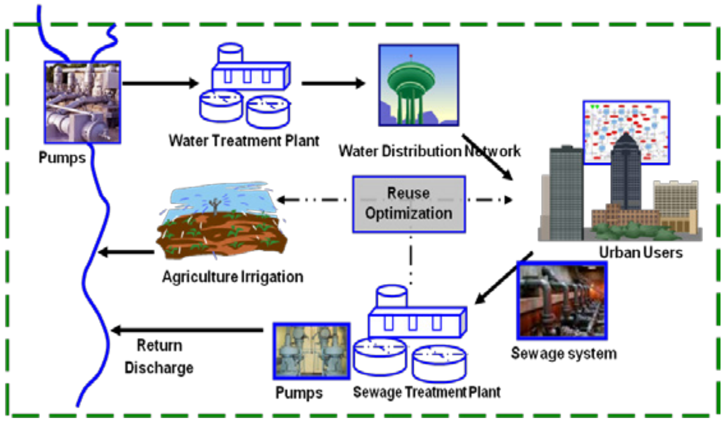
Management of Complex Water Networks

Water security is one of the most tangible and fastest-growing social, political, and economic challenges faced today. It is also a fast-unfolding environmental crisis. In every sector, the demand for water is expected to increase and analysis suggests that the world will face a 40% global shortfall between forecast demand and available supply by 2030.

This outlook bears potential for crisis and conflict since water lies at the heart of everything that is essential for human life: food, sanitation, energy, production of goods, transport, and the biosphere. Water ensures not only mere survival of humans, but also social well-being and economic growth. In addition, water is a renewable, yet not inexhaustible, resource—it cannot withstand constant over-extraction and being depleted faster than being renewed. What is more, water cannot be substituted.

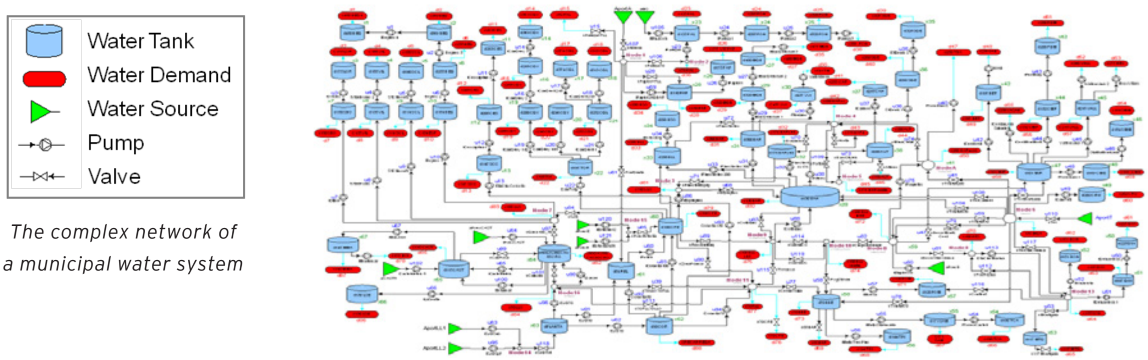
—World Economic Forum 2012



Municipal Water Management System Scope

Control and optimization solutions for municipal water management systems will need to encompass a set of interacting layers that define a variety of problems.

- The water cycle starts with water sources and mechanical/chemical/biological water treatment; here, fairly standard advanced process control approaches can be used to produce a given amount of potable water with predefined quality and minimized consumption of energy and chemicals.
- The next step is to transport the water to the tanks and water towers; optimal energy-efficient control of pumping stations and valves is closely related to network topology, altitude profile, storage capacities, pumping efficiency curves, and electricity cost profile. For model maintenance and real-time responsiveness to network topology changes, tight integration with a geographic information system (GIS) is beneficial. Energy efficiency can be significantly improved if reliable prediction of water demand/consumption is available. The transport layer also contributes to more effective quality control by mixing water from different sources; quality constraints related to water aging are also treated here.
- The water from the tanks is distributed to end users; optimal control of this distribution layer covers pressure zone monitoring and control by booster pumps and reduction valves to guarantee minimum pressure to all consumers and reduce leakage by maximum pressure reduction.
- The sewage water collection and treatment process follows a similar hierarchy of layers and also usually involves storm water management.



The complex network of a municipal water system

Contributors: Vladimir Havlena and Pavel Trnka, Honeywell, Czech Republic; Bill Sheridan, Honeywell, USA

Municipal Water Management System: Hierarchy and Time Scale

Economic optimization and planning of network topology and instrumentation updates is done over several years.

The water treatment and transport layers operate with a control/optimization horizon of up to 1 week with a sampling rate from 15 minutes to 1 hour to capture periodic demand, varying production costs, and electricity tariffs. Typically, heuristic control laws with intermittent operator interventions are used today. The next-generation solution of this large-scale spatially distributed control and optimization problem can be achieved by distributed model predictive control. Prediction of electric energy cost and water demand is a key component of such a solution.

The distribution layer is typically operated by programmable logic controllers (PLCs) with sampling periods of 0.1–1 sec. Several preprogrammed pressure levels (day/night) or fixed pressure setpoint profiles are used in the distribution network feeding points. The next-generation solution should provide active pressure zone control based on network pressure profile monitoring by sensor networks.

Challenges: Modeling

Mathematical models are the primary information source for advanced model-based control and real-time optimization techniques. A succession of reduced-complexity models for individual layers of the optimization, control, and monitoring hierarchy, with automated adaptation to network changes (network extensions, manual adjustment of routing valves), is needed. For facilitating model maintenance, tight integration with detailed reference hydraulic models available in a GIS is desirable.

Traditional issues such as modeling of nonlinear mechanical control valves (altitude valve, check valve) and maintenance of pump performance curves (mostly tabulated) will have to be resolved on a large scale. Expertise in new domains such as modeling of water aging/chlorination will also be needed.

Challenges: Planning and Scheduling

Operation planning is based on uncertain predictions of water availability and demand profiles. Estimated availability from the wells with lowest treatment cost may depend on rainfall prediction. Emerging technologies, such as rainwater harvesting and wastewater reuse, may reduce the level of uncertainty.

Models can also be reused as a decision support tool for long-term strategic planning and what-if scenario analysis.

Challenges: Network Control Theory

Modeling and control of the network with flows following Kirchhoff's laws (incompressible fluids) can build on structural information. Examples include model reduction for control/optimization/monitoring; aggregation in time and space (skeletonization); and structural controllability/observability analysis based on network topology. Advances in network control theory will also be beneficial for optimizing locations of additional actuators and sensors in the network to meet more stringent performance criteria.

Challenges: State Estimation

Network monitoring operates with limited information subject to unmeasured disturbances. Raw data reconciliation and leakage assessment are essential to minimize loss of treated water. Monitoring approaches should incorporate bottom-up (pressure zone modeling) and top-down (balancing individual metered areas) approaches and leverage the capabilities of smart sensor networks. The Bayesian approach for nonlinear state estimation enables use of model-based techniques to detect abrupt changes (bursts) as well as background losses. Overdosing of chemicals can be reduced if a reliable estimate of water quality/chlorine concentration is available. Maintenance of buried pipes based on proven corrosion monitoring algorithms can save significant investment costs as well as reduce water losses.

Challenges: Advanced Control and Real-Time Optimization

The advanced control and real-time optimization problem has a well-defined structure described by varying network topology and multi-objective optimization criteria. For the network operator, independent operation of individual subsystems with strong interactions must be enabled, with a progressive area-by-area approach to the commissioning of an overall solution. For large municipal applications, computational complexity is still prohibitive for closed-loop real-time applications; however, feasible computation time can be reached by decentralized solutions based, for example, on dual decomposition methods. The control strategy must be robust to communication failures and demand prediction uncertainty.