

# **USING ADVANCED ALGORITHMS FOR CONTINUAL MONITORING OF SOURCE AND ENVIRONMENTAL WATERS FOR SECURITY AND QUALITY**

By

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## **ABSTRACT**

There are a number of potential problems with implementing a monitoring system for source and environmental waters. The basic concept here is to actively and continuously monitor a variety of basic water quality parameters and look for significant changes that may be indicative of an event. There are a variety of source water parameters that may find application for this sort of system. Various manufacturers in the environmental market have for many years combined a variety of this sort of instrumentation into self contained data collection bundles that can feed data back to a central location via wireless telemetry or hard wired packages. There are a number of parameters currently available for on-line monitoring. The relative low cost of these instrumentation packages allows monitoring at a variety of sites. The major drawback is the huge amount of data that must be analyzed and correlated to determine if a change is significant or the result of natural variation. The use of advanced chemometrics techniques have been proven to be effective in recognizing and classifying events in the complex matrix of the drinking water distribution system. The application of these same algorithms with a different sensor set to environmental water is described here. This new tool opens a new vista for source water monitoring for both terror and pollution related events.

## **KEYWORDS**

Source water, Monitoring, On-Line, Chemometrics, Algorithm, Event Detection

## **INTRODUCTION:**

The vulnerability of source waters to contamination attacks is limited by a number of factors including dilution effects and natural attenuation. The fact that the water also has to traverse the treatment plant barrier before it can affect consumers also helps to mitigate the hazard. Even so, the risk of an intentional contamination event, not to mention the risk of an accidental spill, is real. While such an event would be unlikely to cause mass casualties it could severely impact the effected area and deny service to that community for some time.

In November of 2005, an explosion at a PetroChina factory in Jilin province resulted in a massive spill of benzene into the Songhua River in northern China. This extensive spill resulted in contamination of the river water and a denial of service to over 4 million customers in Harbin the capital of China's northeastern Heilongjiang province. As the spill migrated down river it affected various other cities and even became an international problem when the contaminant plume crossed

the border into Russia. This massive spill didn't result in any casualties but it did cause a panic and hoarding of bottled water and food in several areas.

This spill was quickly reported and protective action was taken to prevent customer exposure to the contaminated water. A scenario can be imagined where an industrial accident is not reported or a deliberate event occurs to cause a similar incident. If the chemical or material involved was highly toxic and no monitoring was being done customers could be exposed. This is a good argument for the benefits of monitoring source waters. In fact, source waters are already monitored in several locations throughout the world. The European Community has been a leader in this area for years.

Heavily industrialized areas in Europe such as the Rhine river valley were recognized early on as great potential health hazards. The heavy industrialization along with the large population reliant upon river water in this area made it an accident waiting to happen. A series of industrial mishaps along the Rhine led to the development of an early warning system that could alert utilities down stream of an impending spill so that water intakes to treatment plants could be shut down before the contaminated water reached the plants. These systems make use of on-line monitoring of a variety of physical and chemical measurements of water condition combined with various toxicological methods to determine river water quality. This system has proven to be effective in preventing serious contamination from reaching the treatment plants.

### **POTENTIAL CHALLENGES IN MONITORING SOURCE WATER:**

There are a number of potential problems with implementing a monitoring system for source water. There is the problem of diurnal (night and day) as well as seasonal shifts in water quality due to a variety of factors such as aquatic plant respiration and decaying vegetation from autumn leaf falls. Varying amounts of sediments, turbidity and dissolved solids due to precipitation events and spring run-off fluctuations may be problematic. Monitoring equipment is often exposed to extreme conditions of heat and cold and is often located in remote areas so that power supply and communications become an issue. Due to the transient and unexpected nature of the events we are trying to detect, the monitoring systems also need to be on-line and continuous because, if we knew when we needed to monitor we wouldn't need to monitor.

One of the chief problems is what to measure. The diverse list of contaminants would make monitoring for individual chemicals or even classes into a futile effort to out guess the terrorists or to be precognitive in surmising what type of accidents will occur. This suggests that rather than testing for each chemical or class of chemical on an individual basis some broad-spectrum form of testing should be utilized to monitor for general changes in water integrity. One of the likely candidates for such monitoring would be bulk monitoring of traditional water quality parameters. An on-line system is considered here, as grab samples would be ineffectual as an early warning system.

### **BULK PARAMETER MONITORING.**

The basic concept here is to actively and continuously monitor a variety of basic water quality parameters and look for significant changes that may be indicative of a contamination event. There are a variety of source water parameters that may find application for this sort of system. Various manufacturers in the environmental market have for many years combined a variety of this sort of instrumentation into self contained data collection bundles that can feed data back to a central location via wireless telemetry or hard wired packages. There are a number of parameters currently available for on-line monitoring. See table1.

**Table 1.**

<b>Parameter</b>	<b>Applicability to Security Monitoring</b>
Ammonium/Ammonia	May help in detecting byproducts from increased bacterial counts such as a sewage spill
Blue-green Algae	Changes can indicate toxicity to the algae as in the WaterSentry discussed previously.
Chloride	May indicate presence of chloride containing metal complexes.
Chlorophyll A	Changes can indicate toxicity to the algae as in the WaterSentry discussed previously
Conductivity/TDS	May indicate presence of ionic species
Dissolved Oxygen (optical or polarographic)	Sudden change may indicate toxic conditions that effect algal respiration or increased levels of bacteria using up the oxygen.
Dissolved gasses (total)	Changes can correlate with some compounds
Light Ambient	May indicate an opaque plume of a toxic compound.
Nitrate	May help in detecting byproducts from increased bacterial counts such as a sewage spill
Oxidation reduction potential (ORP)	May indicate sudden changes for oxidative or reducing species introduced into the water.
PH	Acid base relationships
Rhodamine	Tracer used in studies to trace plumes
Salinity	May indicate presence of ionic species
Turbidity	May indicate some chemical compounds or increased bacterial levels
UV Absorption	Capable of indicating changes in concentration of some organic species.
General Physical parameters (barometric pressure, depth, temperature etc.)	Little security utilization but can help coordinate and adjust readings from multiple locations

Most manufacturers offer the customer a choice of which parameters to monitor. The majority of these sensors are traditional electrochemistry methods for the parameters in question. Exceptions are optical measurements of turbidity and new luminescent quenching methods beginning to be offered for dissolved oxygen. Also the chlorophyll and algae methods are based on UV fluorescence. The relative low cost of these instrumentation packages allows monitoring at a variety of sites. The major drawback is the huge amount of data that must be analyzed and correlated to determine if a change is significant or the result of natural variation.

### **THE HACH HST APPROACH**

For the past several year scientists at Hach Homeland Security Technologies (HST) have been actively engaged in the development and testing of an early warning system for detecting water quality problems including those related to an intentional terrorist attack in the drinking water distribution system. As the approach for source water described in this paper relies upon many of

the same algorithms, this paper gives a brief summary of how the system works in the drinking water distribution system.

Monitoring in the distribution system, as in source water, 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. This doesn't even take into account the even larger number and diversity of compounds that may accidentally find their way into our drinking water. To counter and detect the unprecedented number and types of compounds that may be encountered, what is needed is a broad-spectrum analyzer that can respond to any likely threat and even unknown or unanticipated events.

The difficult mission of detecting such a wide variety of potential threats is not the only challenge confronting a monitoring system for the distribution system. The environment that any such sensor would be exposed to is extremely harsh. Extreme variability in water conditions is routinely encountered in the pipes. Much of the existing water supply infrastructure is also aging and in poor condition. This results in conditions of corrosion and scaling that may cause the fouling of sensors that are not robust enough to operate under such conditions on an extended deployment timeframe. Biofilms may also form on exposed surfaces leading to sensor failure over time. What is needed is an extremely rugged sensor that is capable of withstanding long-term deployment and has the ability to respond to all types of threat agents.

Rather than attempting to develop individual sensors to detect contaminants or classes of contaminants, the Hach HST approach was 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 logic behind this is that these are tried and true technologies that have been extensively deployed in the water supply industry for a number of years and have proven to be stable in such situations. One of the difficulties encountered when designing such a device is that the normal fluctuations in these parameters found within the water can be quite pronounced.

The problem then becomes, can we differentiate between the changes that are seen as a result of the introduction of a contaminant and those that are a result of everyday system perturbation? The secret to success, in a situation such as this, is to have a robust and workable baseline estimator. Extracting the deviation signals in the presence of noise is absolutely necessary for good sensitivity. Several methods of baseline estimation were investigated. Finally, a proprietary, patented, non-classical method was derived and found to be effective.

In the system as it is designed, signals from 5 separate orthogonal measurements of water quality (pH, Conductivity, Turbidity, Chlorine Residual, TOC) are processed from a 5-parameter measure into a single scalar trigger signal in an event monitor computer system that contains the algorithms. The signal then goes through the crucial proprietary baseline estimator. A deviation of the signal from the established baseline is then derived. Then a gain matrix is applied that weights the various parameters based on experimental data for a wide variety of possible threat agents. The magnitude of the deviation signal is then compared to a preset threshold level. If the signal exceeds the threshold, the trigger is activated.

The deviation vector that is derived from the trigger algorithm is then used for further classification of the cause of the trigger. The direction of the deviation vector relates to the agents characteristics. Seeing that this is the case, laboratory agent data can be used to build a threat agent library of deviation vectors. A deviation vector from the monitor can be compared to agent vectors in the threat agent library to see if there is a match within a tolerance. This system can be used to classify what caused the trigger event. This system can also be very useful in developing a heuristic system

for classifying normal operational events that may be significant enough in magnitude to activate the trigger. When such an event occurs the profile for the vector causing it is stored in a plant library that is named and categorized by the system operator. When the event trigger is set off the library search begins.

The agent library is given priority and is searched first. If a match is made, the agent is classified. If no match is found, the plant library is then searched and, the event is identified if it matches one of the vectors in the plant library. If no match is found, the event is classified as an unknown and can be named if an investigation determines its cause. This is very significant because no profile for a given event need be present in the libraries for the system to trigger. This gives the system the unique ability to trigger on unknown threats. Also, the existence of the plant library with its ability to store plant events results in a substantial and rapid decrease in unknown alarms over time. The developed system has been subjected to strenuous testing in both laboratory and field scenarios.

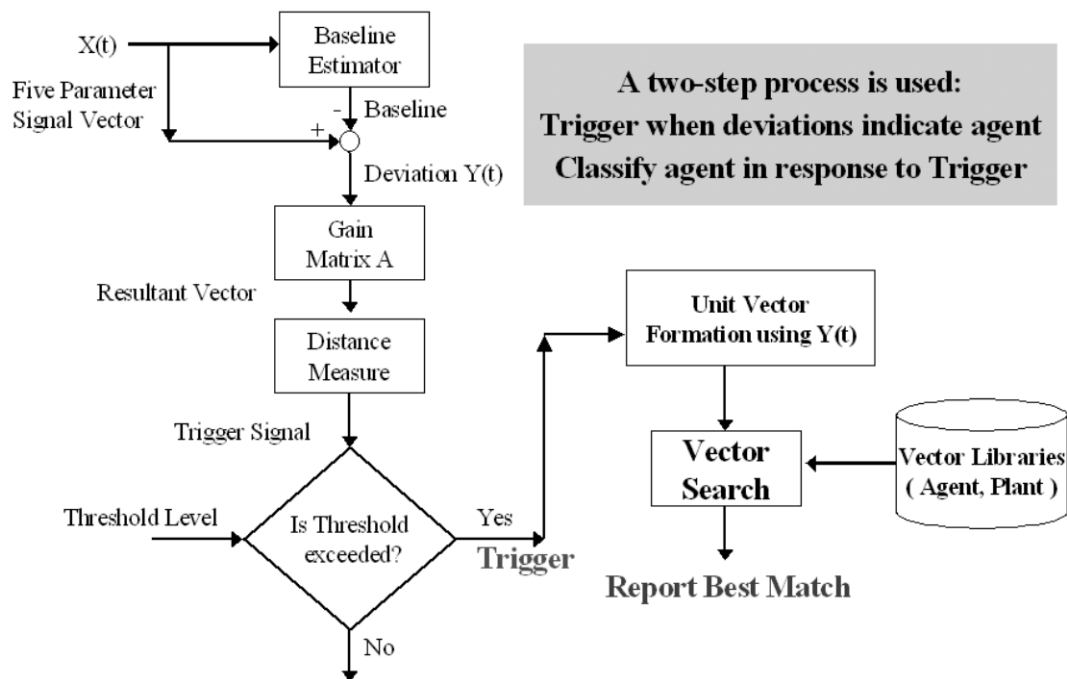


Fig 2. Flow chart depicting algorithm functionality.



Fig. 3. A real world deployment site showing the system in operation.

### **SOURCE WATER PROJECT:**

The use of advanced chemometrics techniques have been proven to be effective in recognizing and classifying events in the complex matrix of the drinking water distribution system. The use of these same algorithms with a different sensor set to monitor source water is described here. A trial program conducted in coordination with the (United States Geological Survey) USGS was conducted to determine if the use of these algorithms for this application is feasible. A series of monitoring stations on a major watershed were deployed in 2006 and 2007. The deployed systems were continuous and online and measured Turbidity, pH, Conductivity, Oxidation Reduction Potential (ORP), UV254 (organics) some stations have also been deployed with Ammonium, Dissolved Oxygen, and Nitrate. The systems were also equipped with automatic samplers that would kick in when triggered to take a sample for further analysis. See fig. 4.



Fig. 4. The instruments were deployed in a weir type arrangement.

Data was collected for a number of months and run through the algorithms to see if events could be recognized and alarm threshold levels set. While the algorithms were successful in detecting and alarming upon major events there were many more alarms than in the drinking water deployments. Much of this was due to non-homogenous nature of the sample stream, which caused more noise in the sensor package. This resulted in more trivial alarms than are commonly present in drinking water samples due to the increased noise function.

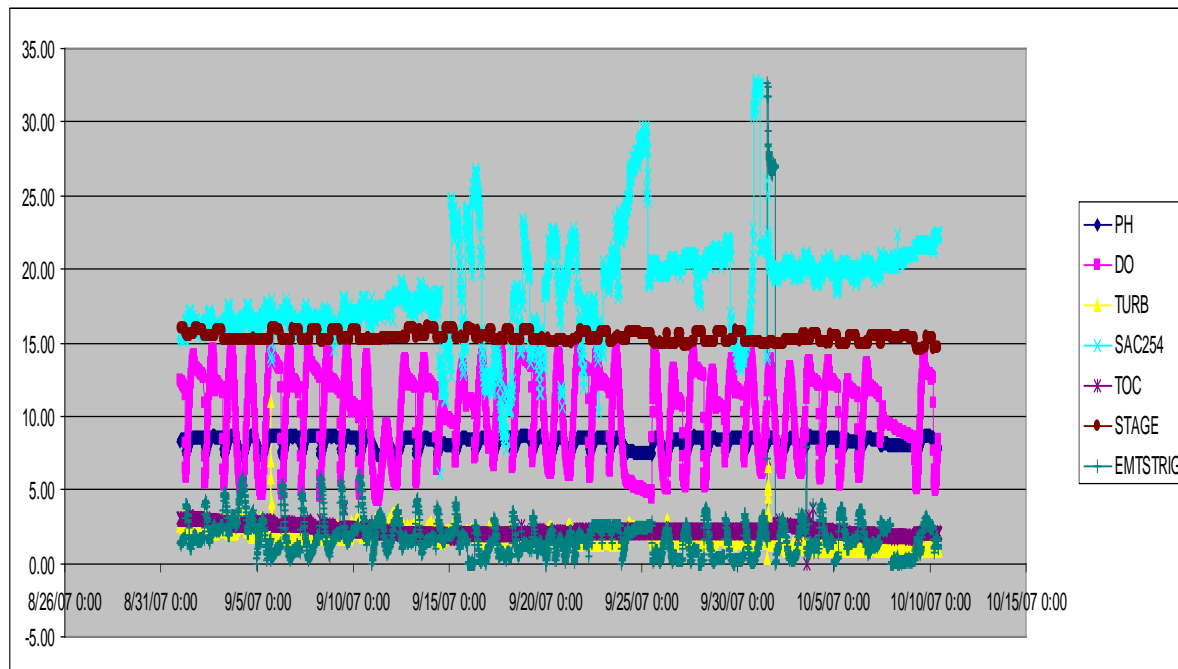


Fig. 5. Six weeks worth of data from one site.

To adjust for this factor a new tuning function was added to the software package to compensate for the noise. Utilizing the new algorithm, the software for the detection system continually adjusts its sensitivity based on the recent noise level in the multiple parameter readings. This adjustment helps

to compensate for changes in baseline conditions over time. If the parameter readings become noisier, the system reduces its sensitivity, and increases its sensitivity should readings become less noisy. This method gives the system the best sensitivity it can have at any given time regardless of conditions. If the system did not automatically adjust its sensitivity, increased noise could generate alarms based on the increased noise in addition to alarms based on water events. With the new tuning function in place, the occurrence of alarms was dramatically reduced while still allowing the system to maintain a level sensitive enough to detect real events with a high degree of confidence.

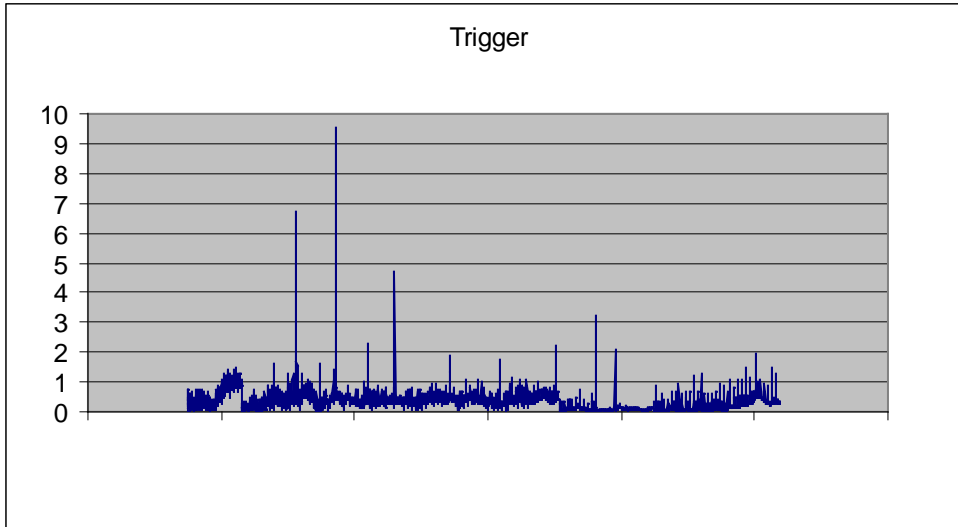


Fig. 6. Graph of trigger signal of combined parameters.

## CONCLUSION:

This modification results in a system that achieves the goals of the source water-monitoring program. It resulted in a system that is continuous and on-line and is capable of responding to a wide variety of contamination events while simultaneously tracking day-to-day water quality parameters of interest. The new variable tuning function allows the system to maintain the desired sensitivity to these events without burdening operators with a continual stream of trivial alarms. This combined with the original algorithms ability to recognize and recall patterns of anomalies makes for a powerful tool for monitoring source water.