Energy Savings in Water and Wastewater Systems

A Bentley White Paper

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Published:
July 2015

Bentley
Sustaining Infrastructure

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Executive Summary

Water utilities face the challenge of providing water services to their customers while at the same time trying to deliver operational cost savings to the organization, which ultimately results in lower bills and charges to all their customers. The most controllable operational cost saving for a utility is energy consumption, the cost of which is typically second only to labor. Pumping for water distribution dominates the operational energy cost of an organization but savings can be found through improved efficiencies in operating the equipment, choosing the correct pump and pump station configuration, optimizing the pump schedule, proper maintenance of equipment, and intelligent manipulation of often complex energy rates.

In 2013 the Engineering Modeling Application Committee (EMAC) published the results of a survey on the state of water distribution modeling that was an update of a study conducted in 1999 from the AWWA M32 – Computer Modeling of Water Distribution Systems. The trend during the period between surveys has seen an increase in the development of all main and system hydraulic models and the move away from using skeletonized models, as well as greater adoption of extended period simulation analysis with less than 50 percent respondents in 1999 compared to close to 70 percent in 2013, and increasing utilization of SCADA and other supporting operational data and systems such as GIS. Hydraulic models are increasingly being used in support of operational workflows and, more specifically, can be exploited to identify and analyze inefficiencies in the operation of the utilities pumping strategy and regime, thereby potentially provide solutions that may result in savings in their energy bill. However, results from the 2013 study suggests that hydraulic models are used infrequently to assist in energy management initiatives when compared to the more prevalent use for planning scenarios and fire flow analyses. Less than 30 percent of the municipalities surveyed use hydraulic models for energy management.

Hydraulic models are increasingly being used in support of operational workflows and more specifically can be exploited to identify and analyze inefficiencies in the operation of the utilities pumping strategy and regime.

This white paper addresses how hydraulic models can be used to instantiate energy savings by reducing energy waste, promote better efficiencies in operating a pumping system, and exploit flexible energy tariffs available in the market place. The paper covers basic topics such as: pump curves, energy calculations to determine how much energy is being used, energy management tools to try to reduce energy use by becoming more efficient, and understanding and manipulating energy rates.

Background

For water utilities around the world, finding the ideal balance between energy and water consumption continues to be a major challenge. Energy use at a water or wastewater utility can be as much as 50 percent of the organization's total electricity consumption, second only to labor costs in most utilities' operating budgets. Energy potentially represents the largest controllable operational expenditure. In addition, the energy industry itself requires a significant amount of water to operate. It takes a lot of water to produce energy, but it also takes a lot of energy to treat and distribute water – and the demand for one could soon cripple our use of the other. Water utilities are some of the largest users of electricity. In the United States for example, the Environmental Protection Agency states that between 3 and 4 percent of all electricity produced is consumed by water utilities. This equates to 56 billion kilowatts costing USD 4 billion per annum.

But a water-energy nexus solution is on the horizon, as more energy-efficient technologies and alternative energy production methods are developed and better use of analytics and smart software are applied to control operational and maintenance costs.

Pumping for distribution of treated water dominates the energy use, and therefore cost, of surface water-based supply systems, usually accounting for a whopping 70 to 80 percent or more of the overall electricity consumption. The remaining electricity usage is split between raw water pumping and the treatment process.

When looking at the overall picture of how much money a utility spends on the water distribution system and in particular on the pumping side of water distribution, a utility will try to break down the cost into equipment costs, energy costs, and other operating and maintenance costs such as labor. In particular for water distribution, where a utility will be pumping against high heads most of the time, it will spend more money on energy than on building and installing the pumping system or maintaining the pumps. So energy use is a major cost for water utilities, in fact it is one of the biggest costs they face.

Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies. Global Water Research Coalition

A system approach is very important for maximizing energy savings in a most cost-effective manner. This requires optimization of system architecture and operation, instead of just focusing on specific equipment. Hydraulic analysis of the entire water supply system can help avoid missing strategic actions and identify system design improvements." Quoted from "A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities" ESMAP (Energy Sector Management Assessment Program), World Bank Technical Report 001/12

Introduction

Walking into a pumping station is a lot like walking into a gold mine. There are little gold nuggets lying around, in this case, in the form of energy savings. Just as in the case of the gold nuggets, those energy savings are not going to shout out to you "Here I am." A pump that is wasting energy (and money) looks, sounds, feels, smells, and probably tastes just like one that is running efficiently. However, with a little bit of work, energy savings can be found, and a hydraulic model of the system, combined with some field measurements, can be an invaluable tool for finding these energy savings.

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Water utility operators are therefore always looking for a magic button that they can push to reduce electricity usage in their water pumping operations. Unfortunately, there are quite a few reasons why utilities don't operate at perfect efficiency. Operators need to first identify where energy is being wasted before they can reduce their energy use and energy costs. Just as a doctor needs to wade through a set of symptoms to determine what is wrong with a patient, an engineer needs to wade through a series of potential inefficiencies to find the worst source of energy waste, those that can provide the biggest potential savings and ultimately identify solutions. Some of the most important sources of energy waste include:

- Mechanical problems in the pump
- Inefficient motors
- Pumps not operating near their best efficiency points due to:
    - Poor pump selection
    - Changes in the system
    - Pump combinations that are incompatible
- Pumping through control valves
- Pumping through undersized or very rough pipes
- Poor layout of pressure zones
- Use of oversized pumps in dead end zones
- Poor pump scheduling

In addition to wasting energy, it is possible to use energy efficiently but spend too much money on pumping due to:

- Pumping too much at times when energy is most expensive
- Having high peak energy use that can trigger peak demand charges
- Not using the best energy rates for the pumps

Because energy is wasted in so many ways, there are many analyses and corrective measures that can save energy and therefore energy costs. A good energy analysis involves using the full set of tools available to dig up the biggest "golden energy nuggets."

Each of the possible ways to waste energy and the possible corrective measures are described in the following sections. The first two sources of energy waste are mechanical and electrical and involve only minimal hydraulic considerations. The remaining issues are hydraulically driven and use of a water model, in particular the energy management tools in Bentley Systems' WaterGEMS and WaterCAD, can provide insights and the quantitative values to analyze and justify corrective measures.

Mechanical Problems in the Pump

As with any mechanical device, pumps wear out. This can be seen by viewing the original pump head and efficiency curves and comparing them with current data from the field. To view the head curve, it is necessary to know the flow, the suction head, and the discharge head. For the efficiency curve, the energy input must be measured. Usually only the electrical input can be measured in the field and this will yield the overall (wire-to-water) efficiency and must be corrected using the motor efficiency to compare with the pump efficiency curve, which is usually the one available. Check the calibration of any gages or meters before and after making measurements.

If a pump is no longer running on its curves, there are a number of reasons that must be investigated:

- Worn or modified impeller
- Excessive roughness in the casing
- Worn bearings
- Clearances that have drifted out of tolerance
- Pump not running at stated RPM

Maintenance personnel need to determine the problem and make the necessary corrections if they are deemed cost effective.

Inefficient Motors

Unlike pumps, which have a fairly narrow band of flow where they work efficiently, motors tend to run near their best efficiency for a range of loads between 50 percent and just over 100 percent of full load. Unless a motor is significantly oversized or worn out, it is probably running near the efficiency for which it was designed. However, recent improvements in motor technology have resulted in motors that are substantially more efficient than old, standard efficiency motors.

Premium efficiency motors can reach efficiencies on the order of 95 percent depending on the size and load. It is easy to compare the efficiency of a new motor with that of an existing motor and determine the savings in energy. Then it is simple economics to determine the payback period if the old motor is replaced. In general, large motors that run most of the time will have a short payback period while motors that only run occasionally, such as stormwater pumps or fire pumps, will have a much longer payback period and are not likely candidates for replacement.

Poor Pump Selection

Most engineers do a good job selecting pumps but sometimes a pump may have not been sized properly. A quick indicator of this is a pump that is not running at its nominal flow, such as a 600 gallon per minute (gpm) pump that is running at 400 or 800 gpm. A nominal 600 gpm pump will not necessarily discharge 600 gpm. However, a more precise way to analyze this issue is to run WaterGEMS and view the operating points over the course of a day. Figure 1 shows a pump that was selected to pump 1,800 gpm against 140 feet of head. However, the actual pump could only deliver 1,250 gpm and as a result, the efficiency dropped from 70 percent to 62 percent.

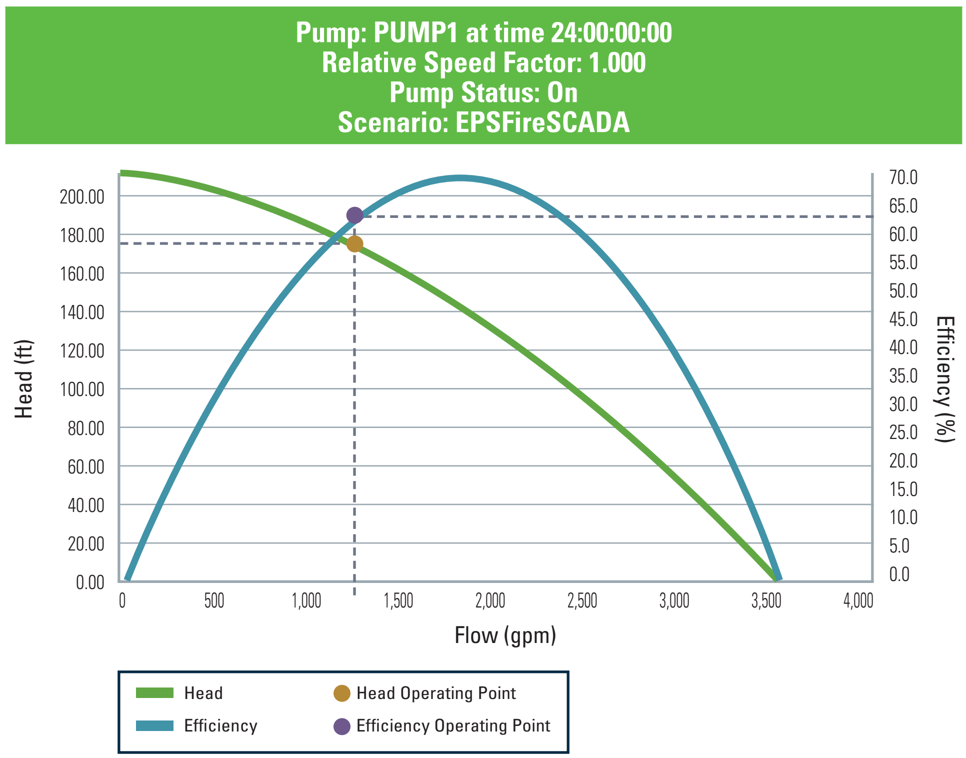

Figure 1. Pump curve display showing operating points

This situation usually occurs when the system head is higher than expected at that flow rate. This can be due to smaller pipes than the pump was sized for, much greater roughness than anticipated, or a tank water level that was not considered in design.

Change in the System

A pump may have been properly selected but the system may have changed, which affects the operating point. An old tank may have been abandoned and replaced with a new one that has a higher water level. Pipes may have become rougher over time or an important valve may have been mistakenly closed. Pipe roughness tends to increase gradually while a closed valve can show up as an abrupt change in performance.

Conversely, a pipe can operate at higher flow than designed if a new pipeline has been installed or a new tank is at a lower water level than expected when the pump was installed. Figure 2 shows that as the tank level drops, the system head curve drops and flow decreases from 75 to 105 million gallons per day (mgd). While such a variation is larger than usual, it is important to remember that systems (and the corresponding system head curves) vary over time, both on an hourly and long-term scale), and these variations can be analyzed with WaterGEMS.

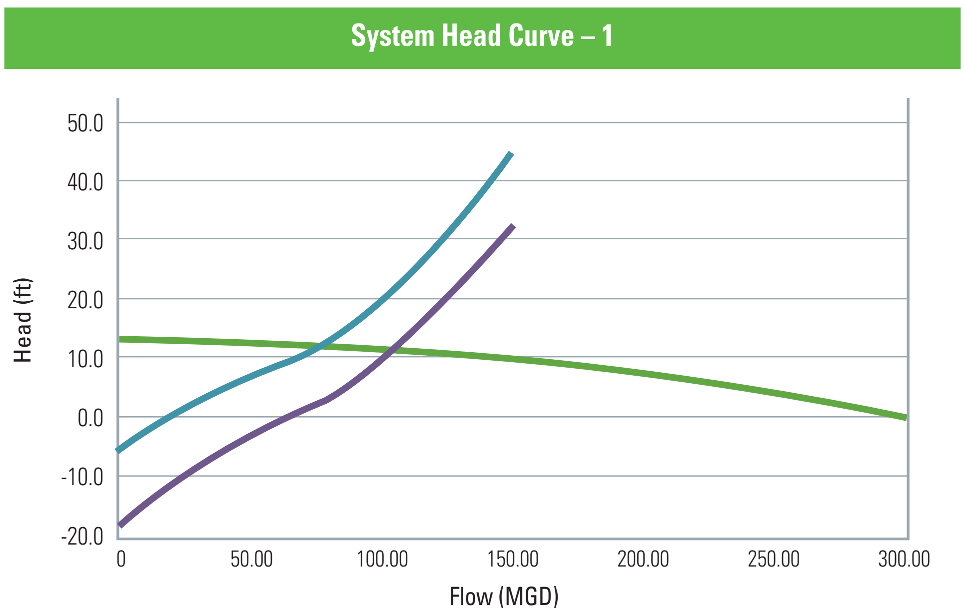

Figure 2. System head curves showing variation over time

In a closed system with no storage, the pumps can wander back and forth along their pump curves over the course of a day and over the long run. It is not uncommon to see pumps operating at a fraction of their design flow because development in an area has not materialized or a large water user has gone out of business.

Incompatible Pump Combinations

Sometimes a pump may be mechanically efficient and run at an efficient operating point when running by itself but run poorly when run in combination with other pumps. An indication that this problem may exist would be a nominal 1,200 gpm pump that usually produces roughly 1,200 gpm when running alone but only produces 900 gpm when run in combination with other pumps. This usually indicates a lack of capacity in the piping system as the pumps fight with one another. The pump with the highest head wins.

WaterGEMS provides tools to analyze the potential for this problem with its Pump Combination display. Figure 3 shows a station with four identical pumps. When one pump runs, the flow is 250 gpm (intersection of pump head [blue] and system head [cyan] curves) and the efficiency at that point (red curve) is 69 percent. When four pumps run, the station discharges 500 gpm (125 gpm per pump) at the intersection of the four-pump curve (green) and the system head (cyan) curves, which produces a 56 percent efficiency rate.

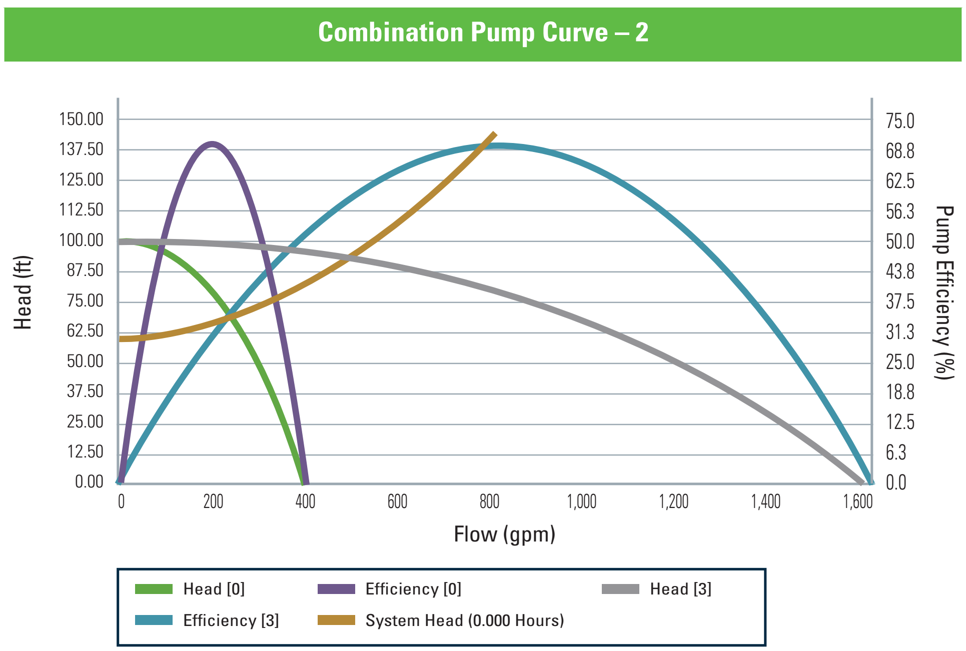

Figure 3. Effect of pump combinations on efficiency

Another type of bad combination can occur when two very different pumps are run together. In Figure 4, both pumps discharge 1 cubic foot per second (cfs) at a peak efficiency of 70 percent when run individually (intersection of individual pump head curves with magenta system head curve). However, when two pumps are turned on, the head increases to 84 feet and the discharge from the higher head pump drops to 0.8 cfs. Meanwhile, the discharge of the lower head pump (red curve) drops to 0.4 cfs and the efficiency drops to 0.43 cfs and the efficiency drops to 48 percent. The higher head pump is essentially "shutting off" the lower head pump.

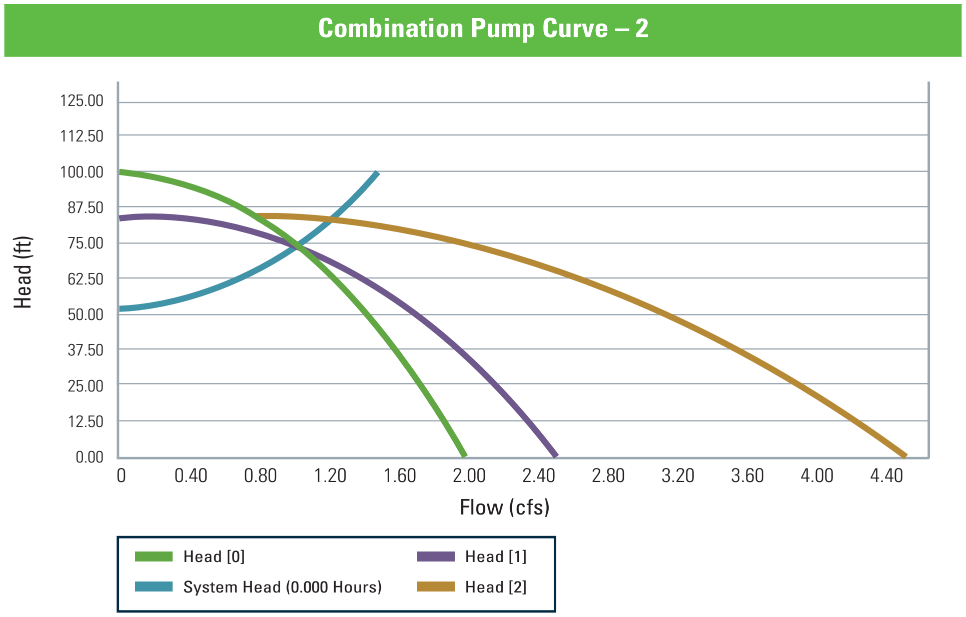

Figure 4. Poorly matched pumps running together

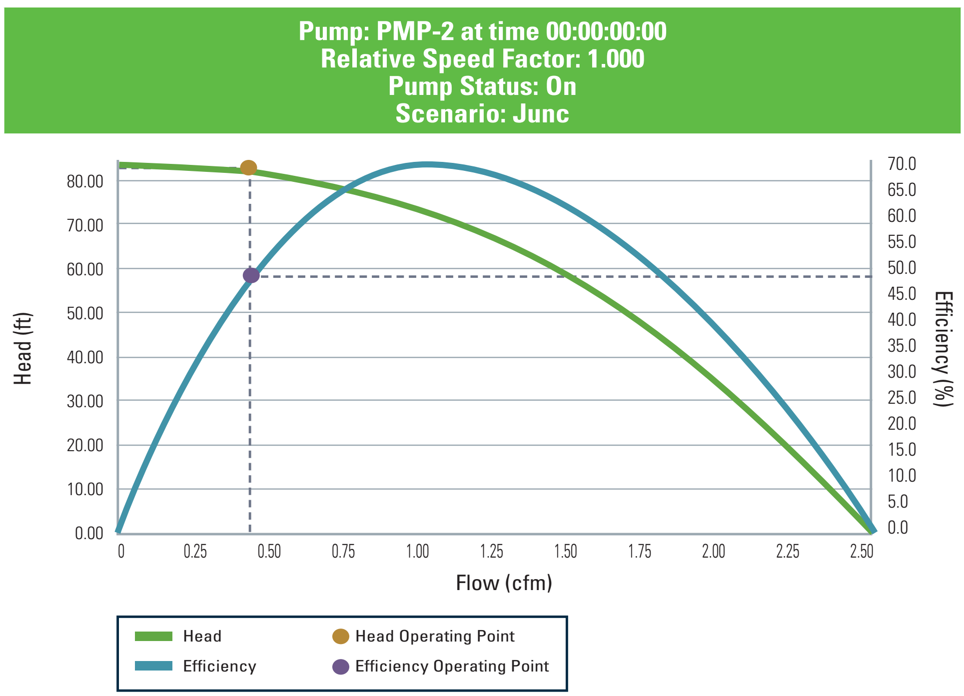

Figure 5. Pump operating at poor efficiency due to interaction with other pump

The long-term solution usually lies in adding piping capacity (i.e., flattening the system head curve). However, in the short run, avoiding bad combinations, usually by pumping at a steadier rate, can reduce energy waste.

Pumping Through Control Valves

In some cases, a pump may be producing too much pressure for the desired system, especially for a system with no storage. The pressure can be reduced using a control valve, either a pressure reducing valve or a manually controlled valve. While this will reduce pressure, it is usually the most wasteful solution in terms of energy. Reducing the pump speed with a variable speed drive, trimming the impeller or installing a lower head pump will all result in energy savings when compared with a throttled valve. WaterGEMS can analyze the energy cost of each alternative as part of a lifecycle cost analysis.

A more subtle form of this problem would be a system that pumps water to a higher pressure zone only to have it drop back into a lower zone, usually through a pressure reducing valve (PRV). If the water is flowing back into the same pressure zone, this essentially means that water is being pumped in a circle. Sometimes, this situation is unavoidable because of the local topography, but usually closing these boundary valves or setting them so that they will only open during an emergency will result in energy savings. WaterGEMS energy management calculations can quantify the energy that is being wasted and the savings that will accrue by modifying operations.

Pumping Through Undersized or Rough Pipes

> Reducing the pump speed with a variable speed drive, trimming the impeller or installing a lower head pump will all result in energy savings when compared with a throttled valve.

More energy is required to pump water through pipes with high head loss than lower head loss. This excessive head loss could be due to undersized pipes or pipes that may have been correctly size at one time but have lost carrying capacity due to tuberculation or scale. Incorrectly closed valves can also have the same effect as undersized or rough piping. Increasing the capacity of the system by adding piping, cleaning pipes, or opening valves can reduce energy use. These issues are usually identified during hydraulic model calibration.

This problem of inadequate capacity is usually not severe in water distribution piping since most of the energy is used to raise the water from one pressure zone to the next and system head curves are relatively flat. It is usually most critical in long transmission mains and sewage force mains (rising mains) where more of the energy is directed to overcoming head loss rather than lift.

To correctly analyze the corrective measures, it is necessary to estimate energy costs. WaterGEMS' energy costing tools can provide that information.

Poor Layout of Pressure Zones

In many systems, pressure zone boundaries have been set up in such a way that customers at the lower elevations in a zone receive water with excessive pressure. The zone boundaries can be moved by modifying valving to place those customers in a lower pressure zone. This means that less water needs to be pumped into the upper zone with a corresponding reduction in energy.

WaterGEMS can be used to color-code customers by pressure along pressure zone boundaries. This will show those customers who have excessive pressure and can be moved to a lower zone while still meeting pressure standards. Lowering pressure has the additional benefit of reducing leakage.

In the figure below, junctions and pipes that have pressures in excess of 100 psi (shown in red) can be shifted into the lower (blue) pressure zone, instead of being fed from the magenta pressure zone by closing valves to the upper zone and opening them to the lower zone. This reduces the amount of water that must be pumped into the higher zone. The WaterGEMS pressure zone manager can quickly show how the demand has changed in each zone when valving is modified.

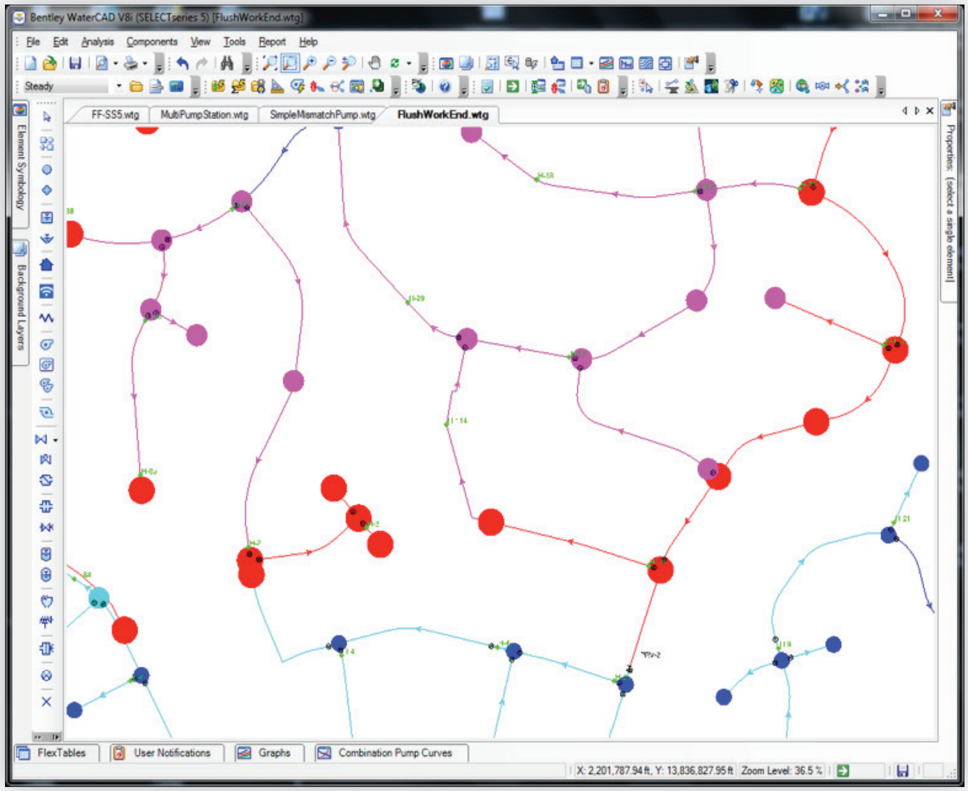

Figure 6. Customers with excessive pressure along pressure zone boundary

Oversized Pumps

Engineers are taught to be conservative in their design, but oversizing pumps can lead to energy waste. In pressure zones with storage, it is possible to fill tanks and turn off the oversize pumps. However, in zones with no storage, the pumps can migrate to very inefficient operating points. If a pump is sized to efficiently produce 100 liters per second (L/s) at peak flow but the normal demand is 20 L/s, the pumps will not be efficient.

Variable speed pumps can reduce this loss of efficiency somewhat. However, they will still be inefficient, but less inefficient than a similarly sized constant speed pump. In some cases for small pressure zones, a hydropneumatic tank can be provided to enable the pumps to be turned off for periods of time but these will not be cost effective for large systems where elevated storage may be needed.

In general, it is better to right-size pumps so that they will usually be operating near their best efficiency points. In the example where the (rare) peak demand is 100 L/s, the lowest capital cost design may be two 100 L/s pumps but if the average flows are much lower, it will be better to install three 50 L/s pumps, which can still meet peak demands with one pump out of service but will normally be operating near their best efficiency points. As shown in Figure 7, WaterGEMS can display how the efficiency varies over time because basing energy calculations on average conditions can be misleading. This could indicate times when it is better to turn on a small "jockey" pump rather than trying to slow down an oversized pump with a variable speed drive.

WaterGEMS' Darwin Scheduler uses genetic algorithms to recommend an optimal pumping schedule.

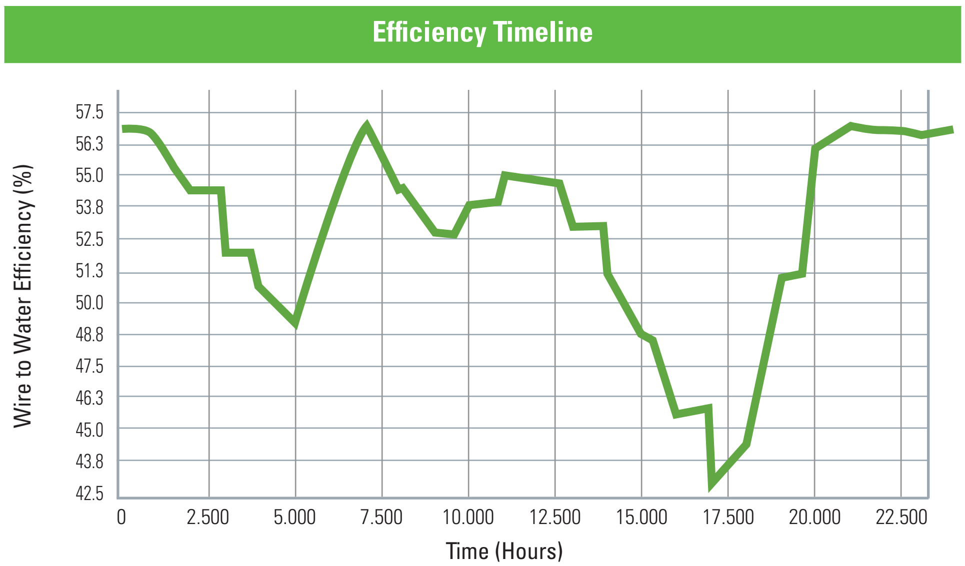

Figure 7. Variability of efficiency in a zone with no storage

Pump Scheduling

Given such complications as pump combinations, time-of-day pricing, peak demand charges, etc., there is some optimal scheduling of pumping to minimize energy use or energy cost. A method that is commonly used for this type of analysis is genetic algorithms, which searches for an optimal schedule in a way similar to evolution, survival of the fittest. WaterGEMS' Darwin Scheduler uses genetic algorithms to recommend an optimal pumping schedule.

Because water utilities must deliver a certain volume of water at a certain pressure each day, there is a certain minimum energy that must be used regardless of the operating schedule.

Darwin Scheduler can be run off line to determine good operating strategies or can be run in the control room to schedule pumps for a given day. Depending on the size and complexity of the system, the solution space (number of possible pump combinations vs. time) can be huge, requiring long run times and the method requires time to be divided into discrete intervals such as an hour even though optimal pump switch times may occur between an hour. In addition, the optimal solution is only as good as the demand forecast used to drive it which always involves some error.

Because water utilities must deliver a certain volume of water at a certain pressure each day, there is a certain minimum energy that must be used regardless of the operating schedule. Nevertheless, Darwin Scheduler can point utility operators toward good operating strategies.

Pumping Too Much at the Wrong Time

The peak water demand, especially during warm weather, usually correlates with the peak energy use for the power company and since power companies cannot store energy, they want to shift electrical demands away from their peak demand time. They do this using time-of-day energy pricing where the price of energy is much higher during the power company's peak hours, which is often afternoons during the summer. Water utilities have the ability to store water (and hence energy) in elevated tanks during times of off-peak energy pricing to reduce their pumping during peak energy rate times.

Figure 8 shows the cost per volume pumped as determined by WaterGEMS for a water utility that must pay significantly more for energy between hours 12 and 18 (noon through 6 p.m.). It would be advantageous for the utility to move as much of its pumping as possible from that peak time period to a period when the energy price is lower.

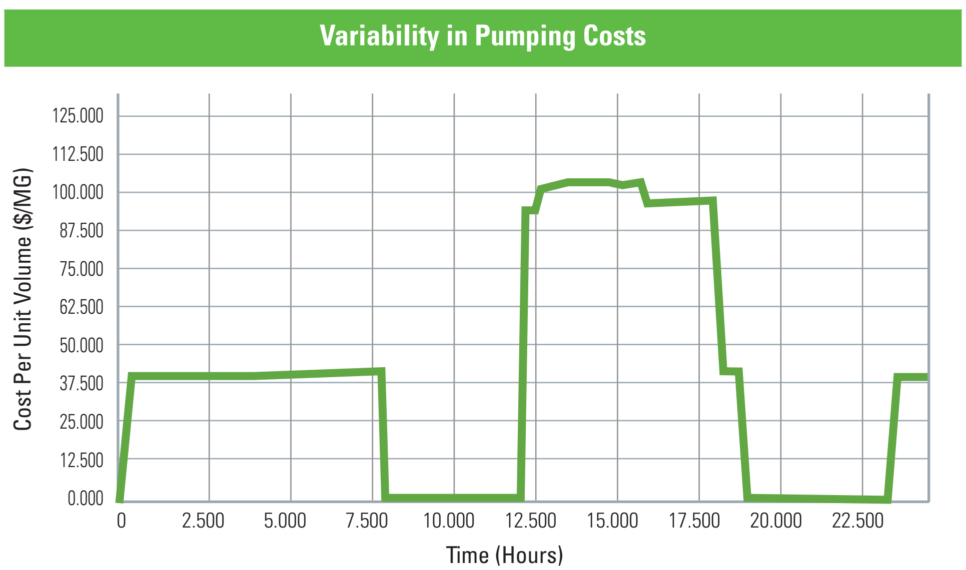

Figure 8. Higher pumping costs during times of peak energy pricing

Peak Energy Use That Triggers Peaks Demand Charges

Unlike water bills, which are generally based on volume used, energy bills are based on multiple components that not only include total energy used but also the peak energy demand. These peak demand charges are usually based on the peak energy use at each water meter during some 15 minute or hourly period. The highest peak during a billing period or even previous year is used as the basis for this charge. This rewards pumping at a steady rate. WaterGEMS provides ways to determine this time of peak energy use so that the water utility can minimize it.

In some case, the peak electric demand is set during a major fire or a large pipe break and there is not much that can be done to reduce the peak. However, in other cases, peaks are simply due to a poor operating strategy or haphazard operation. Figure 9 shows how a peak power draw occurred during the duration of a fire from hours 3 through 10 in this system.

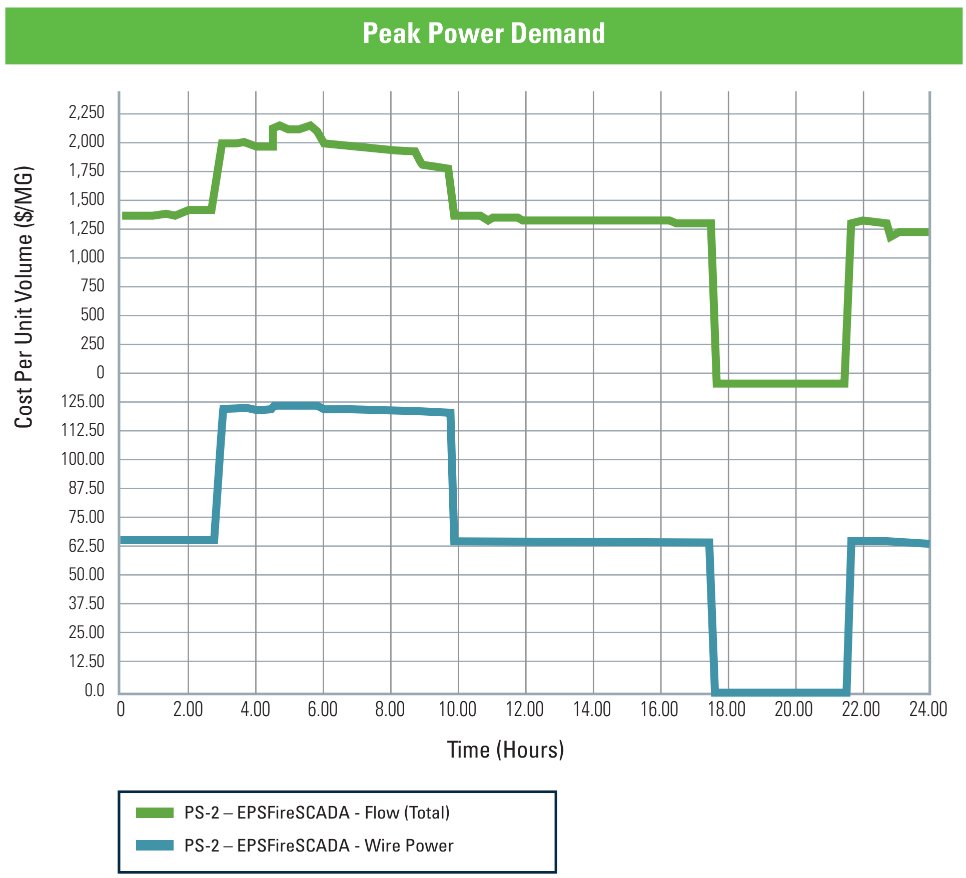

Figure 9. Power draw related to flow showing peak power demand

Using the Best Energy Rates

In many cases water utilities have choices as to which energy company is supplying the energy or which rate is the most desirable. The tariffs can include such complications as block rate pricing, peak demand charges, different tariffs for different pump stations and costs for non-pumping energy use.

The energy management tools in WaterGEMS provide a way to quickly and accurately calculate energy costs over multiple scenarios and time periods even if different pump stations may have different energy tariffs. WaterGEMS can produce energy cost results aggregated over power meters, pumps, or scenarios. Figure 10 shows one power meter over a monthly billing cycle but the results can be presented system-wide to provide such results as the present worth of energy costs over a long-term planning horizon.

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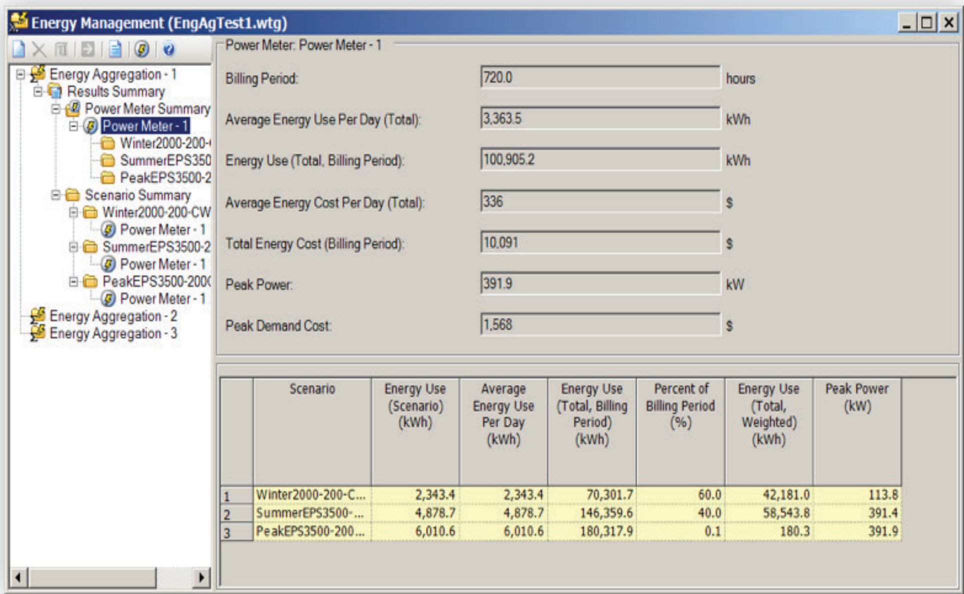

Figure 10. View of energy management analysis results

It is often helpful to simply compare the energy bill predicted by WaterGEMS to the energy bill received from the power company. The comparison may reveal discrepancies in billing and may provide insights into where energy costs can be reduced.

Summary

So a pump that at first sight appears to have a simple function operating in a straightforward way in fact turn out to be a greedy consumer of energy, can be costly to run, and has plenty of scope to be operated inefficiently. This white paper has attempted to show that there are numerous options to investigate and identify why a pump may be operating inefficiently. This is hopefully good news as there is plenty of scope to improve the situation. But of course, because there are many ways that energy can be wasted in water system pumping, there are many analyses that need to be conducted to determine the source of wasted energy and perform the economic analysis to determine the best solution. Using analysis tools available in hydraulic models such as WaterGEMS can help in identifying problems, studying alternative solutions, and quantifying the benefits of the solutions. These tools provide pumping operations with the capability to study:

- Pump operating points
- System head curves
- Combination pump curves
- Energy cost analysis
- Graphs of any energy-related property over time
- Pump scheduling
- Energy management

There will be few utilities that cannot find pumping energy or energy cost savings somewhere in their water distribution and pumping systems, and WaterGEMS provides the tools to find the "gold energy nuggets."

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