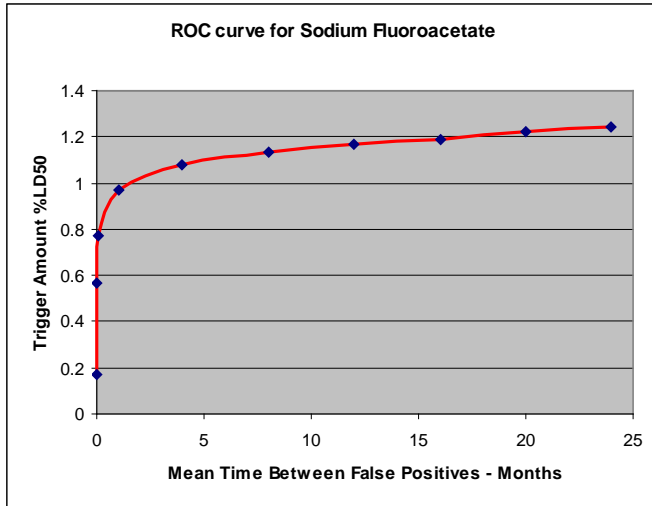


Figure 4.

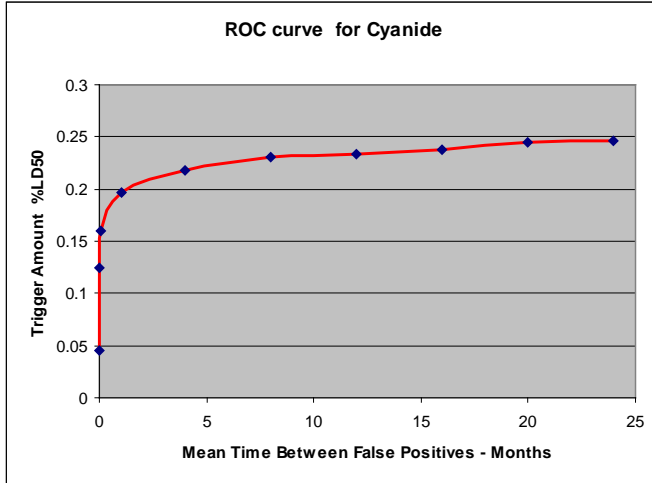


Figure 5.

ROC curves were generated for a select set of agents and show very similar results. The shape of the curve is similar for all, but the % LD50 on the vertical axis changes for each agent, and the scaling on the horizontal axis changes according to the system noise level at a given installation site.

10. CLASSIFICATION ALGORITHM (PATENT PENDING)

The sensor signals provide data that gives a geometrical representation of the agent present. The sensor signals can be compared to a library of agent “fingerprints” derived from laboratory testing of the actual agents in drinking water. This pattern recognition method allows classification of the agent type.

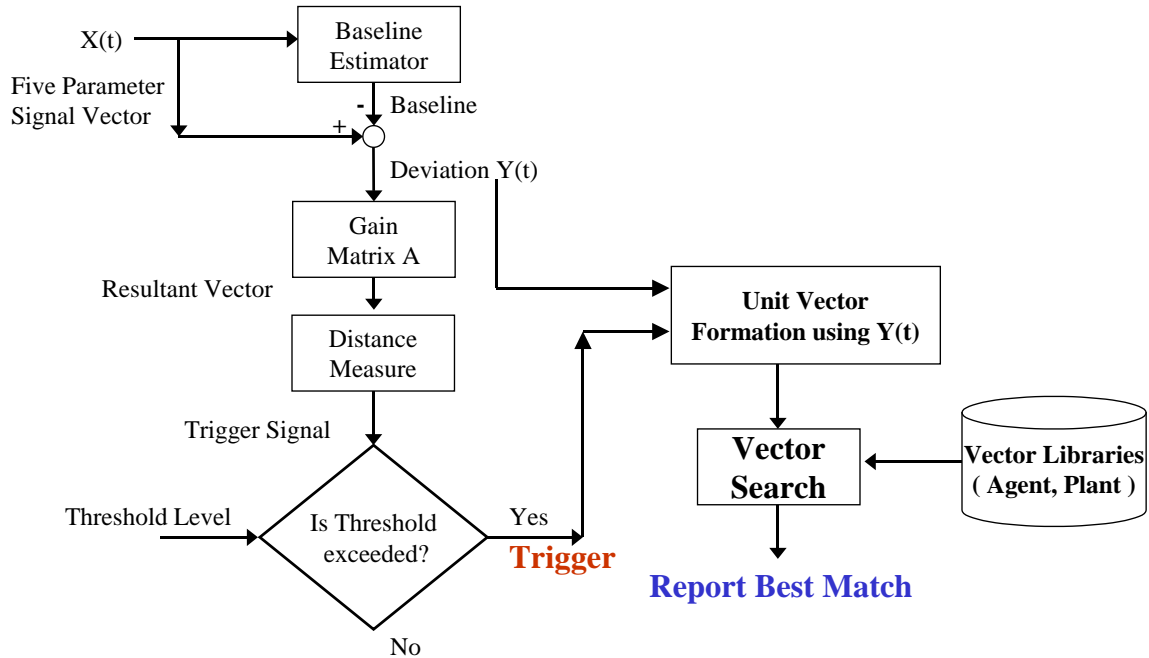


Figure 6.

11. CLASSIFICATION ALGORITHM TESTING

Detection Test results on a cyanide stimulant

The system was tested to see if it could recognize a cyanide stimulant. This “agent” was injected into a water line and the instrument responses were processed by the Trigger and Classification algorithms. The graph below shows that an alarm was triggered, and cyanide recognized.

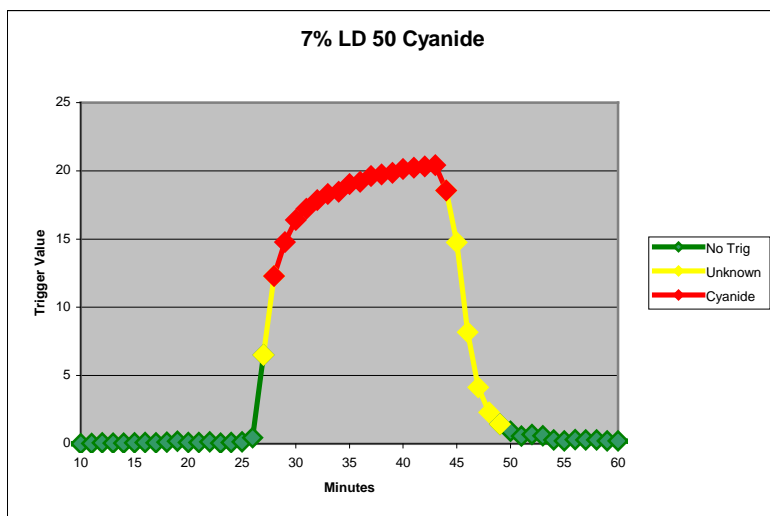


Figure 7.

Similar tests were run at multiple concentrations. A number of agents were tested, and demonstrated that the method and equipment are able to trigger when agents are present, and able to recognize the agents.

Minimum Detection Limits for selected agents

The table below shows the minimum trigger/detection limits for some agents of concern. MDLs for Trigger and Detection are shown because triggering is done by one algorithm and detection by another. Each algorithm has its own performance characteristics.

The values shown in the table are the minimum detection limits for the agent, measured in % LD50 (in 1 Liter of water).

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

Figure 8.

Clearly, there is adequate sensitivity to trigger on these agents of concern.

Quantification Ability

If an agent can be specifically recognized, the parameter deviation information can yield an estimate of the quantity of the agent present. Note that this applies only to chemicals that are clearly identified. The bulk parameter sensors do not provide the specific information needed for estimates of quantity and viability for bio-agents. That ability awaits the arrival of better sensors for bio-agents.

Testing of 15 different threat agents shows that quantification accuracy varies with specific agent. Worst case accuracy is +/- 50%, while typical accuracy is +/-15%. Given the non-specific nature of the measurements, this is deemed adequate.

12. LEARNING, STATISTICS AND TRANSFER OF AGENT FINGERPRINTS

Learning

Many plants regularly experience changes in water quality for various reasons. One example would be switching between different water sources, which could produce a transient change in water quality parameter readings.

Such events are harmless, but could trigger the monitoring system. Plant operators do not want to investigate alarms caused by normal operation. To avoid those situations, the monitoring system can store the fingerprints found when the event occurs. These fingerprints can be manually associated with the event cause (given a descriptive name) and the monitor set to show that set as Normal operation instead of giving an Alarm.

Some plant events that can be learned in that way may indicate equipment failure which requires attention. Such events can have their fingerprints named for the event, and give an Alert status, indicating the need for corrective action.

Thus, the monitor can learn events and become a useful too in plant and system operation.

Learning also reduces the false Unknown alarm rate over time. If events are learned over a period of time, a recurrence of the event will be recognized as Normal, avoiding a false Alarm report.

The graph below illustrates how learning reduces false Unknown alarms caused by plant events.

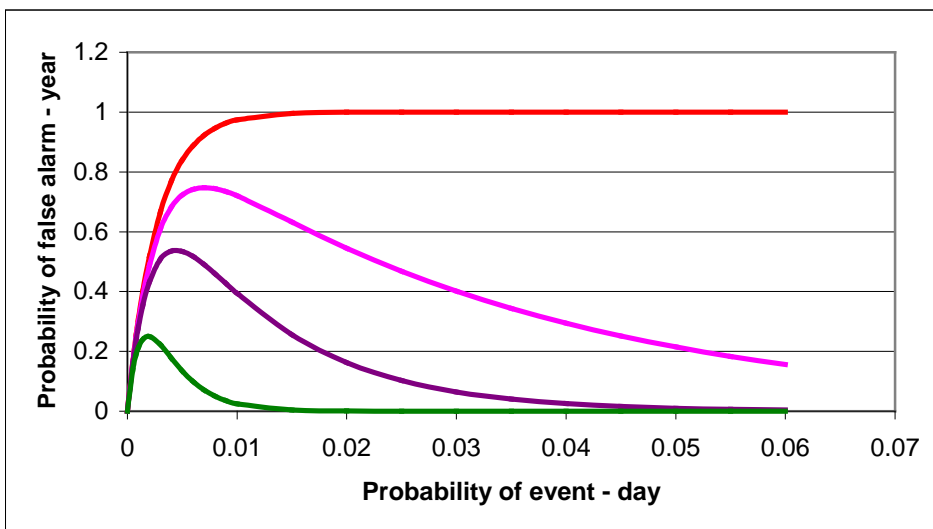


Figure 8.

The four curves represent the results for different periods of learning.

The horizontal axis shows the probability of occurrence for a given event. Rare events are on the left, and frequent events are on the right. The vertical axis gives the probability that that event will show as a false alarm during the year following the training period.

The upper curve shows the result without any learning. With no learning, frequent events will surely cause false Unknown alarms during the year. The other curves show results for learning periods of 30, 90 and 365 days of learning. The lower curve (365 days) shows that with a long learning time, false alarms on frequent events are essentially gone. The only false alarms are produced by events that were not encountered during the training time.

Of course, the concept of a training time is academic; the system would be operated in the operational mode with training continuing over time.

Statistical information about a recurring plant event

The monitor's ability to recognize recurring plant events allows the program to show the statistics for those events. For example if the same event shows up 17 times since the installation of the monitor, it could report statistical information:

Number of occurrences	17
Date/time of first occurrence	6/17/04, 1:47 am
Date/time of last occurrence	4/03/05, 2:32 am
Mean time between events	11.2 days
Minimum value of Trigger Signal	2.5
Average value of Trigger Signal	2.97
Maximum value of Trigger Signal	4.7
Standard Deviation	0.23
Standard Score for this event	-0.17

Such statistics may be of diagnostic use that helps plant operators identify the cause if previously unknown, and they would show if the given event was statistically out of the ordinary for the class of event.

Transfer of agent fingerprints

Suppose that a site is attacked with an agent that is not found in the monitor's library of agent fingerprints. The system is triggered, but the agent not found. The parameter deviations that caused the trigger are saved in memory and represent the "fingerprint" of the unknown agent. That fingerprint can be down-loaded from monitor(s) at the site of the attack and up-loaded to monitors at other sites, giving them the ability to recognize the formerly unknown agent. This is analogous to updating a computer with anti-virus software when the latest virus is being sent around.

13. ANCILLARY EQUIPMENT

An agent monitoring system can drive external modules in response to an attack.

A water sampler can be triggered to collect multiple water samples for later laboratory analysis. In the short term, water samples can be analyzed on the spot with toxicity test kits.

The picture below shows an instrument panel with pH, conductivity, chlorine and turbidity instrumentation. Next to that panel is an analyzer for Total Organic Carbon. Below the panel is a sampler, and to the left of the sampler is a toxicity test kit.



Figure 9.

The fact that the monitor has a rapid response time (in the order of a few minutes) makes it practical to treat water that is on the way to the site being attacked. The combination of prompt treatment of the water, and early warning to the site could prevent large-scale fatalities. Physical arrangement of the equipment for monitoring and treatment will be site-specific.

14. SUMMARY

A practical system for detecting agents in drinking water has been demonstrated. There now exists an apparatus and method for protecting against attacks via backflow events, or injection of agents into a water distribution system. The system uses existing sensor technology and intelligent software to provide effective triggering, detection, quantification and alarm.

The system is generally responsive to changes in water quality and can therefore be used to monitor daily operations of the water plant(s) and distribution system. This ability can be used to not only provide a security function in case of terrorist attack, but also provide a means for process optimization, and alarm on deviations caused by aberrant system operations or conditions.

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