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DEVELOPMENT OF REAL-TIME DRINKING WATER DISTRIBUTION SYSTEM (DWDS) MODELING TECHNOLOGY USING THE EPANET EXTENDED PERIOD SIMULATION (EPS) MODELING TOOLKIT

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Real-time modeling of drinking water hydraulic and water quality implies that the network model is continually revised to reflect the knowledge that is available from real time SCADA data. The "improved" real-time model can then be used for a variety of purposes including the prediction of hydraulic and water quality parameters that are not available in the field measurements, and to detect contaminant intrusion through model-based anomaly detection [1]. This paper examines how this type of real-time modeling was built on top of the EPS foundation provided by the EPANET toolkit and was applied to real-life networks. These applications posed some interesting modeling challenges when the hydraulic time-step was reduced down to a minute (or five minutes) to match the SCADA data frequency. For example, physical pumps and valves often do not start within a minute, but model elements do. This can cause major mismatches between SCADA and modeled data, and these can be further exasperated if all control rules are completely removed from the real-time model.

Since the “real-time” EPS hydraulic model tries to accurately balance the “produced” pumped amount and the “known” tank demands with the “consumed” demand, turning ON a large pump instantly in the model can many a times cause “unbalanced” model conditions since actual field conditions often show gradual operation. Although the hydraulic simulation can recover gracefully from such conditions, the advanced water quality simulations such as EPANET-MSX usually fail to continue past those instances. Increasing hydraulic time-step to fifteen minutes or one hour can reduce the ‘hydraulic’ problems but has the unfortunate consequence of masking the water quality spikes. The accurate modeling of these spikes is important for anomaly detection and for reduction of false positives in containment warning systems. There are additional issues involved in the construction of EPS models in a real-time framework. For example, an EPS model may represent a battery of pumps with a single pump curve, and it becomes necessary to develop realistic individual pump curves to match the SCADA data. The authors conclude that although the EPS toolkit behaves well through the major portion of the real-time situation, further modeling advances will be necessary to improve the match with SCADA data. Specific changes were made to EPANET and EPANET-MSX in the current project to meet some of the real-time needs.

REAL-TIME MODELING

Water distribution network modeling is an extremely important part of providing reliable and affordable water to large populations. Common uses include utilizing the models for master planning, water quality investigations, operations, system design, and contaminant intrusion identification and analysis. Real-time modeling has seen growing interest in recent years as new software has emerged and application and benefits of using a model in real time continues to expand.

Background

Water distribution system (WDS) modeling has been around for a long period of time, but it saw extended interest and advancements following the public release of USEPA's EPANET software in 1993. EPANET has seen continual support and advancements including a recent extension that performs multiple-species water quality simulations (MSX). Traditional WDS modeling software supports two simulation methods: steady state (or a snapshot of the system) and extended period simulations (EPS). EPS models are used to evaluate network performance over time, and are consequently used for a large amount of analysis and planning projects. The time period variability also allows the application of this type of simulation to real-time scenarios. The EPANET programmer's toolkit provides programmatic access to the computational capabilities of EPANET, and has been widely used by researchers and private companies to build a variety of applications.

HydroTrek Software

The software suite titled HydroTrek was created with the intent to improve hydraulic and water quality modeling by implementing a model in real-time. By creating a real-time model, SCADA data can be collected and used to actively influence model results. In this way, the model is always evolving and reacting to what is actually happening in the network. The HydroTrek software includes multiple modules which help achieve these advanced modeling goals. It also supports the concept of demand zones natively to enable the modification of the demand patterns in the model at a granular level based on the SCADA-based demand zone consumption values. The models that are modified in such a manner show significant agreement between the modeled tank levels and the measured tank levels.

The primary HydroTrek software, RMX (Real-time Modeling extension) uses the EPANET toolkit as described above (or alternatively can use the Bentley WaterObjects engine) to simulate both network hydraulics and water quality (including multiple-species). However instead of being a static EPS, the model is actively updated in real-time or historic time frames. HydroTrek continuously refines model elements (including demands, statuses, and valve settings) based on incoming SCADA data at each timestep. This results in higher accuracy simulation results compared to a static, long-term EPS. Additional changes to the EPANET toolkit were made to achieve higher accuracy from a 64 bit compilation and to calculate incremental water quality changes corresponding each hydraulic timestep.

MODELING CHALLENGES

Though HydroTrek software has been successfully deployed to model real WDS networks, several challenges inherent in real-time modeling had to be overcome. Additionally, some nuances exist that do not have a simple solution for this type of application. The following section provides insight on some of these challenges that have been encountered and solutions that have been explored.

Pump and Valve Operation

The operation of pumps and valves in a normal WDS model do not often reflect their operation in the field. While a pump or valve suddenly turns on or off in a model situation, they often see a more gradual ON/OFF cycle in real-life. Additionally, SCADA reporting or hydraulic timestep differences may result in mismatches between data that is being reported compared to when the actual pump is cycling on or off. These issues can cause major discrepancies between SCADA data and modeled results.

HydroTrek can operate pumps by determining the actual pump status from the flow coming from SCADA. Therefore, when SCADA shows a pump changing to an OPEN status, it subsequently turns the pump on in the model. However, because the pump is turned on gradually, SCADA and model values can show a major difference in flow values depending on how the actual pump is being operated. The table below shows an instance where a pump is being turned on gradually, but the model shows immediate cycling that is resulting in major flow differences.

Table 1. Example of gradual operation of pump compared with equivalent model

Time	**SCADA Flow (GPM)**	**Model Flow (GPM)**	**Pump Status**
4:55	0	0	Closed
5:00	0	0	Closed
5:05	1440	2321	Open
5:10	2315	2323	Open
5:15	2324	2315	Open

Valves can also often be operated gradually in real-life systems. For example, a tank inlet may begin to gradually close before a tank reaches its maximum level rather than immediately shutting off as occurs in a model situation. Additionally, pressure reducing valves (PRV's) can be varied gradually over time in actual networks. The valve pressure settings are sometimes adjusted over time by operators to provide the best service, but in a model this is usually a static valve setting parameter.

Some of the gradual behavior can be resolved with clever modeling techniques. A varying valve setting was created by continually adjusting the model setting based on incoming SCADA downstream pressures. Using a continuous adjustment method like this in HydroTrek caused not only the valve to be operated closer to real-life, but also subsequent model flows and system dynamics showed major improvements over a static pressure setting value. Gradual pump operation has been investigated with the use of speed parameters, and so far results from this type of modeling look promising. Ideally, both valves and pumps should have model behavior and operational options that are inherently closer to reality without the need for these clever modeling techniques.

Real-Time Controls

If a real-time model is updated by discarding 'all model rules' and strictly on the basis of the SCADA component status values, then tank level discrepancies can become exacerbated through the opening or closing of valves that have a major influence on model behavior. Therefore, it is actually desirable to have a combination of SCADA control and model rules to achieve the desired amount of model stability.

For example, say only SCADA status is used to control a major internal network valve. If the valve is turned on exactly when SCADA turns on, a nearby tank whose model levels are still filling may not reach the correct operating value. In turn, the tank model results become mismatched with SCADA and soon the entire network is not representative of actual field conditions.

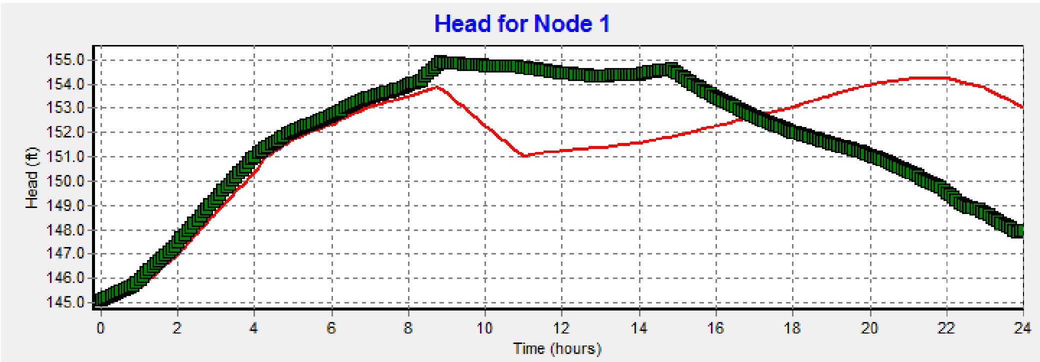

Figure 1. Example of model misbehavior with SCADA status operation only

Ideally, a combination of SCADA values (for example, system input pump states) and updated controls (for example, rules for internal valves or booster pumps) should be used to operate the model. In this way, the model tank can continue to fill while the valve is open before being closed at a time that will not cause later model instability. While this may results in slight offsets between model and SCADA results, it represents a better situation than the entire network model having stability issues later on.

SCADA Data Transformation
A significant challenge with real-time modeling is the processing of incoming SCADA data. This data is being used to actively update model demands, so it is important to properly handling this incoming raw data. Since sensor data is often subject to some amount of noise, smoothing and data massaging becomes incredibly important in terms of resulting model behavior. The tank demands are usually calculated from the tank levels, and any noise in the tank levels can cause drastic noise in the tank demands. Noisy tank demands can be quite detrimental to effective real-time simulations.

When data is smoothed in a real-time sense, the software must be careful to both reduce noise and also reduce any smoothing offsets that may occur. If certain data needs to be smoothed more than other data, the resulting offsets may cause discrepancies in the resulting demand calculations. Resulting SCADA demand spikes or calculated negative demands can occur, which in terns throws off the model simulation for those periods.

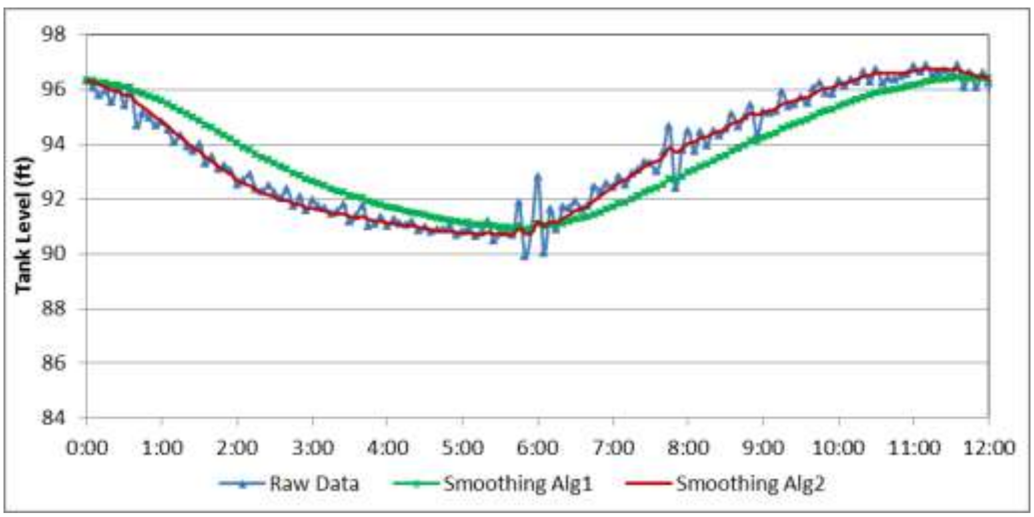

Figure 2. Example of tank level smoothing resulting using different algorithms

For adequate data management, a simple moving average approach does not satisfactorily reduce noise and offsets. Even more advanced smoothing methods (see Smoothing Alg1 in Figure 2) were shown to cause major offsets between actual behavior and transformed results. A complex smoothing algorithm (Smoothing Alg2 in Figure 2) was required before resulting transformed data offset were finally removed while providing a good amount of noise reduction.

CONCLUSIONS

Real-time hydraulic and water quality modeling poses a new set of challenges compared to a traditional EPS simulation run. The term real-time modeling is sometime used to describe situation where the EPS model results are compared side-by-side with a live SCADA connection in graphical user interface. Although that approach improves the understanding of the model behavior, it does not lead to any improvements of the model results in automatic fashion. The implementation of real-time modeling in the HydroTrek platform that was discussed in this paper shows how the EPS model can be modified in real-time as the SCADA data arrives from the field. That type of implementation leads to automatic improvement of the model results that match the field measurement to a much better degree compared to a traditional EPS model. Challenges that arise from this advanced approach along with solutions for overcoming those issues were discussed in this paper.

REFERENCES

[1] Kshirsagar S., Monks V., Grayman W., Anand D. and Song R., “Lessons Learned in Converting a Planning Model to an Operational Model for Real-time Water Distribution Systems Modeling”, *World Environmental & Water Resources Congress*, Cincinnati, (2013).