Real-time modeling of water distribution systems: A case study

PAUL F. BOULOS,[1] LAURA B. JACOBSEN,[2] J. ERICK HEATH,[3] AND SRI KAMOJJALA[2]

[1]Innovyze, Broomfield, Colo.
[2]Las Vegas Valley Water District, Las Vegas, Nev.
[3]Innovyze, Arcadia, Calif.

Water utilities worldwide face increasing challenges to preserve the hydraulic and water quality integrity of their water distribution networks. These challenges stem from burgeoning populations and migration to urban cities that continue to increase the load on aging, inefficient, and already strained infrastructures. This has created a pressing need for integrating supervisory control and acquisition systems with network simulation models for proactive management of these networks. Such an integrated platform is the basis for the real-time smart water network decision support system (SWNDSS) described here. The proposed system has the power to transform a water utility's routine network modeling functions from planning and design to full-spectrum engagement that drives more efficient operations—including managing water quality and energy, developing daily operating plans, addressing planned and emergency outages, and diagnosing and resolving field issues. Aspects of the SWNDSS ar described in a case study from the Las Vegas Valley Water District in Las Vegas, Nev.

Keywords: *energy management, operations, optimization, supervisory control and data acquisition, time modeling, water quality*

The water distribution system is an essential component of every water utility. Its primary function is to economically provide a safe, reliable water supply at an acceptable level of service, and failure to do so is a serious system deficiency. Therefore, maintaining the hydraulic integrity of the water distribution system is of paramount importance. Breaches in hydraulic integrity can also lead to external contamination as well as degradation of water quality associated with increasing water age and the loss of disinfectant residual, compromising the integrity of distribution system water quality (Clark, 2012; Boulos et al, 2006; NRC, 2006; Lansey & Boulos, 2005).

BACKGROUND

State of drinking water infrastructure in the United States. The US drinking water infrastructure, which serves 315 million people, is in serious need of replacement, upgrading, and maintenance if it is to continue to support a growing population. AWWA has warned that the cost of repairing and expanding US drinking water infrastructure will top $1 trillion through 2035 or $1.7 trillion through 2050, and that this cost will likely be funded primarily through higher water bills and local fees (Water Utility Council, 2011). The outlook for the nation's drinking water infrastructure is grim. Particularly in older cities, much of this infrastructure is deteriorating and in need of replacement. The American Society of Civil Engineers 2013 Report Card for America's Infrastructure gave drinking water a near-failing grade of D, only a slight improvement over the D minus awarded in the previous Report Card, issued in 2009 (ASCE, 2013, 2009).

Water infrastructure in the United States is clearly aging, and capital spending is not able to keep pace with needs. Demand management and sustainable practices are essential but cannot solve the problem alone. The growing gap between the capital needed to maintain drinking water infrastructure and the investments to meet that need will only widen over time, and addressing that gap will become increasingly expensive. This makes it increasingly difficult to preserve system hydraulic and water quality integrity and assuage the public's health and economic concerns and maintain its confidence in a safe and reliable drinking water infrastructure.

Water and energy are inextricably linked. Water utilities are energy-intensive, and consumers use water in energy-intensive ways such as water heating and pressurizing. Globally utilities are spending nearly $184 billion each year to supply clean water; $14 billion of that figure is spent on energy needed to pump water around the current networks (Sensus, 2012). Nationally, the US population uses more than 520 million MW·h per year, or 13% of the nation's electricity consumption, on water (Boulos & Bros, 2010). The carbon dioxide embedded in the nation's water represents 5% of all US carbon emissions and is equivalent to the emissions of more than 62 coal-fired power plants (Griffiths-Sattenspiel & Wilson, 2009). Even as water conservation and management practices are evolving, concerns about energy use are fueling a move to smart technology solutions that promise more efficient and sustainable water systems (Lewis & Hendrix, 2012).

Distribution system integrity is best evaluated using real-time methods to provide warning of potential breaches in sufficient time to effectively respond and minimize public exposure (NRC, 2006). Boulos and Wiley (2013) described the various information management and real-time monitoring systems that can help water utilities drive efficiency gains and become more proactive in the operation and management of their water distribution networks. These systems can also help utilities achieve regulatory compliance, provide enhanced security, and aid in the decision-making processes for network integrity assessment and financial planning. Table 1 lists the key systems and their specific functions.

This article focuses on an on-line, real-time network modeling system and its application at the Las Vegas Valley Water District (LVVWD) in Las Vegas, Nev. The main objectives in implementing the system were to reduce water age and enhance water quality, decrease the operational cost of the network by developing improved daily operating plans and pump control rules, address planned and emergency outages, and diagnose and resolve field issues.

REAL-TIME NETWORK MODELING

Benefits of effective simulation models. Hydraulic and water quality simulation models represent the most effective and viable means for predicting network behavior of water distribution systems under an array of demand loading and operating conditions. Using laws of conservation of mass and energy and reaction kinetics, the models determine pressure, flow, and water quality (movement and transformation) conditions for specified system characteristics and operating conditions (Rossman, 2000). The predictive capabilities of these deterministic models provide a powerful tool for evaluating system response to various operational and management alternatives aimed at meeting specific performance goals (Clark, 2012; Boulos et al, 2006; NRC, 2006). The Partnership for Safe Water has developed performance goals (Lauer, 2011) that focus on ensuring the network hydraulic integrity (e.g., maintaining a minimum pressure of at least 20 psi) and water quality integrity (e.g., maintaining a disinfection residual > 0.2 mg/L for free chlorine).

To be effective, these models must draw on an accurate, continuously updated view of the state of the water distribution network. This can be realized by synthesizing supervisory control and data acquisition (SCADA) and other real-time telemetry data with a network model in an automated fashion. The real-time SCADA data are used as boundary conditions (e.g., tank water levels) and operational statuses (e.g., pump speeds or on/off status, valve settings) in the network model, and the model demands are updated to reflect network aggregate flow (Hatchett et al, 2010). The resulting real-time model is referred to here as the smart water network decision support system (SWNDSS).

Advantages of the SWNDSS. The SWNDSS runs in near real time by reading SCADA measurements as they become available, updating the network model boundary conditions and operational statuses, pausing execution and generating the corresponding network analysis results, and then waiting for the new SCADA measurements to reload the network model and rerun the network simulation. The SWNDSS gives water utility operators continuous near real-time insights into water distribution network performance. This constant stream of data at specified intervals (e.g., at 15-, 30- or 60-min intervals, or longer, depending on the application-specific needs), coupled with network modeling capabilities, enables operators to quickly assess developments as they occur, identify potential problems before they reach a critical level, respond decisively to operational challenges, and minimize downstream effects.

For example, operators can analyze the effect of a predicted low storage tank level on network hydraulics and pinpoint all customers who will be negatively affected by low pressures. They can conceive and formulate alternative operating scenarios that can then be quickly and accurately analyzed and compared to determine their respective levels of improvement and associated costs; the most desirable scenario can then be selected and implemented. Operators can assess the effects of main breaks; pump, valve, and reservoir shutdowns; other scheduled maintenance or repair; as well as any planned or unplanned incidents. They can then respond swiftly with appropriate countermeasures. Operators can also predict key network parameters (e.g., flows, pressures) where data loggers are unavailable and predict system performance should SCADA feeds go off line.

Water distribution systems work best with minimal fluctuations in pressure. A real-time network model allows utilities to effectively manage their pressure zones, including adding new zones or adjusting existing boundaries to maintain adequate pressure differentials throughout the network. This proactive type of real-time pressure measurement reduces leaks, breaks, and pumping costs; improves reservoir turnover rates; and avoids overpressurizing the system.

Using real-time network modeling, water utilities can progress from a purely reactive approach to more proactive network management. This can ultimately result in network operations that are significantly more efficient and economical, as well as greater network integrity, and improved network maintenance and customer service.

CASE STUDY

For the past eight years, the LVVWD has used real-time network simulation models to develop daily operating plans to manage energy and water quality, calibrate the hydraulic model, manage planned facility outages, and aid in emergency response. This case study outlines real-time network model development and application of operational modeling at LVVWD to gain the benefits of real-time network simulation of the SWNDSS outlined previously.

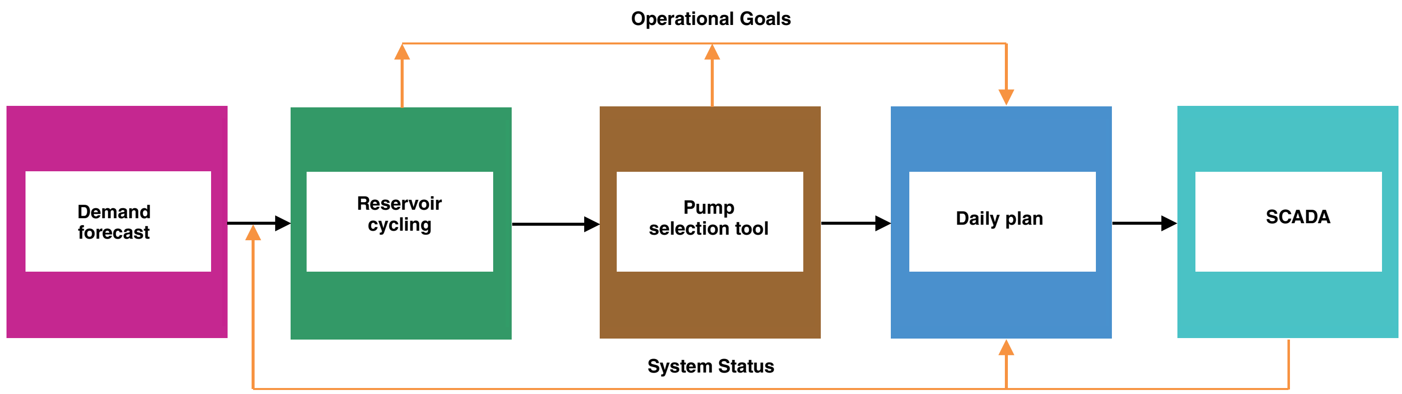
Need for real-time modeling. *Distribution system.* The LVVWD serves a population of 1.3 million people. Water is delivered from treatment facilities at Lake Mead to the district's distribution system through 10 supply turnouts, and this supply is supplemented with 62 groundwater production wells during the summer months. The system has 24 pressure zones. Water is conveyed through the distribution system via 52 pumping stations comprising 256 pumping units. The system has 41 storage reservoirs with a total available storage volume of 916 mil gal. LVVWD spends approximately $12.7 million each year on power. Managing water quality and energy costs is the primary driver of the district's efforts to move toward real-time modeling.

TABLE 1 Models/systems and their roles

Model/System	Smart Water Network Role
On-line sensors/smart meters	Report and collect real-time data on selected network parameters Automate sampling Improve understanding of water quality changes Develop water use patterns
SCADA	Report and collect real-time network parameters data Calculate accurate water balances Issue alarm notification Remotely contain and control events Reinitiate normal operation after elimination of event
GIS	Visualize all system facilities Allocate demands Identify and alert affected population Map modeling results
Real-time network modeling	Manage water quality and energy Improve daily operating plans Determine appropriate response to network/service interruptions Optimize planned and emergency facility outages (criticality analysis) Improve pressure management and reduce breaks and leaks Develop unidirectional flushing sequences for decontamination Locate on-line monitoring stations
Real-time operations optimization	Minimize wasted energy costs Reduce carbon footprint Improve network operational efficiency Optimize operational expenditures
Real-time network monitoring and anomaly detection	Identify network anomalies like leaks and breaks Estimate potential future leaks Manage leakage Detect potential pipe breaks Reduce pipe repair costs Recognize abnormal operating conditions Improve water conservation Eliminate dependence on customer alerts Issue alarm notification
Real-time event detection and early warning	Deliver accurate and timely water quality compliance reports Conduct automated water quality sampling Identify contaminant intrusion Warn of low disinfectant levels Improve public health monitoring Allow rapid intervention to mitigate potential hazards Issue alarm notification
Asset integrity management and capital planning	Predict pipe failure timing/risk profile and associated impact Develop short-, medium- and long-term pipe renewal strategies Minimize capital expenditures for pipe Eliminate misdirected network maintenance Reduce downtime and unforeseen problems Increase useful life of assets Map maintenance work orders and coordinate response units

GIS—geographic information system, SCADA—supervisory control and data acquisition

FIGURE 1 Daily model plan



SCADA—supervisory control and acquisition

Water age management. LVVWD uses water age as a surrogate for water quality in terms of maintaining adequate chlorine residual and minimizing disinfection by-product (DBP) formation in the distribution system. Areas with high water age tend to occur on the outer margins of the distribution system and typically are associated with regions of new growth where major facilities have been constructed but relatively few homes are currently occupied. (These water-age hot spots generally disappear over the course of two or three years as additional homes become occupied.) Another factor influencing water age in the system is the drought affecting the Colorado River, which has resulted in significantly lower water levels in Lake Mead, the district's primary water source. As lake levels fall, water temperature increases, causing DBPs to form more rapidly. The DBPs of primary concern to the district are total trihalomethanes (TTHMs), which are suspected human carcinogens.

Daily operating plans. In 2005, LVVWD began using its hydraulic model of the distribution system to develop plans each day for operation of the system over the next 24 h. Boundary conditions are updated through integration with SCADA, and a daily demand forecast is incorporated into the model. The plans are customized each day to accommodate operational goals, scheduled maintenance activities, previously issued water and power orders, and facility outages. With a large volume of available reservoir storage, small variations in customer demand and delivery of water supply can be absorbed by the system.

This system, currently in use at LVVWD, has assisted the district in reducing water age and energy costs, provided insight into distribution system performance, and supported the identification and resolution of field issues. In addition, emergency response is enhanced, and a wealth of calibration data is available to further refine modeling efforts. The system allows the operator to monitor model-predicted versus actual distribution system performance in real time. The daily plan approach offered low upfront cost, while still providing all the benefits outlined previously.

Modeling requirements. The LVVWD recognized that implementing real-time modeling would require a well-calibrated model with accurate facility information and spatial distribution of demands. Additionally, the model had to be easily integrated with other data systems, including geographic information systems (GIS), SCADA, and other enterprise systems (e.g., billing).

When integrated with other data sources, the model becomes a powerful tool for decision support. Integration also provides for automation of certain processes, such as model construction and spatial allocation of demands. Integration of the model with GIS provides information on the physical components of the distribution system, accurate allocation of demands within the model, and display of model results in GIS. Integration with enterprise systems provides information such as consumption data used for model demands and project schedule information for facilities in the model. Integration with enterprise systems may also be used for customer notifications for scheduled and emergency system outages. Integration of the model with SCADA provides information on facility status, pressures, and flows and is used to set boundary conditions for modeling, determine abnormal operating conditions, and perform hydraulic model calibration. The district uses a database management system together with in-house applications and hydraulic modeling software for data integration.

REAL-TIME MODELING PROCESS

Daily model plan. LVVWD uses the hydraulic model to develop a daily operating plan to minimize energy costs and water age (Jacobsen & Kamojjala, 2009). The process consists of a demand-forecasting component, a reservoir-cycling component, and pump-selection tools. Boundary conditions such as initial reservoir levels are downloaded from SCADA. A pumping plan is developed manually by quickly evaluating several operational scenarios for optimal energy use and water quality with the use of automated tools.

The daily operating plan (including pump schedules and projected reservoir levels, pumping station flows, and water age) is electronically transferred into a corporate database for approval by the LVVWD operations department and is downloaded by the operator into the SCADA system, which runs the plan. This step is deliberate and necessary because of security protocols associated with the district's SCADA system. The operators approve and transfer the plan from the corporate database to SCADA with a push of a button. Operators have the ability to take over at any time during an emergency; however, they often request a revised plan during unforeseen occurrences such as a major pipeline break. Figure 1 shows a simplified version of the process. While the loaded operational plan is running, with the help of an automated tool, the model-predicted reservoir levels are compared with SCADA-obtained reservoir levels to identify anomalies and emergencies, ensure smooth system operation, and calibrate the model.

Immediately after completion of the previous day's operational plan, an automated tool is used to download the actual system operation into the model from the archived SCADA data, and the model-predicted reservoir levels are compared with the SCADA levels. Any major differences in reservoir level between the predicted and actual system operation are investigated for field issues and adjustments to model parameters. Verification and calibration of the model are performed daily, and a comprehensive annual calibration checks pressures and flows at numerous locations in the system as well as reservoir levels. Finally, using the model with the actual system operation, the water age is calculated for various locations in the system and loaded into the database.

The following sections provide additional details of the real-time modeling process and associated tools. Figure 1 indicates the tools and processes involved in the development of the daily model plan.

Operational goals. In addition to minimizing water age and energy costs, operational goals may include adhering to or providing for short- and long-range power orders and ensuring that solar power facilities are used in accordance with existing contracts. Short-range power orders are typically issued two to three days in advance and are a function of projected demands and the resulting water order from the treatment plant. Power use by facility is calculated for each iteration of the operating plan as it is prepared. Plans are also prepared to provide for artificial recharge and facilitate planned facility shutdowns. Annual goals for artificial recharge are determined through a separate water resource planning process. Facility outages are generally planned well in advance by the LVVWD operations department in order to minimize inconvenience to customers. Artificial recharge flow rates and hours of operation are incorporated into the operating plan, as are planned time frames for facility outages.

FIGURE 2 Pump run time report

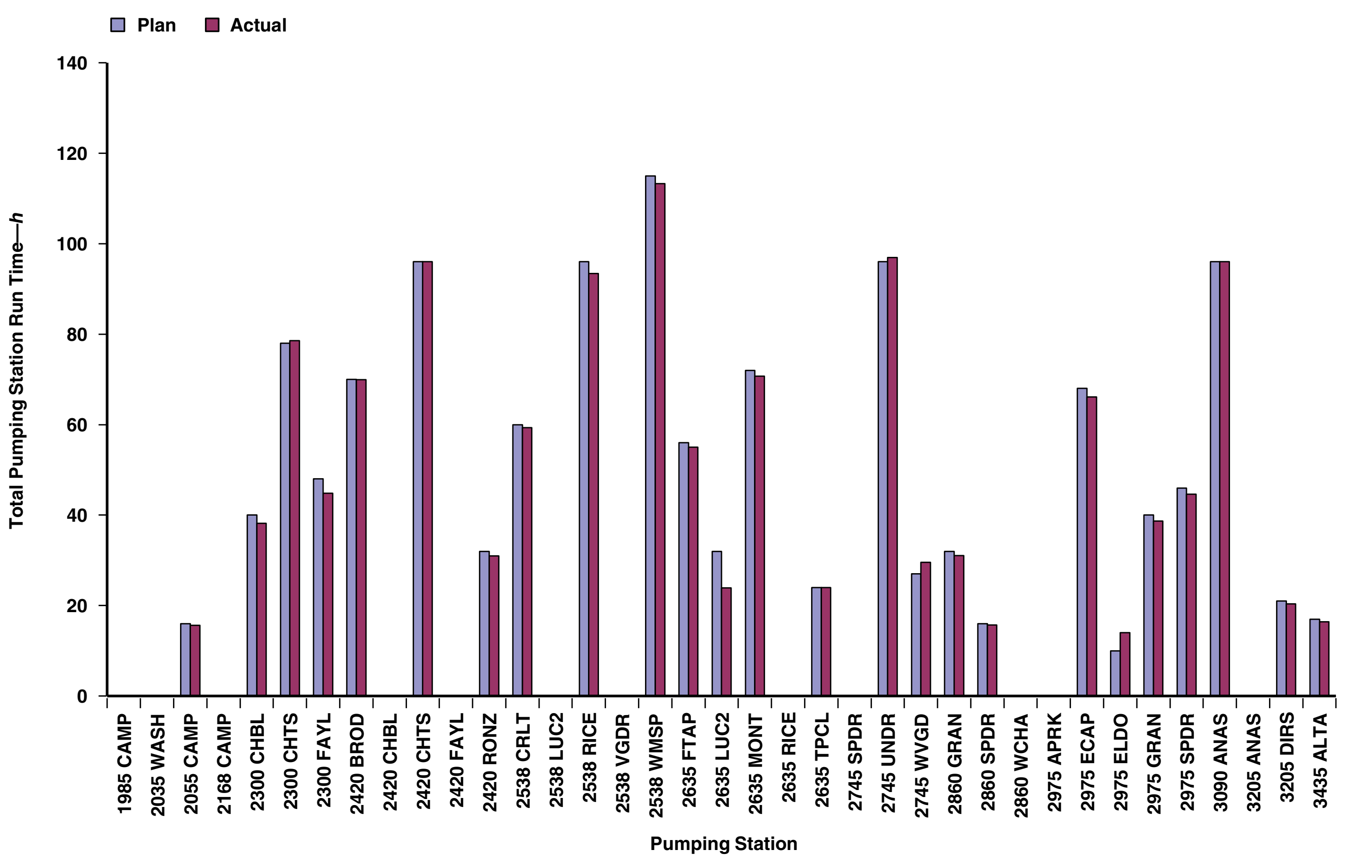


Figure shows run time comparison of submitted plan versus actual operation for the period from 1:00 p.m. on May 16, 2008, to 1:00 p.m. on May 17, 2008.

Demand forecasting. An updated maximum day demand forecast is prepared annually for the LVVWD hydraulic model. To ensure proper spatial demand distribution (which is essential to operational planning), demands are based on the district's GIS land use coverage and customer meter records. Seasonal adjustments, based on customer meter records for the previous year, are made to this demand distribution to account for variations in use at specific locations in the distribution system. In addition, LVVWD prepares a current-day demand forecast (used to prepare the daily operating plan) and a 10-day demand forecast (used for water and power orders that need to be placed in advance). The district uses a neural network model and three regression analysis models to create these short-term demand forecasts. Data inputs for these models include historical demand, historical weather, consecutive days of rain, forecasted weather, day of the week, month of the year, seasonal lawn watering restrictions, and extreme weather.

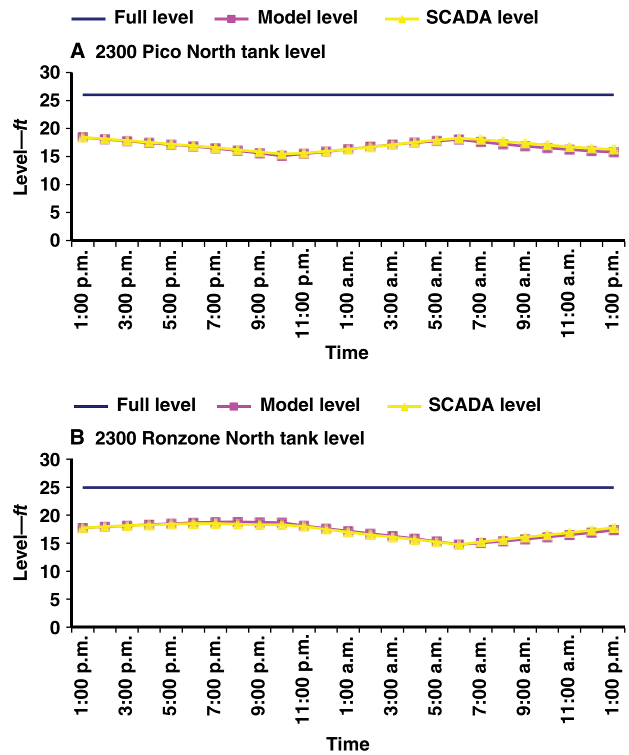
Hourly demand variations are developed for the model using information from SCADA. These hourly demand patterns change by season of the year, primarily because of lawn watering restrictions. Hourly patterns for specific areas of the distribution system, such as the Las Vegas Strip, are incorporated into the model as they are developed through field studies and the daily calibration process.

Reservoir cycling and pump selection. Reservoir cycling and pump selection are used to customize the daily operating plan on the basis of actual system conditions and current operational goals. Water age in the system is calculated on the basis of actual operations and SCADA reservoir levels, as noted previously. The water age for each day is loaded into the database and is used to initialize water age for the subsequent day. This process has allowed the district to correlate water quality–sampling data with water age at each sampling location and determine approximate water-age thresholds for specific areas of the distribution system. Reservoirs with high water age are identified and targeted for cycling and volume reduction. Pump-selection tools, developed by the LVVWD operations department, help choose the most-efficient combinations to move water across the system and notify the engineer that a pumping unit is out of service. Pumping unit priorities are developed using pump efficiencies and maintenance information such as pump tagouts and run times.

Real-time modeling tools and automated processes. Because of the size and complexity of the distribution system, LVVWD needed to develop automated processes and tools to streamline the real-time modeling process. The use of automated tools speeds up the process, enhances the accuracy of the data, and reduces data redundancy. In addition, automated tools improve user efficiency by automating tedious or repetitive tasks. Many automated tools required for real-time modeling are now available in vendor-provided hydraulic modeling software. Some of the automated tools used by the district include

- a tool to load initial reservoir levels into the model from SCADA,
- a tool to compare pump run times for planned versus actual system operation (Figure 2),

FIGURE 3 Reservoir level comparison report



SCADA—supervisory control and acquisition

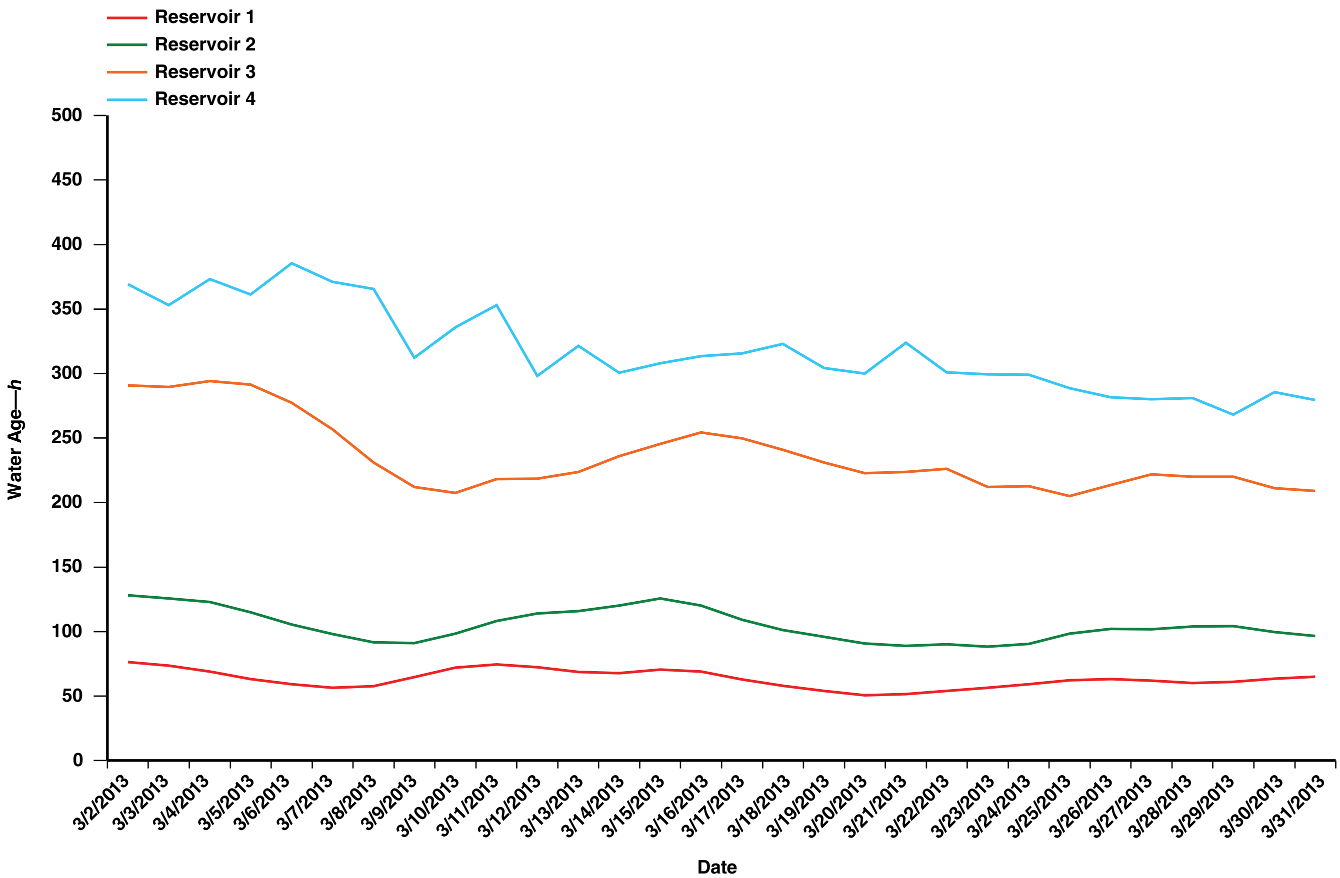
- a tool to compare model-predicted versus actual reservoir levels at any point in time while the plan is running or at the conclusion of the plan (Figure 3) for daily calibration,
- a tool to calculate water age (Figure 4), and
- a tool to develop a pumping plan (Figure 5).

The daily water age calculator enables the engineer to automatically download boundary conditions and actual pumping information from SCADA and initialize the model with water age at the end of the previous day. The tool also allows calculated water-age data to be loaded into the database and generation of a report (Figure 4) showing water-age trends; these trends are monitored to develop reservoir cycling goals and allow alternative operating strategies to be evaluated for their effect on water age.

Development of the daily operating plan is an iterative process using the model; without tools, such a process would be difficult to accomplish in the time allowed for plan preparation. Typically, more than 600 control instructions (rules) are needed to model the operation of the district's 256 pumping units.

The tool for developing the pumping plan (Figure 5) interfaces directly with the model to allow changes to the pump controls through a spreadsheet-like interface and provides pump status for each pumping unit throughout the day. Pump tagout information is dynamically loaded into the tool from SCADA. The tool allows pumping units to be filtered by pumping station to focus on just one facility at a time or by pressure zone to look at all pumping units serving a particular pressure zone. It enables the

FIGURE 4 Daily water age report



Daily model results are shown for reservoir water age (South I).

user to check power use by hour to ensure that power consumption stays within a previously issued power order for the day from multiple power sources and provides charts projecting reservoir levels and water age during the development of the operational plan. The tool allows the user to quickly see the effect of pump changes on power use, reservoir levels, and water age and also greatly streamlines the iterative process.

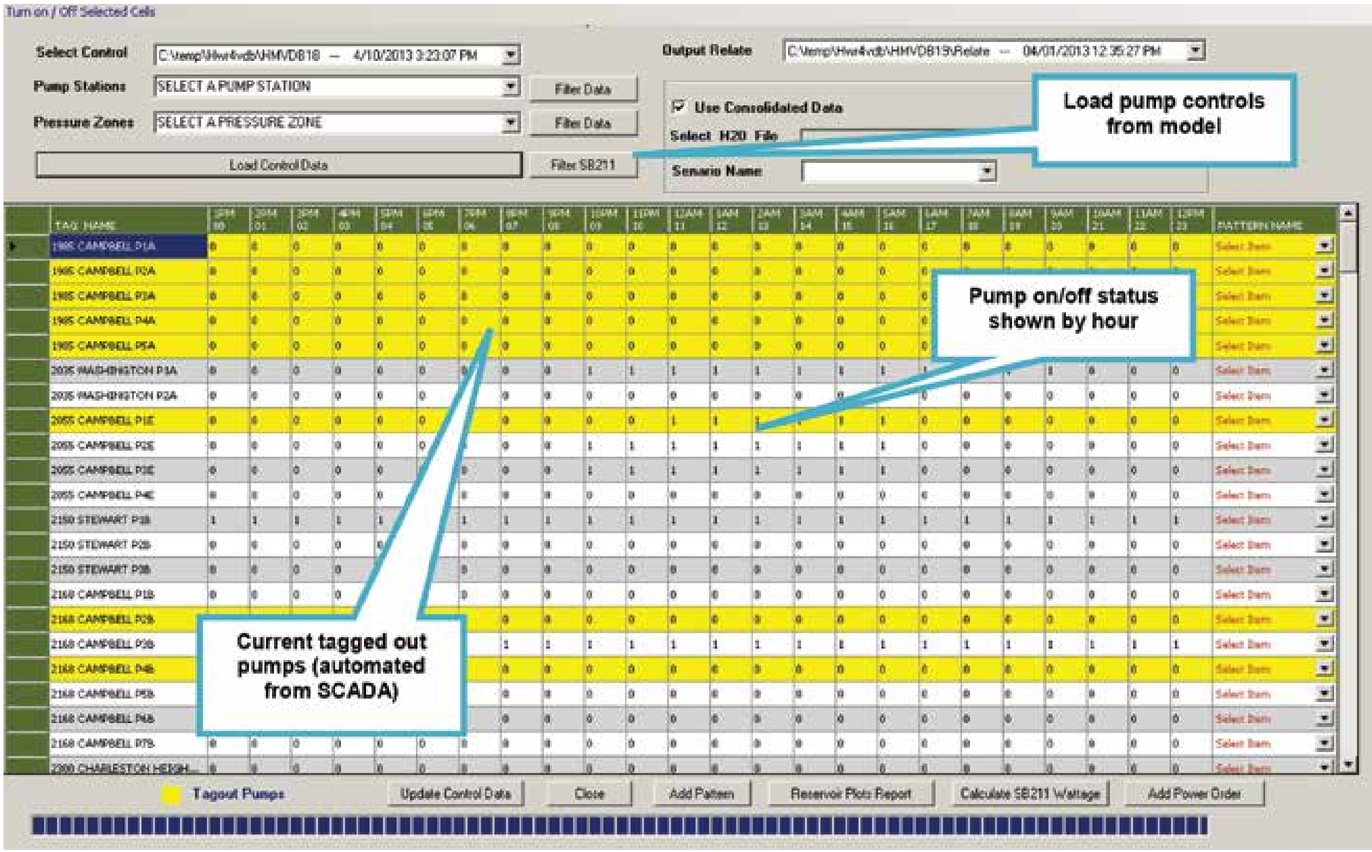
REAL-TIME MODELING RESULTS

Improvements in water quality and energy consumption. As a result of real-time modeling, the LVVWD has seen a significant improvement in TTHM control, thanks to such real-time modeling benefits as better monitoring of water age in the system. In addition, the district saw a significant drop in energy consumption between 2004 and 2005, the time period when the daily operating plan process was first implemented. Figure 6 tracks LVVWD energy use over time. The bars show the weighted elevation of water delivered in the system, which was calculated by multiplying each pressure zone's design hydraulic grade line by its corresponding share (percentage) of total annual customer consumption and then summing the results. The solid line shows power consumption in terms of kilowatt-hours per million gallons delivered. Figure 7 compares TTHM sample results from before implementation of the daily operating plan in January 2005 with results from one year later in January 2006. Winter is the season when TTHM concentrations are typically highest in the distribution system; customer demands are much lower than in the summer.

There are limitations to the improvement of water quality through system operations, however. Some areas of the LVVWD distribution system are so distant from the water treatment plants that operational management alone cannot resolve high water age and TTHM formation issues. The district has moved forward with installation of aeration equipment for TTHM removal in some of these areas. In addition, variations in source water quality, customer demand, and composition of the distribution system make TTHM levels unpredictable. It is anticipated that the future addition of water quality sensors will improve prediction capabilities and TTHM control. For now, monitoring water age provides insight into water quality sampling results, assists in identifying areas with low circulation, and improves reservoir cycling strategies.

Figure 8 compares TTHM sample results from 2005 to 2013, results that reflect the installation of aeration systems at some of the reservoirs starting in 2010. Therefore, Figure 7 better

FIGURE 5 Screenshot of the tool for developing the pumping plan



SCADA—supervisory control and acquisition

FIGURE 6 Energy use before and after implementation of daily pumping plan

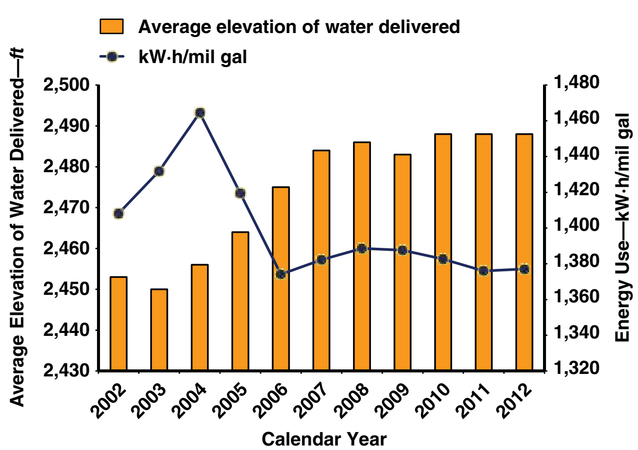
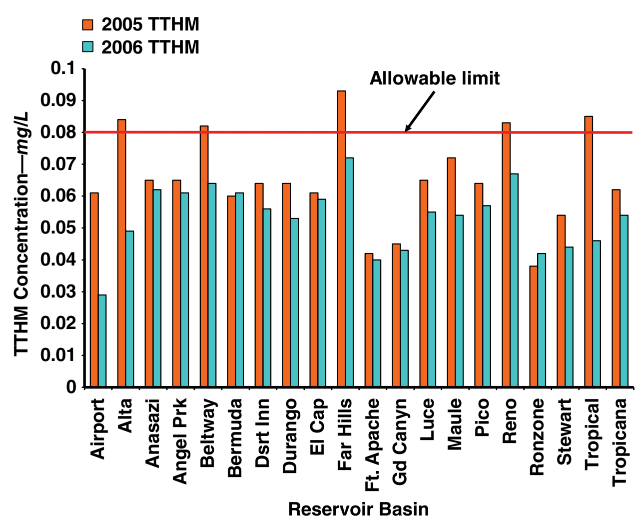


Figure shows calendar years from 2002 through 2012. Pumping plan was implemented in July 2005. Elevation of water delivered is plotted against kilowatt-hours of energy consumed per million gallons of water delivered.

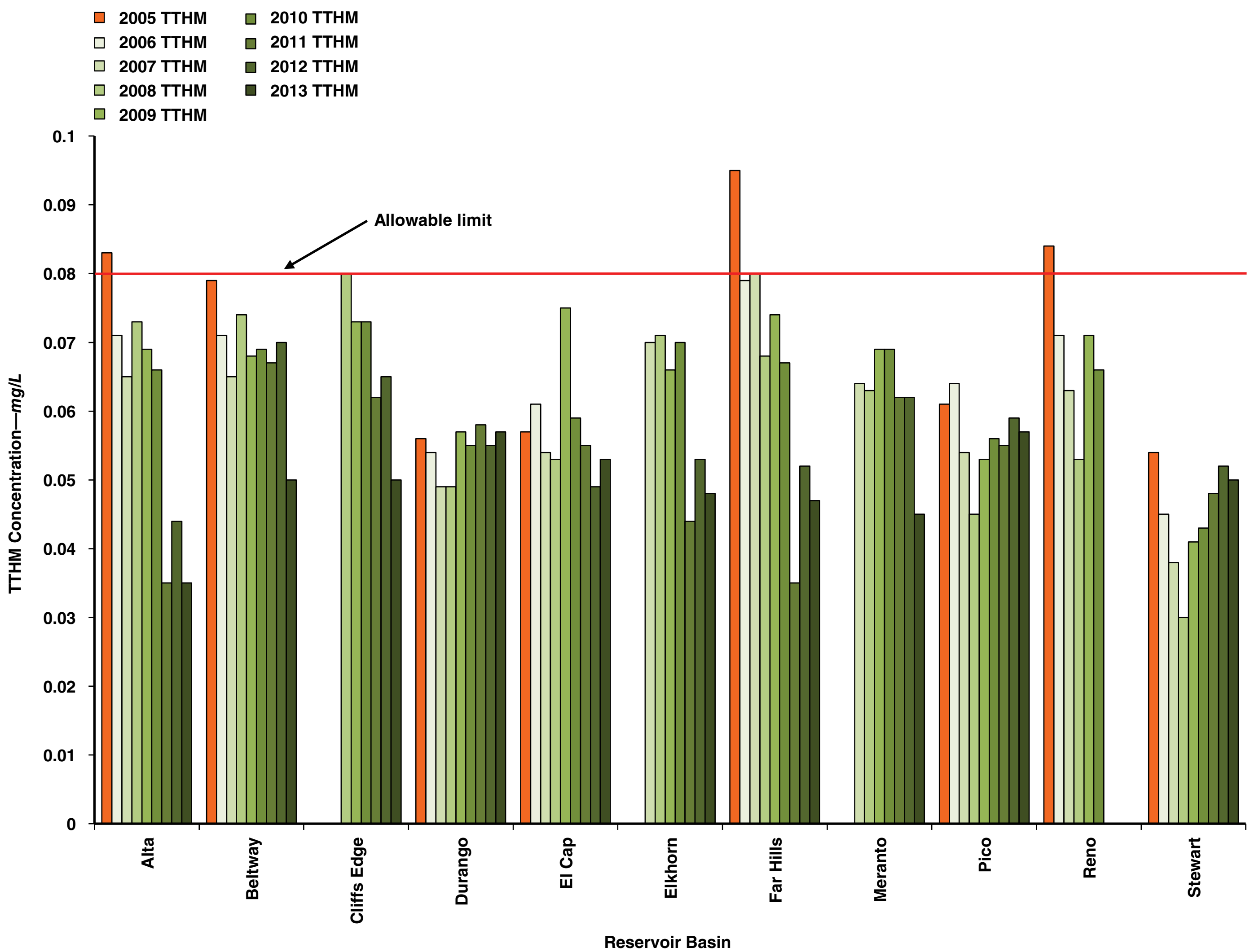
FIGURE 7 Water quality before and after implementation of daily pumping plan



TTHM—total trihalomethane

Figure compares TTHM levels in January 2005 and January 2006. Pumping plan was implemented in July 2005.

FIGURE 8 Water quality comparison 2005–2013



TTHM—total trihalomethane

Figure compares TTHM levels in February of each year.

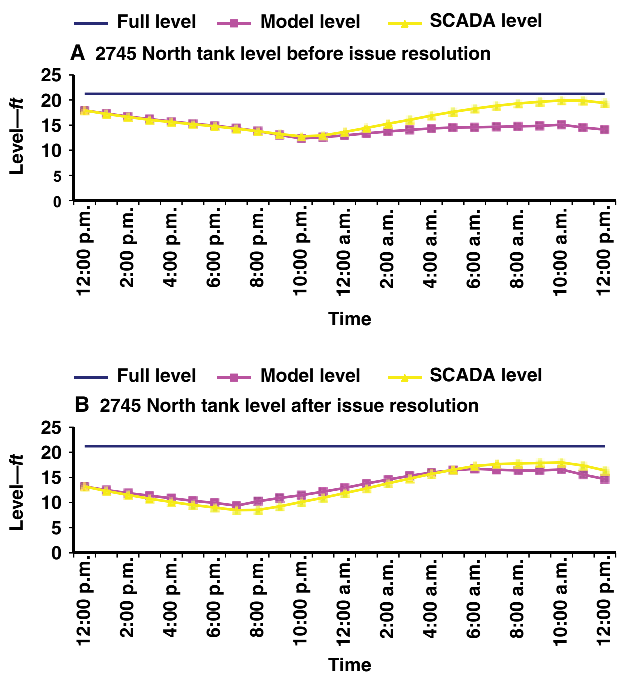
depicts the effects of the implementation of the daily plan because the figure shows TTHM comparisons before implementation (2005) and immediately after implementation (2006) of the daily operating plan.

ADDITIONAL APPLICATION OF REAL-TIME MODELING

Water quality regulatory compliance. In addition to system boundary conditions, a reasonable estimate of initial water quality condition is required for network water quality simulation. LVVWD uses real-time models to run a day-to-day time sequence based on actual operations so that a stable and reasonably accurate initial water quality condition is achieved. This is particularly useful when a water quality simulation is requested after a field incident or before or during sample collection. Stored real-time model information can provide invaluable information that supplements SCADA data and working records. Real-time water age results allow engineers and operators to visualize areas of concern and the effect of changes to operating strategies.

Resolving field issues. The real-time modeling process allows for quick identification of model and field issues. The reservoir-level comparison tool (Figure 4) is frequently used for this purpose and has the ability to generate SCADA-versus-forecasted results anytime during the current plan. Monitoring SCADA in comparison with model predictions allows anomalies in the system to be rapidly identified, investigated, and corrected. In some instances, energy savings are realized not only by optimizing the pumping schedule but also by correcting field conditions that are costing money. For example, a reservoir water-level tracking report at the district's 2745 North Reservoir showed that the reservoir was filling faster than the model had

FIGURE 9 2745 North reservoir tracking before and after issue resolution



SCADA—supervisory control and acquisition

predicted (Figure 9, part A). In this case, the problem occurred in an area of fairly heavy development activity. The investigation found three zone isolation valves were open, conveying water to lower-pressure zones and filling the 2745 North Reservoir. When the valves were closed, the reservoir tracking returned to normal (Figure 9, part B). This is a case in which the LVVWD operational modeling program quickly drew attention to a field issue that might otherwise have gone unnoticed for a long period of time at significant cost in wasted energy.

Planned and emergency outages. One of the major benefits of the real-time modeling system is an improvement in the district's ability to address both planned and emergency outages (Jacobsen et al, 2013; Jacobsen, 2006). The hydraulic model is already set up with all current operating conditions and pumping schedules. This allows immediate analysis to be performed with minimal setup time. Multiple scenarios can be created quickly. The rushed pace of an emergency response can lead to errors. However, when the model is already set up with the daily operating plan, the modeler can focus on the issues and potential solutions. The daily model facilitates an organized response to the issue.

EVALUATION OF FUTURE ENHANCEMENTS

Further development of operational modeling is expected to lead to additional benefits; however, additional software, maintenance, and resources will be required for these enhancements. Currently, an operating plan at the LVVWD is developed within two or three hours. Addition of an optimization component to automate the creation of an optimal operating plan would be of great benefit. With advances in hardware technology and software, optimization algorithms that quickly produce a set of near-optimal solutions for improving system operations of a large complex system are becoming increasingly realistic. The addition of sensor equipment throughout the distribution system may yield additional benefits, particularly as an early warning system for water quality episodes, leaks, and main breaks. However, the cost of procurement, installation, and maintenance must be considered.

The approach described in this case study outlines some of the steps that the LVVWD has taken to implement real-time network modeling, an effort that has yielded significant benefits at low cost. The district has found its real-time modeling efforts to be effective in reducing power consumption and improving water quality in the distribution system. In addition, the district's ability to address both planned and emergency outages has improved. Communications have been enhanced with customers and among multiple work groups. The daily calibration process has improved confidence in the model, and field issues are identified and resolved in a timely manner. The district's initial real-time modeling efforts were focused on the processes that provided the greatest benefit for the least cost. LVVWD is constantly seeking to improve processes and is looking into other aspects of real-time network modeling in order to reap additional benefits.

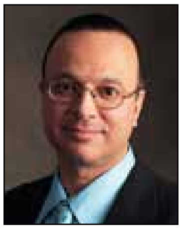
CONCLUSION

Of all infrastructure types, water infrastructure is the most essential to human life. However, drinking water distribution systems are living, dynamic entities in a constant state of change and can serve as a transmission vehicle for a variety of hazardous agents that can be detrimental to human health. When hydraulic and water quality integrity are compromised, the distribution system may be exposed to internal and external sources of contamination that increase the risk of negative public health outcomes.

Water distribution system integrity is best evaluated using real-time methods that provide warning of potential breaches in time to effectively respond, thus minimizing public exposure and economic consequences for individuals and businesses. An SWNDSS is an essential component of a smart water grid because it gives water utilities real-time surveillance and control over the viability and health of their distribution systems. It plays a key role in enabling utilities to continuously monitor the integrity of their water systems, confirm normal system performance, locate operational bottlenecks, evaluate problem-solving approaches, control their networks during critical failures, optimize their emergency response and consequence management plans, and establish an accurate baseline for measuring and improving operational efficiency.

By leveraging existing investment in real-time data acquisition and telemetry, the SWNDSS propels a utility's routine network modeling applications beyond planning and design to emergency and maintenance response, improved water quality and energy management, carbon footprint reduction, and regulatory compliance. Such real-time modeling capabilities can greatly enhance the ability of water utilities to effectively manage, operate, and maintain their water distribution systems and deliver an adequate level of service to their customers.

ABOUT THE AUTHORS



Paul F. Boulos *(to whom correspondence should be addressed) is the president, chief operating officer, and chief technical officer of Innovyze, 370 Interlocken Blvd., Ste. 300, Broomfield, CO 80021; paul.f.boulos@innovyze.com. He holds BS, MS, and PhD degrees in civil engineering from the University of Kentucky at Lexington and has more than 25 years of experience in water, wastewater, and navigation engineering. He is the author of 9 textbooks and more than 200 technical articles and has received numerous honors from national and international scientific and engineering societies, government and research organizations, and nongovernmental organizations. Laura B. Jacobsen is manager of the planning division of Las Vegas Valley Water District in Las Vegas, Nev. J. Erick Heath is a vice president of Innovyze in Arcadia, Calif. Sri Kamojjala is a senior civil engineer in the planning division of Las Vegas Valley Water District.*

PEER REVIEW

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