Recent advances in smart water network technology have armed control room operators with a comprehensive set of decision-making capabilities that position operators as a major force for system improvement, regulatory compliance, and financial planning. **BY PAUL F. BOULOS AND AMANDA N. WILEY**

The drivers of smart water networks are compelling. Globally, water demand and energy costs are rising, resources are diminishing, aging water infrastructures are rapidly deteriorating, and the problems of water loss and leakage are relentless. Although water conservation and management practices are evolving, these global concerns are fueling a move to smart technology solutions that promise more efficient, sustainable water systems.

Technological advancements in smart water networks (SWNs) are helping water utility operators boost efficiency and proactively manage and control distribution systems. The principal objective of implementing such a network is to improve performance by optimizing system operations, rather than relying solely on capital improvements.

**THE POWER OF AUTOMATION**

Geographic information system (GIS) technology, supervisory control and data acquisition (SCADA) systems, smart meters, and advanced metering infrastructure (AMI) can help operators locate utility assets, monitor water usage and system operations, track trends, and remotely control pumps and strategic valves. However, such technologies don’t have predictive network modeling and optimization capabilities (system dynamics) to assess the effects of operational or physical changes in system performance and integrity.

They also lack the power of predictive analytics required to manage and exploit data and analyze trends and patterns. This prevents operators from making sound, informed decisions, forcing them to rely on experience and intuition.

Now many system dynamics and analytics models are fully integrated with GIS, SCADA, smart metering and sensing systems, and AMI technologies to help operators optimize network operations and performance in real time. These
models can be divided into five general categories.

**Real-Time Network Models.** Hydraulic and water quality network models represent the most effective and viable way to predict water distribution system behavior under a wide range of demand loading and operating conditions. The models use the laws of mass and energy conservation and reaction kinetics to determine pressure, flow, and water quality (movement and transformation) conditions for specified system characteristics and operating conditions. Through their predictive capabilities, these deterministic models provide a powerful tool for evaluating system response to various operational and management strategies to meet specific performance goals.

AWWA’s Partnership for Safe Water has developed performance goals that focus on assuring the integrity of three network components:

- Water quality preservation—maintaining a disinfection residual greater than 0.2 mg/L for free chlorine
- Hydraulic reliability—maintaining a minimum pressure of 20 psi
- Physical infrastructure—reducing main-break frequency to less than 15 per 100 miles of pipeline

To further these goals, the models require an accurate, continuously updated view of a water distribution network’s state. This can be accomplished by synthesizing SCADA and other real-time telemetry data with network models.

The resulting network models provide utility operators continuous real-time insights regarding water network performance. A constant stream of data (at 15-, 30-, or 60-minute intervals, for example), coupled with predictive modeling capabilities, enables operators to quickly assess events as they occur, identify potential problems before they reach a critical level, respond 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 customers who will be negatively affected by low pressures. Alternative operating scenarios can be quickly analyzed and compared to determine the most appropriate solution.

Operators can also assess the effects of main breaks; pump, valve, and reservoir shutdowns; and maintenance or repair; as well as any other planned or unplanned incidents. They can also predict key network parameters (flows, pressures, etc.) where data loggers aren’t available and predict system performance should SCADA feeds go offline. Using real-time network modeling, operators can progress from purely reactive to proactive network management. Doing so can ultimately result in significantly more efficient and economical network operations, greater network integrity, and improved network maintenance and customer service.

**Real-Time Operations-Optimization Models.** These models extend use of SWNs to help operators improve water network efficiency and ensure more reliable operations at maximum cost savings. The models automatically read real-time field data, instantly update the network model, and determine pump and treatment plant operation schedules that will yield the lowest operating costs while satisfying desired system performance requirements (e.g., tank trajectory curves, minimum and maximum flows and velocities, and total pump flows).

It’s common to combine an optimized mass-balance storage model with the real-time network model to quickly produce near-optimal solutions for improving system operations. The network model automatically defines the mass-balance storage model, accounting for changes in demand, controls, and other factors in each time step of the simulation period. The mass-balance storage model is then optimized using optimization theory (e.g., genetic algorithms). Electricity tariffs and pump switching costs are usually considered. The optimized pumping schedule can then be fed to the SCADA system for use in implementing the resulting network control policies.
Automated Systems

**Real-Time Network-Monitoring and Anomaly-Detection Models.** These models extend SWN use to predictive forecasting and condition-assessment capabilities. They allow operators to assess their network hydraulic performance in real time and compare current network dynamics with expected and historical values (based on time of day, day of the week, season, etc.) to quickly identify unexpected performance problems and target effective interventions, such as locating the appropriate valve closures to isolate a main break and notify affected customers.

For example, high nighttime flows in specific areas could indicate excessive leakage, unexpected low pressures, and excessive pumping. A drop in storage-tank levels in a specific area could indicate a large main break. Anomalous events can include large water-usage deviations; sudden flow, pressure, and level changes; and anomalous hydraulic conditions caused by leaks, breaks, tank failures, hydrant ruptures, online equipment malfunctions, and other operational inefficiencies or losses of system integrity.

These are fundamental advances in how water utility operators can effectively monitor network efficiency and integrity and take remedial action the moment problems are detected, quickly mitigating adverse public health and economic impacts. These models also enable operators to pre-empt future network failures and prepare for and respond to emergencies. This model puts operators at a tremendous advantage in managing their water supplies and distribution systems more efficiently, allowing them to take rapid, informed action to minimize water leakage, reduce pipe-break frequency, save energy, lower operational and maintenance expenses, maintain system integrity, increase sustainability, and improve customer service.

**Real-Time Event-Detection Models.** Event-detection models enable SWNs to continuously monitor and assess water quality dynamics, allowing operators to compare water quality data against regulatory requirements (e.g., maximum contaminant levels) as well as identify water quality changes and the onset of anomalous events. The models' primary capability is quick detection of potential hazards to allow operators to mitigate adverse public health and economic impacts (public health surveillance monitoring).

The models are generally based on a conceptual framework and statistical techniques used by real-time network monitoring and anomaly-detection models. They can analyze standard water quality parameters—total chlorine, free chlorine, chloride, pH, electrical conductivity, total organic carbon, turbidity, total dissolved solids, and other parameters—over time from continuous water quality sensors, compare them with expected and historical values, and recognize changes. Sophisticated pattern recognition techniques help differentiate normal water quality patterns from anomalous conditions and screen out false alarms.

**Asset-Integrity Management and Capital-Planning Models.** These models extend the utility of SWNs to include predictive analytics that estimate the remaining useful life of pipes, anticipate network deterioration, and plan pipe replacement. They can be used to assess and score the risk profile for each pipe in a network (taking into account the probability and consequence of failure) and identify the worst-performing ones. Attention can then be focused on pipes at highest risk. This ranking process enables water utilities to create fully prioritized short- and long-term pipe replacement, rehabilitation, maintenance, and management plans and develop cost-effective capital programs to support them. The process also helps extend network pipes' useful life, improve predictive maintenance, reduce downtime, and preserve capital. The result is improved asset and capital planning, network capacity, reliability, performance, and sustainable water service.

Used together with SCADA systems and smart sensors, these complementary models constitute a powerful and comprehensive SWN decision-support tool for operators. The models provide operators significant management advantages, including greater operational efficiency and emergency preparedness, reduced water loss and system vulnerability, shortened response time, optimized spending on network renewals and energy consumption, increased network reliability and longevity, improved water quality and sustainability, more informed decision making, and stronger customer ties.

**TAKE NETWORK MODELING TO THE NEXT LEVEL**

Water distribution system integrity is best evaluated using real-time methods that warn of potential breaches in sufficient time for operators to respond effectively and minimize public exposure and economic impacts. An SWN is a critical component of a smart water grid. It plays a key role in enabling operators to continuously monitor system integrity, confirm normal system performance, locate operational bottlenecks, evaluate problem-solving approaches, control networks during critical failures, optimize emergency response and consequence management plans, and establish an accurate baseline for measuring and improving operational efficiency.

By leveraging current investment in real-time data acquisition and telemetry, an SWN propels a utility's routine network modeling applications from planning and design to emergency and maintenance response, remote leak-detection and pipe-break prediction, optimized energy costs, carbon footprint reduction, and water quality management. Such capabilities greatly enhance a water utility's ability to conceive and evaluate reliable and economical water network management and security alternatives, ensure more efficient water systems, secure regulatory compliance, and protect public health.