SUMMARY OF MADISON WATER UTILITY/UW-MADISON CEE RESEARCH PROJECTS

Introduction

The collaborative research partnership between Madison Water Utility and UW-Madison's Department of Civil and Environmental Engineering has been in place since September 2002. Since that time, nine graduate students have completed an MS Thesis having practical value to the utility and a tenth graduate student is working toward completion in the spring of 2019. It is difficult to accurately estimate total savings, however it is speculated that since its inception in 2002, the graduate program has saved MWU over $600,000 in operational costs.

There have been three general areas of research covered by these thesis reports:

- Free chlorine residual and control of microbial growth in the distribution system.
- Unidirectional flushing strategies for control of turbidity spikes in the distribution system.
- Energy saving strategies for system operational optimization.

The next three pages summarize the benefits to the utility from each of these three research areas.

Administrative Overview

Projects are staffed with a graduate student pursuing a Master of Science in Civil and Environmental Engineering at UW-Madison. These students typically:

- Spend 16 to 24 months on a project (the average has been 20.2 months for MWU).
- Work about 20 hrs/wk for the first 9 months, 30 to 40 hrs/wk for the remainder of the project.
- Receive monetary compensation for 20 hrs/wk, health benefits, and tuition remission for the duration of the project.
- Receive academic credit towards their degree for the hours without monetary compensation.
- Take 18-24 credits of coursework from UW-Madison faculty, contributing ideas to the project.
- Produce a thesis report for MWU use at project completion.

Given the above, a typical MS student works over 1500 hr/yr, receiving about $43,000 in overall annual compensation (at about $27.50/hr, including benefits) and 6.5 academic credits per year. A Master's level engineer (Engineer 2) at MWU would work 2023 hr/yr at $62,000 in salary and $23,560 in benefits. Total cost for an equivalent 1,500 hours would be $64,170 ($42.78/hr).

Other key project costs are summarized as follows:

- The faculty advisor contributes about 50 hr/yr of weekly meeting time with the student, 25 hr/yr of monthly meeting time with the water utility, and 25 hr/yr of time on review of student work, concept development, and administrative matters. The overall value to MWU of this 100 hr/yr is about $13,300 annually and is not recovered from the utility.
- The utility provides the research assistant with working space, computer equipment, access to its hydraulic model, and use of its software at no cost to the University. In exchange for this, the university does not charge indirect costs to the utility (about $6,500/yr).

Total cost to MWU is $43,000 per year for the graduate program. Total benefit to MWU in salary and benefits is $83,970, a savings of $41,000 per year. Over 16 years, salary savings are estimated to be in excess of $570,000. It is estimated that since 2002, recommendations developed by the graduate program have also saved $40,000 in water quality labor and sampling, $450,000 in flushing labor, and $110,000 in energy costs.

Free Chlorine Residual and Control of Microbial Growth

Period of Study: September 2002 through December 2006

Summary of purpose, conclusions, and benefits

Prior to this research, MWU practiced maintenance of a detectable free chlorine residual throughout the distribution system, with "detectable" referring to a non-zero chlorine concentration with a hand-held DPD test kit. In addition to monitoring free chlorine, MWU routinely monitored total coliform counts and heterotrophic plate counts (HPC) throughout the system, with HPC analysis based on the plate count agar method and testing performed by the public health lab. A positive coliform detection and boil water notice event in 2001 reinforced the need to ask whether the chlorine residual policy was adequate.

Key findings from this period of research were as follows:

- HPC testing with the R2A agar method revealed the presence of microbial growth in the distribution system, which was not revealed by the plate count agar method.
- HPC testing with the R2A agar method, combined with testing for assimilable organic carbon (AOC) concentration, was a fundamentally sound method for establishing a target distribution system chlorine residual.
- Full-scale results suggested that a chlorine residual of 0.3 mg/L would be capable of maintaining an HPC < 500 cfu/mL, when HPC was measured with the R2A method.
- A chlorine residual of 0.1 mg/L was observed to reduce both bulk water and biofilm HPC by two orders of magnitude when compared to a non-detectable chlorine residual.
- Unidirectional flushing achieved a sustained reduction in HPC counts for at least 30 days.
- Hydraulic modeling identified areas of the distribution system in which chlorine residuals were at risk of falling below target values.

Based on these results, MWU slowly increased chlorine residual targets for the distribution system. Increased free chlorine residual provides better public health protection. Having that reassurance was particularly important for public confidence in the drinking water system when evidence of pathogenic viruses were discovered by another researcher in some of Madison's wells as this research was being completed.

Thesis reports

1. Srinivasan, Soumya. *Analysis of Bacterial Growth in Madison Water System*. August 2004. Currently employed with MITRE Corporation in McLean, Virginia.
2. Moran, Judith. *Pilot-Scale and Full-Scale Analysis of Heterotrophic Bacteria Control in the Madison Water System*. December 2005. Currently employed with Metropolitan Water Reclamation District of Greater Chicago in Chicago, Illinois.
3. Campbell, Ryan. *Management of Regrowth and Modeling Chlorine Residuals in the Madison Water Utility Distribution System*. December 2006. Currently employed with Jacobs consulting engineers in Corvallis, Oregon.
4. Judy Moran's pilot-scale work was also analyzed separately for a portion of Soumya Srinivasan's PhD dissertation. *Managing Bacterial Regrowth and Presence in Drinking Water Distribution Systems*. May 2008. This was performed at no additional cost to the water utility.

Unidirectional Flushing Strategies for Control of Turbidity Spikes in the Distribution System

Period of Study: January 2007 through August 2012

Summary of purpose, conclusions, and benefits

In 2006, MWU implemented a unidirectional flushing program in an effort to more rigorously remove iron (Fe) and manganese (Mn) sediments from pipes in the distribution system and minimize the risk of colored water events at customer taps. In the beginning stages of the unidirectional flushing program, there was some uncertainty regarding the desired frequency of unidirectional flushing at various locations in the system. In general, it was expected that more frequent flushing would be desired in areas served by wells with higher Fe and Mn concentrations, but research was needed to develop the target frequencies. The research was also critical in establishing flushing parameters such as water velocity and end of flushing hydrant turbidity. The question of flushing frequency required an understanding of what turbidity levels would be considered unacceptable during a spike event and the quantity of solids pumped into the system since the last flush.

Key findings from this period of research were as follows:

- Based on customer surveys, turbidity spikes more than 1.5 nephelometric turbidity units (ntu) would lead a typical customer to restrict water use during the spike event.
- Based on a comparison of observed turbidity spike events with customer complaint records, turbidity spikes more than 2.5 ntu would lead to an increase in customer complaints.
- Half of turbidity spikes higher than 1.0 ntu could be explained by planned unidirectional flushing and 20% could be explained by a water main break within 2 miles of the spike's location.
- Flushing velocities need to exceed 5 ft/sec to achieve removal of most sediments.
- Flushing to a turbidity of less than 1 ntu was sufficient to clean the main.
- Frequency of turbidity spikes was correlated with volume of water pumped from wells with high iron and manganese concentrations. Thus, the frequency could be reduced by reducing the volume of water pumped from these wells or by adding treatment processes to these wells.
- Approximately 60% of the distribution system could be unidirectionally flushed at a frequency of once every 2 to 3 years, instead of annually. This provided scientific support for a significant savings in person-hours and labor costs needed for unidirectional flushing.

Based on these results, MWU was able to develop data-based annual flushing plans with significant cost savings. MWU is also able to regulate the volume of water pumped from wells containing iron and manganese to optimize flushing requirements. Flushing operations can be scheduled based on well pumping volume, iron and manganese concentrations, and historic flushing turbidity data. Directed flushing schedules work to prevent consumer complaints. Turbidity spike information also gave MWU the ability to troubleshoot customer complaints about turbidity.

Implementing free chlorine residual data developed as noted earlier and using information gained from studying unidirectional flushing schedules and operations has greatly benefited the Madison system. Distribution system cleanliness is high, customer complaints are down, chlorine residuals are stable, and positive coliform samples are very rare. Every year the MWU unidirectional flushing program improves, mains are noticibly cleaner, flushing times and flushing labor hours are reduced, and costs go down.

Thesis reports

1. Holzem, Ryan. *Turbidity as an Indicator of Unidirectional Flushing Frequency and Prioritization*. July 2008. Currently employed as assistant professor at the University of Wisconsin – Green Bay.
2. Scott, Brian. *Monitoring of Turbidity and Modeling of Turbidity Resuspension in a Drinking Water Distribution System*. May 2010. Currently employed with Brown and Caldwell consulting engineers in Seattle, Washington.
3. Pitman, Mary. *Customer Perception of Turbidity Caused by Iron and Manganese*. August 2012. Currently employed with Smith Engineering in Washington, DC.

Energy Saving Strategies for System Operation

Period of Study: September 2012 through May 2019

Summary of purpose, conclusions, and benefits

Drinking water utilities are significant consumers of energy and Madison Water Utility is no exception. In 2017, MWU used 20 GWh of electricity at a cost of $2.2 million dollars. Since 1998, MWU has averaged an energy intensity of 2000 kWh of energy consumed for every million gallons of water pumped at a cost of $170 per million gallons. Over the same time period, electricity costs have averaged 15% of the total annual operations and maintenance expenses for the utility. Water conservation is a significant approach to reducing energy consumption, but does not reduce energy intensity. Since 1998, annual pumping and energy consumption have declined at rates of 1.2% per year and 0.9% per year, respectively. However, energy intensity has increased at 0.4% per year. The current emphasis of the research program has been to assist MWU in reducing energy intensity as well as reducing energy costs.

Key findings from this period of research are as follows:

- Over 99% of energy use at unit well sites could be attributed to pumping.
- Energy intensity savings are best achieved by reducing the amount of drawdown exerted by deep well pumps, suggesting that lower specific capacity wells have the largest potential for energy savings. Reducing drawdown can be accomplished by installing variable frequency drives (VFDs) on appropriate deep well pumps, allowing them to be operated at lower flow rates for longer periods of time to achieve the same total water production.
- Energy intensity savings with VFDs are enhanced when reduced pumping speeds coincide with increased pump efficiency. This occurs when pump selection at 100% speed indicates higher flow rates and lower total dynamic head than the best efficiency point on the pump curve. Following VFD installation as the pump is slowed down, the pump efficiency will increase.
- The top candidates for VFD installation on deep well pumps are Unit Wells 30, 6, 13, 9, and 11. Purchase and installation of VFDs on these five deep well pumps are estimated to save over 840 MWh and over $75,000 annually, with payback periods less than 5 years. VFDs could be installed with a payback of 10 years or less on approximately half of the deep well pumps in the system.
- Understanding energy use by well can inform pumping schedules, thereby reducing energy requirements and pumping costs. Studying how wells interact by zone or region will allow the development of pumping strategies focused on reducing energy use and costs. These strategies will include peak versus off peak pumping and high versus low efficiency facilities.
- Shifting both deep well and booster pumping to off-peak electrical demand periods can produce significant savings in energy expenses, albeit with little reduction in energy use. Although field testing has only just begun, current estimates suggest that off-peak pumping in Pressure Zone 8 could save around 40% of the annual electricity costs in this portion of the system.

Studying Zone 4 well supply pumping in anticipation of bringing Well 31 online in 2018 provided information on how to minimize energy costs in the southeast corner of the City. Installation of a VFD on the deep well pump at Unit Well 30 saved nearly 100,000 kWh and $8,500 in electricity costs in just 6 months of operation. This occurred with no observable impact on energy use at Unit Well 18 or Booster Station 118, the two facilities most likely to be infuenced by the change in operation at Unit Well 30. Consideration of VFD installation at other wells is now a part of capital improvement planning. Research indicated that installation of VFD's on booster pumping systems does not have a great potential for energy savings and should only be considered for operational advantages. Pumping strategy based on facility efficiency has the potential to substantially change how MWU operates some portions of the system. A protocol of primary and secondary supply facilities may provide significant energy benefits to the system. Benefits associated with off-peak pumping are currently under investigation.

Thesis reports

1. Baniel, Nicholas. *Energy and Efficiency Analysis of Municipal Drinking Water Infrastructure*. December 2013. Currently pursuing a Doctor of Jurisprudence degree at Vanderbilt University in Nashville, TN
2. Hayes, Matt. *Evaluation of Energy Saving Alternatives at Madison Water Utility*. May 2015. Currently employed with Black and Veatch in Milwuakee, WI.
3. Mancosky, Connor. *Evaluation of Energy Savings Potential from Deep Well Variable Frequency Drive Installation*. July 2017. Currently employed with Carollo Engineers, Seattle, WA.
4. Luthin, Adam. *Optimizing Pumping Operations for Minimum Energy Use*. Expected completion date: May 2019.