WATER QUALITY AND GEOSPATIAL MODELING FOR WATER SECURITY MANAGEMENT

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ABSTRACT

Managing a contamination event for a water distribution system is a challenging task. It is imperative for a water utility to be able to accurately predict the constituent movement throughout the system, efficiently identify the contamination source, and provide timely notification to customers, effectively minimizing the contamination risk. A contaminant may be intentionally injected from any water source, including tanks, reservoirs, pump stations, and a customer service connection. A standard water quality model can be used to analyze contaminant concentration and trace the contaminant from a particular water source throughout the system, but lack of geospatial information of water system assets and customer information limits its effectiveness. This paper presents an approach for assisting water security management. It integrates the water quality analysis model, the latest technology of ArcGIS with open database hydraulic modeling architecture WaterGEMS™ and its extensible object library WaterObject™. The integrated approach WaterSafe™ leverages standard water quality analysis and provides not only insights into how the contaminant is propagated throughout the water system but also facilitates contaminant source identification as well as emergency response preparation. The open database modeling architecture paves the way for linking the water quality analysis statistics with other real-time database systems, such as public health data, to better monitor the water quality and track the source of an outbreak in a timely manner when it occurs.

INTRODUCTION

Drinking-water security has increasingly become a concern for water utilities around world. One of the major security concerns is intentional contamination that may occur at a variety of locations in a water system. To better prepare for such an event and manage it when it does occur, water utilities need to be able to monitor water quality along with other data sources, such as public health statistics; be capable of identifying possible contaminant sources; and be aware of the behavior of constituent movement from any water source, including tanks, reservoirs, pump stations, and any possible location where a contaminant can be deliberately injected.

A water quality model is able to accurately predict and simulate the movement of a constituent (Walski 2001), but detailed geospatial information of water facilities and customers is critical to achieve good water security management. Identifying the contaminant source is another challenging task for water security management. It requires identifying the possible source of a contamination incident for a water distribution system. Trace analysis allows a modeler to predict the nodal flow contribution from one source node at a time, but multiple water sources often exist and must be analyzed in order to identify the actual contaminant source.

This paper presents an approach that integrates the enhanced water quality analysis, the latest technology of ArcGIS with the extensible modeling object library WaterObjects™. It leverages water quality analysis by providing not only insights into how the contaminant is propagated throughout a water system but also facilitates source identification and emergency response preparation.

CONSTITUENT SIMULATION

Characterization of a contaminated water source will require accurate constituent simulation of a water distribution system. A standard water quality model allows a user to analyze one constituent from multiple source locations (i.e. **source nodes**) with different source injection patterns over time. A constituent simulation predicts the concentration at a node for each time-step of an extended period of time. This standard water quality constituent analysis has been enhanced for water security management as follows:

- Allowing multiple constituent analysis;
- Processing constituent statistics for all the hydraulic elements;
- Presenting dynamic graphics representation of the result statistics.

Multiple-constituent analysis allows a modeler to simulate the movement and propagation of different chemicals under the same hydraulic scenario. Each constituent simulation can be performed by applying user-specified bulk reaction rate coefficient, which can be calculated using either a one-day decay rate or half-life (the number of days that a constituent decays to half of its initial concentration).

In an addition to the constituent concentration, WaterSafe™ produces constituent mass and mass accumulation for all the chemicals at all junctions. The amount (i.e., mass in units, such as g/day) of a constituent can be calculated for each node when a constituent simulation is conducted. The calculated constituent mass is summed up over time to produce an accumulated mass of the constituent for all the nodes in a system. This will generate the accumulated mass of a constituent at any time for any node.

Both constituent mass and accumulation are useful information for a modeler to better visualize the water quality simulation throughout a system. The constituent mass indicates the amount of chemical at any node at any time since the beginning of a simulation, and the accumulated constituent represents the total amount of a chemical that has been flowing out at a node at a given time during a given time period. Concentration statistics can be performed for one constituent over a specific period of time as the user chooses. It may include concentration average (mean), standard deviation, and variance for any given location in a system.

TRACE ANALYSIS

Source trace analysis is used to track water throughout a system over time. It calculates the percent of water reaching any node from a particular source node. The source node can be any node including storage nodes and junctions in a water system. Source tracing can show water percentage from a given source blends with that from other sources, and how the spatial pattern of this blending changes over time.

Trace analysis is useful for identifying the possible sources of a contamination incident in a water distribution system. Percentage of flow contribution from a source node to each individual junction may be used to represent contamination contribution from the source. A typical water quality model can perform the trace analysis for just one source node in simulation one run. WaterSafe™ trace analysis allows a user to select multiple sources (inflow nodes and/or a number of junctions). The batch runs of trace analysis are then simultaneously conducted for each source for the same period of time. Each trace run determines a percentage contribution of flow/contaminant from one source node to all the other nodes for a given time step.

A dynamic flow percentage/contaminant contribution from all the sources is obtained for the junctions. For a given junction, a dynamic animation of flow percentage contribution can be presented for all the source nodes. A modeler can intuitively view the variation of flow contribution or contaminant concentration (chemical mass) over the simulation period. It keeps the modeler informed on the flow contribution of all the possible sources in a system. The results of the analysis may be used for comparison with other real-time data sources, such as public health statistic data to identify the outbreak incident in a system [e.g., the Ontario E. Coli outbreak in May/June 2000 (Aramini 2001)].

An Extended trace analysis includes:

- Multiple source tracking analysis;
- Flow contribution and accumulated flow for each junction from each trace source;
- Trace statistics and dynamic graphics presentation.

In addition to the percentage of water, flow contribution is used to determine how much water is coming from which source. This information helps the engineer to understand the source contribution to any node in a system. Similar to the constituent statistics, trace statistics are performed for each source node over a specific period of user-selected time. The statistics includes flow percentage average (mean), standard deviation, and variance for any trace source.

OBJECT-ORIENTED GEOSPATIAL MODELING

Geospatial data for hydraulic network elements in general and geocoded customer data in particular is vital to achieve good customer management as an integral part of water security management. Customer management is to keep customers informed of water supply performance such as pressure and flow availability, water quality status, maintenance schedule as well as incident impact.

Coupling a hydraulic network model with customer information (e.g., customer ID and address) and an extensible water modeling object library (WaterObjects™) paves the way for developing a customer management report based on hydraulic and water quality simulation results. Customer data is largely spatial-based information. It is often stored in a customer information system (CIS), which can be geocoded for a modeling application. Customer spatial analysis is carried out by applying polygon intersection and overlapping and then geo-referenced customer information is associated with modeling nodes (pipes), a meter-node (pipe) relationship, based on the proximity of the nodes and customers, by aggregating and allocating customers to a node and pipe (Wu etc. 2003). Using WaterGEMS™ open database architecture and WaterObjects™, a customer report can be generated by using the meter-node (pipe) relationship for routine operation and security management.

The customer spatial analysis essentially leverages hydraulic and water quality modeling capabilities, enables the modeler to better use the open database model, and provides customer management along with hydraulic and water quality simulation results. It also helps for producing timely customer notification for an incident or a routine maintenance such as flushing, network facilities and pipeline work.

To effectively manage an event of maintenance or contaminated incident, the affected area must be minimized by isolating the area from all the water sources. With a good representation of flow control elements, such as all the valves and pumps, an affected area can be isolated by applying GIS network tracing analysis to identify the minimum number of control facilities and then change the operating status to close the water supply to an affected area.

Locating the control elements is the key for the isolation. In order to programmatically find the control elements, a trace/search algorithm is employed for identifying the valves and pumps. The user will start by specifying the control (closable) elements by using a built-in selection tool, system isolation will search for the flow control elements for all the flow paths of user-selected elements (links and nodes). Once the control valves are found, the control status can be changed to CLOSE to isolate the area. Isolated elements and/or customer reports can be generated for the whole area that is isolated.

CONCLUSIONS

Water security management involves a wide range of tasks. Hydraulic and multi-quality modeling alone cannot meet water utilities' needs for achieving a secured water supply. The proposed approach has integrated various latest techniques, including ArcGIS and the extensible modeling object library WaterObjects™ on an open database hydraulic modeling platform WaterGEMS™. The integrated tool WaterSafe™ enables a modeler to analyze the movement of multiple constituents and track multiple sources for a given period of time. It will keep the modeler informed on the characteristics of constituent propagation and flow contribution dynamics of all the possible sources and thus facilitate tracking water contamination.

The water quality analysis statistics may also be used for comparison with other real-time data, such as public health statistics, to closely monitor water quality status and help engineers to identify the source of an outbreak in a system when it does occur. An integrated modeling tool will be useful at assisting engineers and decision-makers to better prepare for a response strategy and recovery plan.

REFERENCES

Aramini, J. (2001). Walkerton, Ontario E. Coli Outbreak. *Proc. of Water Security Summit*, Hartford, CT, pp. 180-197.

Walski, T. (2001). Water Distribution Models for Emergency Response. *Proc. of Water Security Summit*, Hartford, CT, pp. 259-269.

Wu, Z. Y.; Wang, R. H.; Diaz, D.; and Walski, T. (2003). Mining Water Consumption and GIS-based Data for Loading Water Distribution Models. 2003 *World Water and Environmental Resource Congress*, June 22-26, Philadelphia, PA.