Waste Not, Want Not! Low-Cost Solutions to Minimizing DBP Formation in Underutilized Potable Water Systems Through Hydraulic Modeling and System Operation

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Across the globe, the picture is critically clear: the world's freshwater supplies are diminishing at an alarming rate. Australia is in the midst of a 30-year dry spell, population growth in urban centers of Sub-Saharan Africa is straining resources, Asia is expected to have a 40 percent deficit between demand and supply by 2030, and the water tables are falling in scores of countries such as China, the United States, and India due to widespread overpumping. It seems like a contradiction in terms to say the world is facing major water shortages, since water covers about two-thirds of the Earth's surface. The problem is that only 3 percent of the world's water is fresh and less than 1 percent is available for human consumption due to accessibility or form, such as that frozen at the poles.

Diminishing Supplies

According to the U.S. Geological Survey, more than a quarter of the total water demands in the U.S. are attributed to water needs in California, Texas, Idaho, and Florida, which includes primarily residential, commercial, agriculture, manufacturing uses. The most recent data from the Florida Department of Environmental Protection (FDEP), projects the population in the state to increase by approximately 57 percent by 2025. Floridians are expected to use an additional 2 billion gallons of water per day (bgd) by 2025. Figure 1 below, from FDEP's 2010 Annual Report on Regional Water Supply Planning, shows the statewide demand and population projections over the next 15 years.

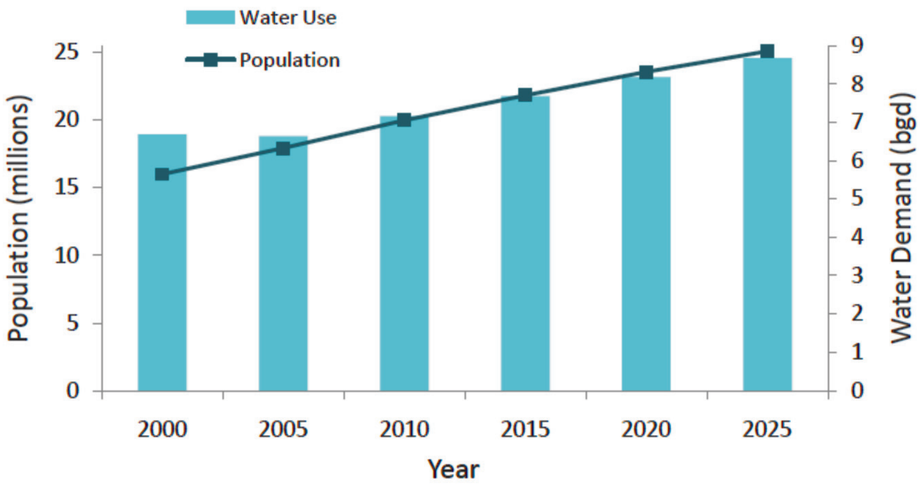
Environmental Initiatives

Increased demands have prompted a number of conservation and regulatory initiatives to address Florida's diminishing potable water supplies. The Florida Water Resources Act, Chapter 373, Florida Statutes, directs the FDEP and the governing boards of the five water management districts in the state to "take into account cumulative impacts on water resources and manage those resources in a manner to ensure their sustainability." For example, in section 373.016, F.S., there is direction to:

- Promote the conservation, replenishment, recapture, enhancement, development, and proper utilization of surface and ground water.
- Promote the availability of sufficient water for all existing and future reasonable-beneficial uses and natural systems.
- Preserve natural resources, fish, and wildlife.

Additionally, section 373.042, F.S., of the statute governs the establishment of minimum flows and levels (MFL), to promote sustainability by requiring the districts to set limits for water bodies beyond which further withdrawals of water for human use would be significantly harmful to the water resources or ecology of the area. This helps ensure that resources such as rivers, lakes, springs, wetlands, and estuaries do not suffer irreparable harm in order to meet human needs for water. As such, water management districts are also reviewing the groundwater withdrawals for their respective water suppliers and requiring many water utilities to reduce their groundwater pumping in order to avoid or minimize environmental impacts and conserve Florida's aquifer systems.

Figure 1: Statewide Demand and Population Projections



This reduction in water resources has resulted in water managers focusing on ways to improve water conservation and water use efficiency by adopting aggressive potable water resource management and reuse programs to meet their current and future needs in a manner that will help sustain natural resources and make every drop count.

Water Resource Management

Over the last 30 years, water management districts across Florida have provided financial and technical assistance to water users and suppliers for the implementation of local and regional water conservation efforts. Water savings have been achieved by many suppliers through a combination of regulatory, economic, incentive-based, and outreach measures:

- Regulatory measures include water restriction codes and ordinances that require water efficiency standards for new development and existing areas.
- Economic measures include inclining block

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rate structures.

- Incentive programs include rebates, utility bill credits, recognition programs, or giveaways of devices and fixtures that will replace older, less water-efficient models.

Other conservation measures that have acknowledged water savings potential and continue to be encouraged and implemented by several districts include sub-metering of master-metered complexes and supply-side water conservation.

Reuse Programs

Reuse programs are another way for water managers to improve water conservation and water use efficiency. Section 373.227, F.S., states that the overall water conservation goal of the state is “to prevent and reduce wasteful, uneconomical, or unreasonable use of water resources.” One such way is by using reclaimed water rather than potable water for uses such as landscape irrigation, cooling towers, and commercial or industrial processes, as well as groundwater recharge to help restore natural systems. Reclaimed water is defined by FDEP as water that is beneficially reused after being treated to at least secondary wastewater treatment standards by a wastewater treatment plant (WWTP). Florida currently leads the nation in water reuse by reclaiming some 660 million gallons of water per day (mgd); however, Floridians use almost 30 times that amount of water per day. The goal of the water management districts is to achieve a 75 percent utilization rate of all WWTP flows by the year 2030 to reduce demands on potable supplies for uses that do not require potable quality.

Alternative Supplies

In 2005, the Florida Legislature, in another effort to help diversify the state’s water supply sources, created the Water Protection and Sustainability Trust Fund and appropriated $100 million to be used to promote the development of alternative water supplies. These funds, along with matching district funds, are awarded as grants to local water suppliers. During the first four years of this program, the water management districts provided funding assistance to local water suppliers for the construction of 327 projects. The vast majority of the projects (63 percent) were reclaimed water projects, followed by brackish groundwater projects (22 percent). The remaining 15 percent of alternative resource projects were primarily from aquifer storage recovery, surface water, stormwater, and seawater.

The districts estimate that when all currently planned alternative water supply projects are complete, they will help create approximately 761 mgd of “new water” available for consumptive use, which is about 38 percent of the additional 2 bgd of water needed by 2025. Currently, there are more than 1,000 desalination plants in the U.S., many in the Sunbelt. The Tampa Bay Seawater Desalination Plant is producing about 25 mgd of fresh drinking water, or about 10 percent of that area's demand. This plant is currently the largest of its kind in North America.

Florida’s water resources support not only the residents but also the state’s tourism and agriculture industries. If the state isn’t able to maintain its high quality natural systems, the effects would be felt throughout the entire economy. Florida continues to make great progress, especially through the implementation of regional water supply plans and the development of alternative water supplies, to ensure that Florida’s water resources are managed in a sustainable manner for future generations.

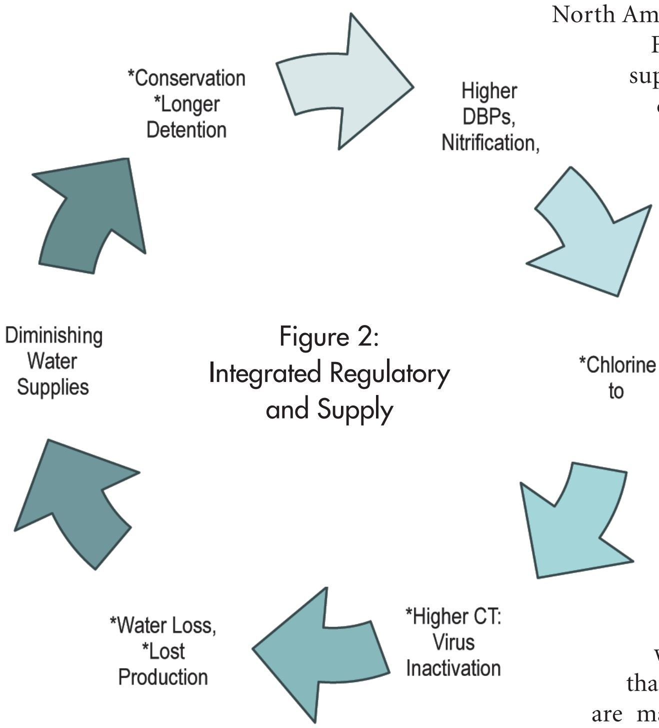
Figure 2:
Integrated Regulatory and Supply

Economic Impacts on Water Demands

The unprecedented increase in house prices between 1997 and 2006 produced numerous wide-ranging effects in the economy. These growing house prices and increasing price gradients forced many residents to flee the expensive centers of many metropolitan areas, resulting in the explosive growth of communities situated beyond the suburbs of a city. In order for water managers to continue providing their existing customers with a reliable, continuous supply of water, as well as meet the demands of the influx of new residents, long-range capital improvement plans were implemented.

Housing prices peaked in early 2006, started to decline in late 2006, and may not have yet hit their bottom. The decline was initiated when the sub-prime mortgage industry started to crash due to increased loan defaults, resulting in numerous foreclosures. As of January 2009, California, Michigan, Ohio, and Florida had the highest foreclosure rates. As a result, the building industry came to a screeching halt, and unemployment rose to its highest rate in 30 years, leaving many homes unbuilt and unoccupied, and water managers with oversized potable water systems.

Water Quality Impacts

To maintain water quality, water managers strive to minimize water age. This is done by ensuring that the water in reservoirs turns over regularly and by minimizing dead ends so that it doesn’t become “stagnant”. This can prove to be a complex problem when dealing with an oversized potable water system. Longer detention times can result in depleted disinfection residuals and increase the potential for disinfection byproduct (DBP) formation in the distribution system.

In 2006, the Environmental Protection Agency implemented the second stage of the Disinfection By-products Rule. The Rule required utilities to conduct an Initial Distribution System Evaluation (IDSE) to identify ‘worse-case’ sampling points for disinfection by-product formation. One of the risk factors for trihalomethanes, a particular group of regulated DBPs, is long detention times. As a result, many utilities have converted from chlorine to chloramine disinfection, as DBP formation is considerably less of a problem. However, this solution presents unique challenges typical to engineering, where the solution to one issue may create a problem somewhere else (See Figure 2).

Despite the benefits of chloramines related to DBPs, they have a relatively weak in-

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activation of viruses and protozoa as compared to chlorine. As such, chloramines require longer contact times and receive less virus inactivation credit, ultimately making it difficult to meet regulatory requirements. Recently, the 4-log virus inactivation requirement has been expanded to groundwater systems; thus, more utilities are facing this challenge. This is especially true of small systems where treatment processes can be limited to disinfection alone. Since these systems are highly dependent on the disinfection credit, many have maintained chlorine as the disinfection chemical of choice. Chlorine application coupled with longer detention times puts these systems at greater risk for elevated DBPs.

Additionally, the ammonia component of chloramines can contribute to nitrification in the distribution system with increased water age. As a result, many utilities regularly flush their systems either manually, or through automatic flushing devices at dead-ends or low demand regions. The irony is that this practice operates conversely to conservation goals: Not only are water savings diminished, but there is the added expense of treating the supply, and in some cases, paying staff to manually flush the system.

As always in water treatment, the key is determining the appropriate balance between the pros and cons of a solution resulting in the greatest public benefit. Similarly to the chlorine-chloramine debate, conservation initiatives are resulting in some water quality challenges that can be addressed and managed with distribution system modeling. Hydraulic analyses can help identify specific problem areas and establish operating protocols to address stagnant areas, reduce water age, and improve water quality, ultimately minimizing and/or eliminating the need to flush lines and effectively reducing system operating costs.

Modeling Solutions for Integrated Issues

A distribution system model can also help predict the behavior of the system to solve a wide variety of design and operational problems. In the past, hydraulic modeling was primarily used as a planning and design tool, as well as for predicting water age for IDSE compliance. However, due to the emerging water quality and water age issues, more and more utilities are using their distribution system models to perform operational studies to solve problems, such as evaluating storage capacity, investigating control schemes, finding ways to deliver water under difficult operating scenarios, and developing unidirectional flushing programs. They are also being more widely used on the water quality side to perform such tasks as tracking chlorine residual and reducing disinfection by-products in a distribution system. Historically, model building was a very expensive and labor-intensive task. Now that models can effectively share data with GIS, SCADA, and customer information systems, the effort to create and maintain a model is more cost effective.

Operational Modeling

As mentioned, a distribution system model can be used as an operational tool, assisting in developing operating strategy, operator training programs, and system troubleshooting guidelines. Operating strategies may be driven by emergency conditions, energy management, water availability, etc.

Energy management in particular is becoming more and more important as utilities try to minimize their operating costs. The major contributor to a utility's total energy consumption is the pumping of treated water. Therefore, more and more utilities are focusing on finding the optimal control of their pumps to reduce their energy consumption charges. In general, energy consumption charges can be reduced by decreasing the quantity of water pumps, decreasing the total system head, increasing the overall efficiency for the pump station by proper selection of pumps, or using tanks to maintain uniform, highly efficient pump operations. Additional savings are achieved by shifting pump operations to off-peak water demand periods through proper filling and draining of tanks. Off-peak pumping is particularly beneficial for system operating under a variable electric rate structure.

The following is a brief list of types of analyses that can be performed in a distribution system to assist in system operations:

- Identify leakage (water loss) in the system
- Fire-flow analysis
- Unidirectional flushing
- Emergency operations scenarios
- Load shifting between treatment plant studies
- Valve criticality assessment
- Water hammer analysis
- Determine the system response to pump station power failures, valve closures, pump restarts, and pump speed changes

A criticality case study performed for a municipality in New Jersey used a distribution system model to evaluate the pipe segments within the water system that would require the most difficult shutdowns and the segments that are the most critical to the system. A pipe segment is defined at the smallest portion of a distribution system that can be isolated. The results of the analysis provided the municipality a priority list, as follows:

- Pipe segments that would require the most isolation valve closures to shutdown,
- Pipe segments with the highest volume of water that would be affected if the segment were shutdown, and
- Pipe segments containing the highest total system demand percent that would not be met if the segment were to be shutdown.

This enabled the operations staff to identify and resolve critical locations within the system with minimal impact to the overall system operation.

Water Quality Modeling

Water quality modeling is another application of distribution system modeling that is becoming more widely used. The primary goal of water distribution systems is to deliver potable water when and where it is needed, with little to no change in the quality of water from the time it leaves the treatment plant until the time it is consumed. The reality is that significant changes occur as water travels through a distribution system. Water quality models use a variety of mathematical equations based on the conservation of constituent mass to represent the transport within pipes, mixing at junction and storage tanks, and reaction kinetics in the bulk liquid phase and at the liquid-pipe wall boundary. Water quality models can be used to predict the spatial and temporal distribution of a variety of constituents within a distribution system. By tracking the transport and outcome of these constituents, water managers are able to perform a variety of water quality studies, such as:

- Design a cost-effective monitoring program
- Identify ways to reduce water age
- Determine the intermixing of multiple water sources
- Identify the most effective sampling locations
- Modify system design and operation to provide the desired blend of water from different sources
- Assess and minimize consumer exposure to DBPs
- Determine the best location for rechlorination stations
- Perform source trace analysis
- Constituent-concentration analysis
- Simulate emergency contamination events

A water age case study performed by McKim & Creed for a utility in Florida used a distribution system model to evaluate and reduce the utilities overall water age within its system. The results of the analysis showed that by converting a specific tank and pump station within the water system to a flow-through pump station effectively reduced the water age 50 percent, resulting in improved water quality, increased free ammonia for reactivation of chloramines, and reduced need to flush their system.

In addition to standard hydraulic and water quality modeling of distribution systems, another related type of model that is being used more widely is storage tank modeling. Tanks and reservoirs are traditionally designed, and subsequently operated, to meet hydraulic objectives: provide emergency storage, equalize pressure in a system, and balance water usage throughout a day. Most if not all commercially available distribution system models represent tanks as completely mixed systems. However, studies have indicated that water quality and mixing issues must also be considered in the design, operation, and maintenance of storage facilities. Improper mixing can cause high water age, which can lead to low chlorine concentrations and high DBPs in the tank effluent. This application of models to represent finished water tanks and reservoirs is a relatively new development to municipal applications. The most common types of storage modeling are computational fluid dynamic (CFD) models. The CFD modeling has been widely used in the chemical, nuclear, and mechanical engineering fields and has only recently been emerging as a modeling tool in the drinking water industry. The CFD models utilize equations describing the actual movement of water within the storage facility and the physical, chemical, and biological processes affecting water quality constituents in the facility.

The Greater Cincinnati Water Works performed a case study using a simple CFD model to assess the mixing in one of their storage facilities where they noticed steep drops in chlorine levels. The results of the modeling showed how a simple modification to the tank's inlet diameter from 5 feet to 2 feet would provide a good mixing pattern within the tank, reducing the time needed to achieve a complete mixing from 20 hours to 8 hours. This ultimately resulted in eliminating the steep drops in chlorine levels within the tank and improved the overall water age in their system.

Another Florida utility case study performed by McKim & Creed used a distribution system model to develop a flushing program for an area of its city that had historically experienced reduced chlorine residuals as compared to other areas. Using a distribution system model, McKim & Creed was able to create a flushing program that would pull higher quality water into the area of concern and purge aged water to help improve chlorine residuals, time between flushing events, and the amount of water used for flushing. This was accomplished by closing valves in conjunction with flushing of selected hydrants within the model to isolate portions of the city and channel flow as desired. This case study provided operational as well as water quality benefits to the utility.

Conclusion

Diminishing water resources have spurred conservation initiatives resulting in better resource management and efficiency. However, economic impacts have contracted water demands in many regions where population growth was expected. This has caused unexpected issues in these regions, especially in Florida, where many systems are now oversized, ultimately impacting water quality and system operations. Over the years, competition and technology advances have driven modeling and software costs down, making it easier for even the smallest water utilities to afford. The costs associated with constructing and maintaining a distribution system model is minimal compared to the cost savings it provides. As can be seen by the case studies described, the possibilities are endless in terms of how a distribution system model can effectively assist a utility to plan, design, operate, and optimize its systems, which ultimately equates to overall cost savings for the utility. ◊