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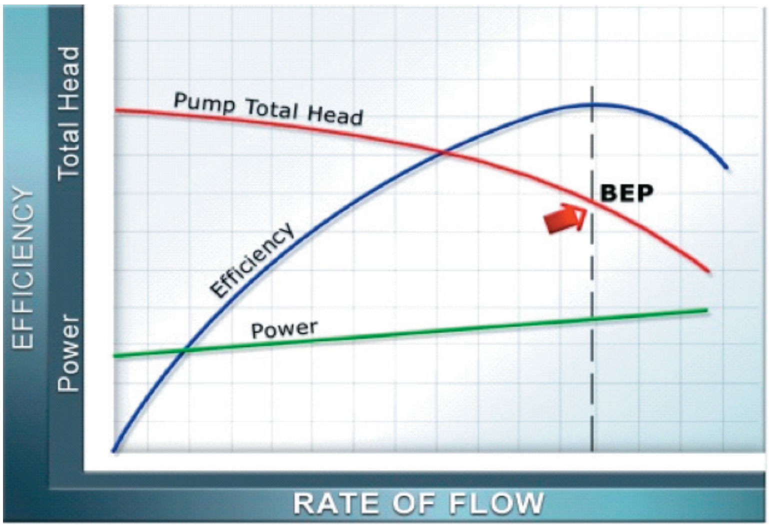
Reducing the GHG footprint at water and wastewater utilities in the US and the UK.

Introduction

Electricity consumption by water and wastewater utilities typically accounts for three percent of all energy consumption in the US and the UK. With national electricity production exceeding 3,000 million MWh/yr, this represents net annual consumption of about 90 million MWh. Between 90% and 95% of all energy purchased by a water utility is consumed by pumps; at the raw water intakes or wells; at the treatment plants; and at the booster pumping stations. As we will demonstrate, energy efficiency investments can yield excellent reductions in energy consumption and as a consequence also substantially reduce the carbon footprint of the utility. Case history data is presented showing that pump efficiency savings of 5% to over 25% in energy consumption can be achieved, with the inherent accompanying benefit of reducing the GHG footprint of the utilities.

Pump Energy Efficiency

A hydraulic engineer typically selects a pump based on the expected discharge head and flow requirements such as being able to re-fill storage overnight within a reasonable time period (typically less than eight hours). This means the pump will satisfy demand on typical days with sufficient pumping capacity in reserve to respond to peak demand days. A pump is then selected so that it runs at its Best Efficiency Point (BEP) on the expected system curve at the calculated head and flow.



While significant progress has been made on matching pumps to their duty requirements to achieve good efficiency, these calculations have relied on a single duty reference point. In practice, pump operating requirements are much more complex. In a typical water distribution system, demand changes seasonally and diurnally, from very high demand in the mornings and evenings to almost no demand overnight. Unless the pump delivers to a fixed head with no off-take demand between it and the tank it is filling it is very difficult to select a pump that will operate efficiently over the entire operating head range. An engineer must also take into account expected growth in demand in an area over the 40 years or so of anticipated pump operating life and will consequentially tend to specify a much larger pump than is required at the installation time, to allow it to cope with future projected demands. This means pumps rarely operate close to their BEP.

In addition, pumping facilities and water distribution networks have become highly interconnected and complex systems. Pumps therefore do not operate in isolation; in fact due to the incompressibility of water, it is typical that any change in operation of one pump, such as a high-lift discharge from a treatment plant, will change pressures in the transmission pipelines and may affect the operating point of many other pumps.

Given the significant ongoing amount that the typical water utility water spends on energy for pumping, one could assume that reasonable effort is made to keep pumps operating efficiently. In practice, that assumption may prove to be the exception, not the rule. For example a major study of pumps commissioned by the European Commission (EU Commission, 2001) determined that very little if any effort was being made in this area. They recommended three strategies:

1. Obtaining better efficiency information prior to selecting and procuring pumps;
2. Matching pump characteristics to production requirements and operating conditions, and countering efficiency deterioration through a proactive preventive maintenance program inclusive of reconditioning pumps;
3. Scheduling pumps to improve efficiency.

Further, the study looked at procurement practices and priorities within the water sector to identify the key criteria used for pump selection. Leading the list, in most cases was initial purchase price and delivery followed by reliability and hence likely maintenance costs. Efficiency trailed as a distant third if considered at all. In fact this is almost directly opposite to typical pump lifecycle costs, where the energy consumed by a pump over its 20

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to 40 year life makes up 95% or more of the life cycle costs, maintenance costs only about 4% and initial purchase price only 1% to 2%.

Pump Scheduling Solutions

Given that energy use by water utilities is significant and that more than 90% of this is used for pumping then software solutions to optimise pump operations would seem a good idea. A number of solutions have been proposed or developed to establish dynamic pump scheduling systems to optimise pump operation. These are intended primarily to leverage time of use (TOU) tariff structures to minimise energy costs as water utilities are in a prime position to maximise pumping to storage during off peak hours when energy rates are lowest, and draw down during peak energy cost periods. This ability to ‘store’ energy is almost unique.

Due to the complexity of most water distribution systems, and the myriad production requirements and operational constraints, it is generally considered impossible to explicitly solve the scheduling problem to achieve lowest cost through mathematics. However predicting system energy use from a given pump schedule is both relatively trivial and extremely fast to compute, and is already a feature of most off-the-shelf hydraulic modelling packages such as EPANET and WaterCAD. A “brute force” approach, modelling every possible pump schedule combination to arrive at the most preferable solution may seem a possible way forward. However, this is not practical. A system with N pumps requiring hourly schedules for a single day has (2^N)^24 possible combinations. So a system with only 11 pumps has about 3 x 1079 possible schedules, which coincidentally is almost the same value as recent estimates of the number of atoms in the entire universe. Even supercomputers would take more than the lifetime of the universe to run through all schedules. Most sizeable water utilities have hundreds or even thousands of pumps. Brute force solutions are therefore impractical and as a consequence, more sophisticated search and optimisation techniques and strategies have been developed to assist in solving this problem.

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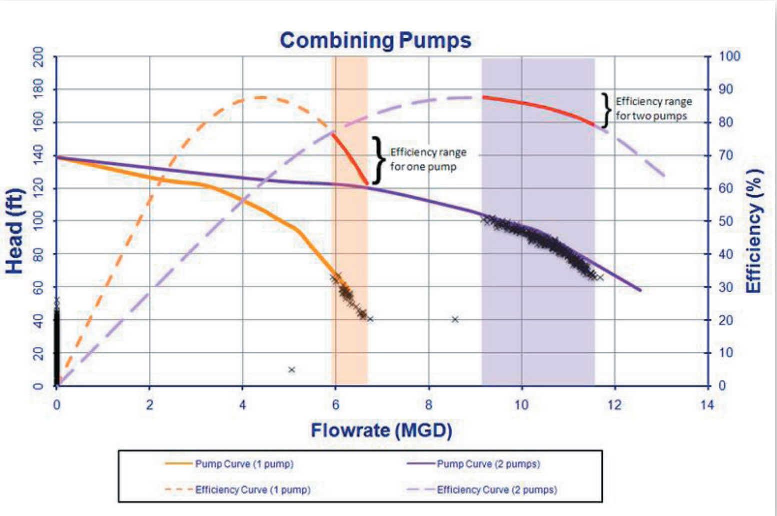
Most approaches to this problem use multi-objective evolutionary algorithms (MOEA), or more specifically Genetic Algorithms (Sotelo, von Lücken, Barán, 1995). There is a large body of research papers on the application of the most popular form of EA, the Genetic Algorithm (GA) to the pump scheduling problem since this is best suited to binary (pumps only being on or off) problems. A good starting point for the interested reader is a paper published by Exeter University (Dragan A Savic, Godfrey A Walters, Martin Schwab, 1995). Related techniques such as swarm optimization (C. Wegley, M. Eusuff and K.E. Lansey, 2000) and simulated annealing (R.S. Powell, and G McCormick, 2004) have also been successfully applied to theoretical problems. Typically energy cost savings of 10%, 15% or more are predicted. The GA approach uses a hydraulic model to trial likely pump schedules but has sophisticated tools to guide the schedules towards useful results meaning that only a few hundred thousand or million combinations may need to be tested to find suitable schedules. The problem has always been one of implementation of these systems into real-world applications. Solutions based on GA have always suffered from relatively slow speed of solution, especially in systems with more than a trivial number of pumps, as even fast computers take time to run millions of hydraulic simulations. More recently the European based Potable Water Distribution Management (POWADIMA) project has looked at speeding up some of the bottlenecks in solving this type of problem through the use of Artificial Neural Nets (ANN). These solve the hydraulic equations thousands of times faster than a hydraulic model can. In one study, (Zhengfu Rao and E.Salomons, 2007), modelling a modest sized system for Valencia in Spain that includes seventeen pumps, and using standard PC hardware, solutions were arrived at in about ten minutes.

Solutions to optimise pump scheduling and also integrate energy efficiency have remained elusive. Our solution, AquadaptTM, avoids GA techniques in favour of the speed of Linear Programming combined with heuristic and non-linear formulations (Bunn, 2005). This software also explicitly models pump efficiency based on live (i.e. real-time) data. Solution times for systems with up to 200 pumps are arrived at in less than 2 minutes.

Optimising Pump Schedules with explicit incorporation of efficiency

Scheduling for electricity tariff alone only achieves part of the savings available. In the four US sites discussed in this paper up to 40% of annual energy cost savings was found to come from efficiency gains. To incorporate efficiency information into a solver we first need a methodology to accurately model efficiency over the expected operating range of each pump.

To be able to effectively operate pumps close to their best efficiency point as well as to track significant deviation from the manufacturer's curve, an energy management system should have the capability to calculate actual pump head/flow curves and system curves in real time and then match the best available pump or selection of pumps to the current instantaneous duty. If a pump only needs to run 8 hours in a day to satisfy demand and replenish storage then this permits operational flexibility as to which hours to use during the day. There may be a requirement to have no more than a designated number of starts per day per pump, but even with these constraints there can be significant flexibility.



▶ *Figure 1: Pump curves for a single pump and two identical pumps running together*

Shown in Figure 1 are the pump curves for a single pump and for two of these pumps operating in parallel. These are actual plots obtained from a Californian water utility. The corresponding efficiency curves are also given. Actual telemetry data, after validation, has been overlaid as the black "x" marks clustered on each line. Note that two pumps working together do not give twice the flow of a single pump, as the higher flow creates higher back-pressure through frictional losses in the pipes which make the pumps operate higher on their curves (i.e. the operating points move up in pressure and to the left on flow). One pump was recorded as operating between 40 and 60 feet of head but two pumps operated between 65 to 100 feet of head as a result of the increase in flow rate creating increased back-pressure. Note also that the black 'x's indicating telemetry value are not a single point but cover a range on the pump curve., This is the effect of changing diurnal demand and static lift changes such as changing level in the destination storage tank. Operators tended to use a single pump most of the time under the basis that they got 6 MGD of flow from the one pump but only 10 MGD from two pumps. Their reasoning was that the "missing 2 MGD" meant using one pump was a better operating regime. However careful review of the chart shows that using two pumps is almost always significantly more efficient that operating one pump. Pump efficiency is measured off the dotted lines by tracing upwards from the points on the solid line, so in this case using one pump has an efficiency range of 60% to 74% while using two pumps has an efficiency range of 75% to 88%. So the operators reasoning in this case is misleading, operating of two pumps being more efficient than operating a single one, despite the increase in dynamic head and hence requiring less net energy to move the same quantity of water. Even this simple example illustrates that experienced operators would have difficulty in determining what combination of pumps would meet production requirements at the minimum cost expenditure. The situation facing the operator becomes even more complex where stations have multiple pumps, with differing sets of pump curves.

Results from four case histories

Derceto Aquadapt™ software is a real-time operations optimisation program that attaches to a SCADA system to fully automate a water distribution system. It continuously reads live data from the SCADA system including current storage levels, water flows, and equipment availability and then creates schedules for treatment plant raw and finished water flows, pump operation, variable speed drive settings and automated valve setpoint schedules throughout the system for the next 24 to 48 hours. It can achieve a solution within two minutes, even for a system inclusive of hundreds of pumps. Every half an hour it runs again to adapt to changing conditions, primarily demand changes and equipment failure. Controls are automatically initiated by Aquadapt via the SCADA system allowing for fully automated unattended operation of even very large distribution systems. The first system was installed in Wellington, NZ in 2000. The first Australian system went into Maroochy Water Services on the Sunshine Coast, QLD in late 2005.

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The first US system went live in July 2004 for East Bay Municipal Utility District (EBMUD) in Oakland California. This was followed by systems installed for Washington Suburban Sanitary Commission (WSSC) in Maryland, Water District No. 1 of Johnson County (WaterOne) in Kansas and Eastern Municipal Water District (EMWD) of Southern California. Each system imposed unique challenges in creating a real-time water distribution optimisation solution to reduce operational costs, mainly energy, in widely varying physical distribution systems. Significant customisation was required for each implementation. Table 1 presents some indication as to the relative size and complexity of these systems.

Table 1: Statistics for Four US Utilities

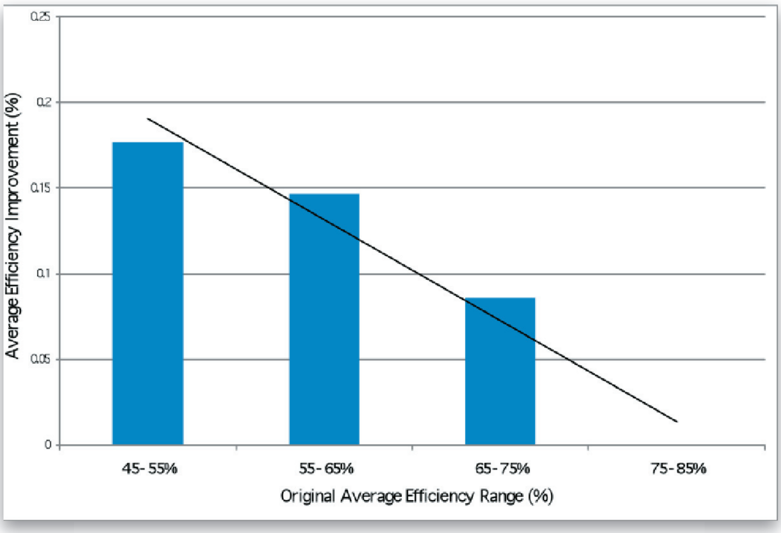
Customer System	Pop. Served	Storage tanks	Pressure zones	Pump Stations	Pumps	Auto Valves	Demand (MLD)
East Bay MUD, CA	660k	28	26	20	66	4	160 to 480
Eastern Municipal, CA	630k	68	44	58	143	9	333 to 643
WaterOne, Kansas	570k	25	3	26	84	11	190 to 400
Washington Suburban, MD	1.6m	57	15	18	81	25	640 to 900

At all four systems, energy efficiency improvements of between 6% and 8.4% overall were realised. For each US State where Derceto Aquadapt operates we obtained greenhouse gas data from public records. More data on greenhouse gas contribution of fuel types is being generated in the US as a consequence of state initiatives due to concerns on climate change. This is particularly evident in California, where Governor Arnold Schwarzenegger has made greenhouse gas reduction a state-wide mandate and introduced Assembly Bill 32 (AB32). Other states are following suit in the absence of a clear directive at the federal level. The greenhouse gas (CO2) reductions achieved by Aquadapt are shown in Table 2 below.

Table 2: Energy efficiency improvements achieved for four US clients

Customer System	Average MWH per Year	Average Efficiency Gain under Aquadapt	EPA eGRID 2004 CO2 Emissions (Tons/MWh)	Extrapolated CO2 Reduction per Year (Tons)
East Bay MUD, CA	26,000	6.1%	0.502	800
Washington Suburban, MD	7,000	8.4%	0.515	300
WaterOne, Kansas	99,000	8.3%	0.547	4,500
Eastern Municipal Water District, CA	94,000	6.0%	0.845	4,800

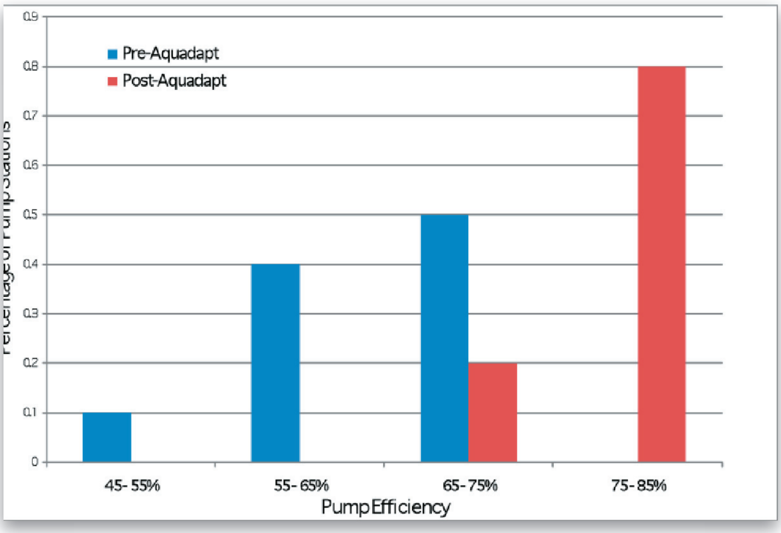
In Figure 2 we have categorised the original pump efficiency into ranges for East Bay Municipal Utility District (EBMUD) in Oakland California. This is based on 6 years of data, two years prior to Aquadapt and four years post Aquadapt. This dataset contains over 600 accurately measured monthly energy and flow data points. The first group is all pumps that were running at 45% and 50% original efficiency, then all pumps between 55% and 65% and so on. The Y Axis shows the efficiency improvement after Aquadapt and as you can see there is a close to linear relationship. Pumps that were running at lower efficiencies made the most efficiency improvements (about 18% on average gain in the first group for example) whereas pumps that were relatively new and performing well, i.e. in the 65% to 75% range showed a 9% improvement after Aquadapt.



▶ *Figure 2: Efficiency improvements versus original efficiency in EBMUD*

If we plot the number of pumps by efficiency range both before and post Aquadapt the results are very interesting.

▶ *Figure 3: Efficiency improvement in pumps at EBMUD*



In Figure 3 the big improvements in the least efficient pumps means that now no pump runs below 65% efficiency whereas before Aquadapt there were many pumps operating between 55% and 65% and half running between 65% and 75% efficiency figures. None were running at better than 75% yet now 80% of pumps and pump stations are achieving this outcome, all done purely through Aquadapt software selecting the right pump or pumps at the right time. This is made possible by Aquadapt's real-time optimiser being able to deduce the moving system curve responding to changing diurnal water demand.

Variable Speed Pumps

The special case of variable speed pumps is also explicitly solved by Aquadapt using a patent-pending technique. Variable speed pumps were promoted as a method of better matching a pump's performance to its duty requirements by altering the speed of the pump and thereby altering its pump curve. In theory this should improve efficiency, especially in the case of over-sized pumps which generate excessive head and flow. The reality is that in many of the variable speed pump installations analysed the vast majority operated less efficiently than was the case for installations consisting of fixed speed pump stations.

In one particular example in the United Kingdom we found that two operators ran the same variable speed pump differently; one preferring 60m of discharge head and the other 66m. The first achieved an average efficiency of 40%, while the second achieved an average efficiency of 66%. It must be noted that neither operator was aware of this fact since efficiency information was not available to the operator.

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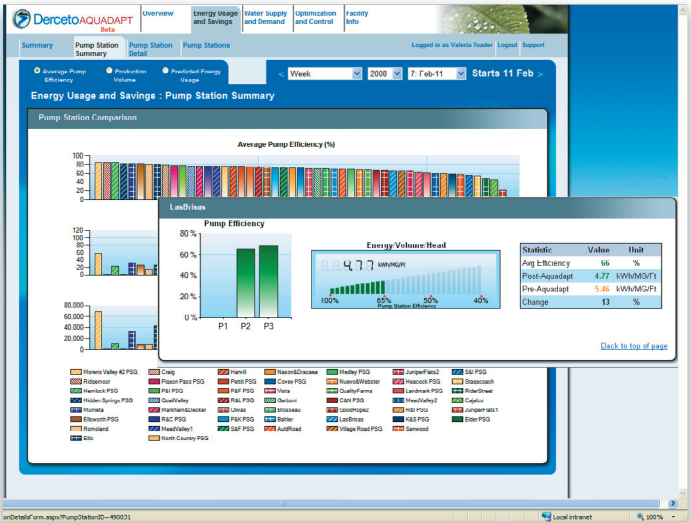
Displaying Pump Performance Data

Presenting continuous efficiency information for pumps is expensive. Aquadapt carries out calculations in real time to determine how each pump is operating. It is useful to display this information in suitable formats to accommodate both real time viewing for system operation and for analysis of historical performance. The Aquadapt Dashboard fulfils these requirements.

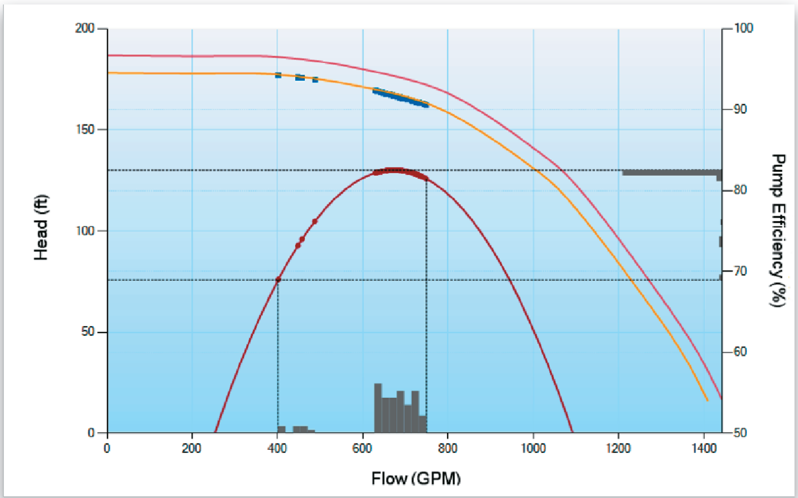
▶ *Figure 4: Drilling in to the data for one pump station to see 1 week of operation on the Dashboard*



Statistic	Value	Unit
Avg Efficiency	66	%
Post-Aquadapt	4.77	kWh/MG/Ft
Pre-Aquadapt	5.46	kWh/MG/Ft
Change	13	%

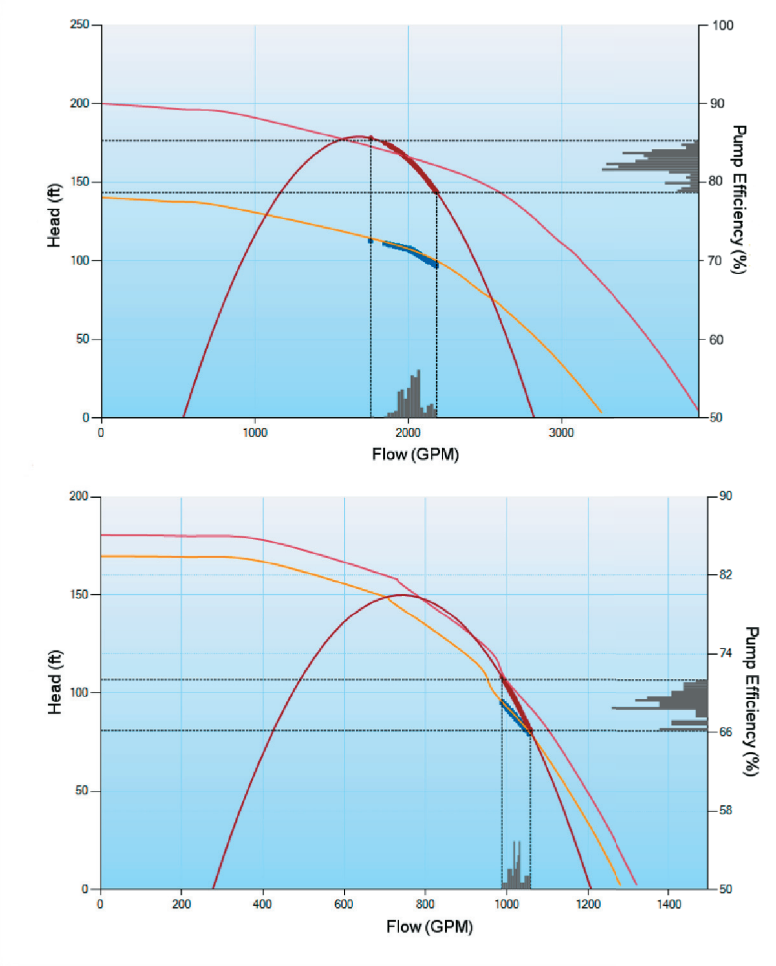
Figure 4 above is a typical dashboard screen, running as an Intranet web page displayed using Internet Explorer. This particular page shows operational data for all pump stations, as a bar chart ranked from the most efficient station to the least efficient. You can easily understand how useful this data is in asset management planning. By holding the cursor over a bar a pop up appears to display individual pump data. In this example only pumps 2 and 3 were operated during the course of the week. As you can see pump 3 operates a little more efficiently than pump 2. The best measure of energy is the kWh/MG/ft of lift. This pump station is operating at 4.77 kWh/MG/ft or 66% efficiency. This efficiency is quite typical based on the hundreds of pumps we have analysed. Operational efficiency of the pump before implementation of Aquadapt is also displayed based on the average of the previous 2 years prior to Aquadapt. For this week the pumps have run 13% more efficiently than did prior to Aquadapt. This data all generated with a single flowmeter for the whole pump station and only discharge pressure being read.

▶ *Figure 5: Real-time pump curve displayed on Dashboard display screen*



Having exposed this level of performance data for the pump station the Dashboard goes even deeper and shows actual performance of each pump. In Figure 5 actual operation of a single pump for one week is displayed. The manufacture's curve is the upper pink line. The calibrated pump curve is shown as a yellow line. Actual measured operating points at differing Total Dynamic Head (TDH) are shown as dots on the curve, each dot representing half an hour's operation. The red parabola is the efficiency curve. The red dots on the efficiency curve match the operating points on the pump curve. The histograms at the bottom and side of the graph summarise frequency of operation at each point. In this case, efficiency values are clustered at the top end of the efficiency range, a good sign that Aquadapt is working well.

▶ *Figure 6: Two nominally identical pumps operating differently*



In the real-life example shown in Figure 6 above we see a quite different picture. Although the two pumps at this station are nominally the same size and capacity, as shown by the manufacturer's pink curves, one is worn much more than the other as evidenced by the yellow calibrated pump curve for pump 1. Even though this pump shows significant wear it actually operates well as shown by the efficiency histogram. Pump 2 with less wear should be expected to be the better pump to operate, yet it is poorly matched to the duty and is 'running off its curve' at less than 70% average efficiency. Without a visualisation tool all of this is hidden from the operator, the client and the engineers.

Conclusions

The benefits of optimal pump scheduling, both to minimise operational costs and net energy consumption, long a theoretical objective and the subject for academic research, is now achievable in practice. In the changing focus on climate change it is foreseeable that energy efficiency improvements could be more valuable to the utility and indeed the environment, than cost savings through load management.

The US water utilities use approximately 50 million MWh of electricity to pump potable water. A reduction of 6% to 10% in this energy consumption through efficiency improvements would therefore lead to saving between 3 and 5 million MWh of electricity production per year. The US average CO2 emission per MWh of electricity production is about 0.5 tons. The potential CO2 reduction therefore, is between 1.5 million and 2.5 million tons. This is certainly not inconsequential and provides another compelling reason for water utilities to consider operations optimisation.

THE AUTHOR

After graduating with a Bachelor of Engineering (Electrical) Simon spent the next 21 years in control systems design, rising to become a partner in The Beca Group in 1999. In 2000 Simon used his experience of control systems and water treatment processes to design the complex software at the heart of the Aquadapt product, the world's first commercially available real-time pump scheduling optimiser. In 2002 Derceto software for Wellington City was judged the top engineering project in New Zealand by ACENZ. In 2005 he was named the "Engineering Entrepreneur of the Year" at the New Zealand Engineering Excellence Awards.

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REFERENCES

Bunn S., (2005) "Optimal pump scheduling for East Bay Municipal Utility District, Oakland, CA, using the Derceto package", CCWI'05, Exeter, UK,

Savic D, Walters G, Schwab M. (1997). "Multiobjective Genetic Algorithms for Pump Scheduling in Water Supply". London, UK : Springer-Verlag, ISBN:3-540-63476-2.

European Commission, 2001 "Study on improving the energy efficiency of pumps", February, AEAT-6559/ v 5.1

Mackle G., Savic D. and. Walters G, "(1995).Application of Genetic Algorithms to Pump Scheduling for Water Supply", GALESIA'95, London,

Powell R S and McCormick G (2004),. "Derivation of near-optimal pump schedules for water distribution by simulated annealing". Journal of the Operational Research Society, Vol. 55, pp. 728-736.

Sotelo L, von Lücken C., Barán B.. (2002) "Multiobjective evolutionary algorithms in pump scheduling optimisation'', Proceedings of the third international conference on Engineering computational technology, Stirling, Scotland, Pages: 175 - 176,

Wegley C., Eusuff M. and Lansey K. E.. (2000). "Determining pump operations using particle swarm optimisation". [ed.] R.H. Hotchkiss and M. Glade. Minneapolis, USA : s.n., Proceedings of the Joint Conference on Water Resources Engineering and Water Resources Planning and Management.

Rao Z. and Salomons E., (2007) "Development of a real-time, near-optimal control process for water-distribution networks", Journal of Hydroinformatics Vol 9 No 1 pp 25–37

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