Energy Savings Analysis Generated by a Real Time Energy Management System for Water Distribution

Sarah Thorstensen
Derceto Ltd, Auckland, New Zealand
sthorstensen@derceto.com

Abstract

Washington Suburban Sanitary Commission (WSSC) purchases the bulk of their $19M energy spend on the real time Pennsylvania Jersey Maryland (PJM) Interchange. A substantial portion of this is used for treatment and distribution of potable water. In 2006 WSSC installed Derceto Inc's Energy Management System to control electrical load at all points in the potable water treatment and distribution system to manage and where possible reduce the cost of energy purchases. The real time energy market offers considerably lower cost energy over-night compared to peak times during the day so load movement can lead to substantial savings. The energy management system also makes savings in efficiency, where less kWh are used to move the same volume of water through improved operation of the pumps on their efficiency curves. The Derceto supplied system also takes maximum advantage of gravity favoring gravity flow valve stations over pumped stations where possible. The practical task of measuring energy kWh and dollar savings against a baseline proved to be one of the more difficult tasks during the project. Not only must the baseline be able to capture all these forms of savings, it also has the added complexity that water distribution systems are undergoing continuous changes, from equipment failures to new capital expenditure programs that can make it very difficult to measure savings where there is no "before" case to compare against. This paper describes the methodologies used for the development of an energy management system baseline and performance monitoring tool. Actual examples using real time and standard offer of service energy contracts are presented.

Keywords
Deregulated electricity market, real-time pricing, energy forecasting, electricity demand, energy load profile, water transmission, pump optimization, performance measurement

1. Introduction

Derceto software is a real-time supervisory program that attaches to a Scada system to automate a water distribution system with the primary goal of reducing energy costs. It reads live data from the Scada system on current storage levels, water flows and equipment availability and then creates schedules for treatment plant raw and finished water flows and all pumps and automated valves in the system for the next 48 hours. Every half hour it runs again to adapt to changing conditions, primarily water demand changes and equipment failure. Controls are automatically initiated by Derceto allowing for fully automated unattended operation of even very large distribution systems.

Typically electricity consumption is the second highest marginal cost, after labor, for water distribution companies. The price of electricity is also rising at a far higher rate than labor costs making it likely that it will become the dominant cost in production and distribution of water in the near future. The primary goal of an energy management system for a water distribution company is therefore to save energy costs for pumped water. The ability to measure those savings is important. Calculating the return on investment in energy management software is required to determine the pay back period and to reassure employees that their input to the project is and will continue to be valuable. Similarly it is a measure of success of the Derceto product for the suppliers Derceto, Inc.

In order to measure dollar savings for an energy management system it is usual practice to develop a baseline tool or methodology to try to recreate how the network had been operated prior to the installation of the system (calibration). This is then used post-implementation of the energy management system to estimate a baseline cost on a daily basis, i.e. how much it would have cost to deliver water if nothing had been done. Ideally the baseline methodology would take inputs from the current operation and output a resulting ‘before’ operation from the baseline period of time. The actual costs can then be compared to the baseline estimated costs to determine the savings generated.

In practice the design, development and application of this baseline methodology is more difficult than it appears to a casual observer. There are multiple factors that must be addressed during the creation of the baseline method to assure an accurate result during the lifetime of the energy management system. These factors are often initially underestimated. This paper discusses a number of examples to demonstrate a range of issues and solutions achieved.

2. Baseline Development

A ‘baseline period’ is usually defined as one to two years immediately preceding the installation of the energy management system where typical or ‘normal’ operation of the network occurred. It is important that all facilities in the distribution system are operable during a significant part of the baseline period. The main aim for developing a baseline methodology is to create an unbiased way to measure the post-implementation dollar savings generated from the energy management system. The baseline tool is generally desired to run automatically and create each month a kWh use and dollar cost report for each pump station detailing the energy use that would have occurred before the installation of the energy management software.

A baseline tool is usually developed several months before the installation of the energy management system to verify it can accurately predict the operation under baseline conditions that have not been previously observed. This time is referred to as the ‘verification period’.

The ‘operational period’ for the energy management system is the time during which it is installed and controlling pump stations and over which the energy savings are to be measured.

Inputs to the baseline development are

- Pump Station, Valve, Water Treatment Plant flow data in MGD
- Time of use Pump Station, Water Treatment Plant energy use data. This is usually available in monthly power bills summarizing kWh energy use and kW demand charges. If energy is billed hourly then hourly kWh data is required, similarly if energy is billed in tariff bands, details of energy use in each band are required.

Outputs from the baseline development are

- An equation or set of equations for each Pump Station and Water Treatment Plant that will convert the sum of flow data over a day in MG to kWh data in a way to match the historically recorded kWh.

The equations used to convert flow data to kWh data are non-linear however it is usually possible to fit a small series of linear regressions to accurately approximate the historical flow vs kWh data for each pump station. Figure 1, an example from a large East Bay Municipal Utility District (EBMUD) pump station, demonstrates this approach. The relationship between daily flow through the pump station and energy used in each tariff band can be approximated by a piecewise linear regression. Of note is the limit of Off Peak energy that can be used as pump flow increases as illustrated by the flattening of the Off Peak relationship line. The verification of this methodology over 11 months of data produced an accurate result to within 0.5% of the total energy bill costs.

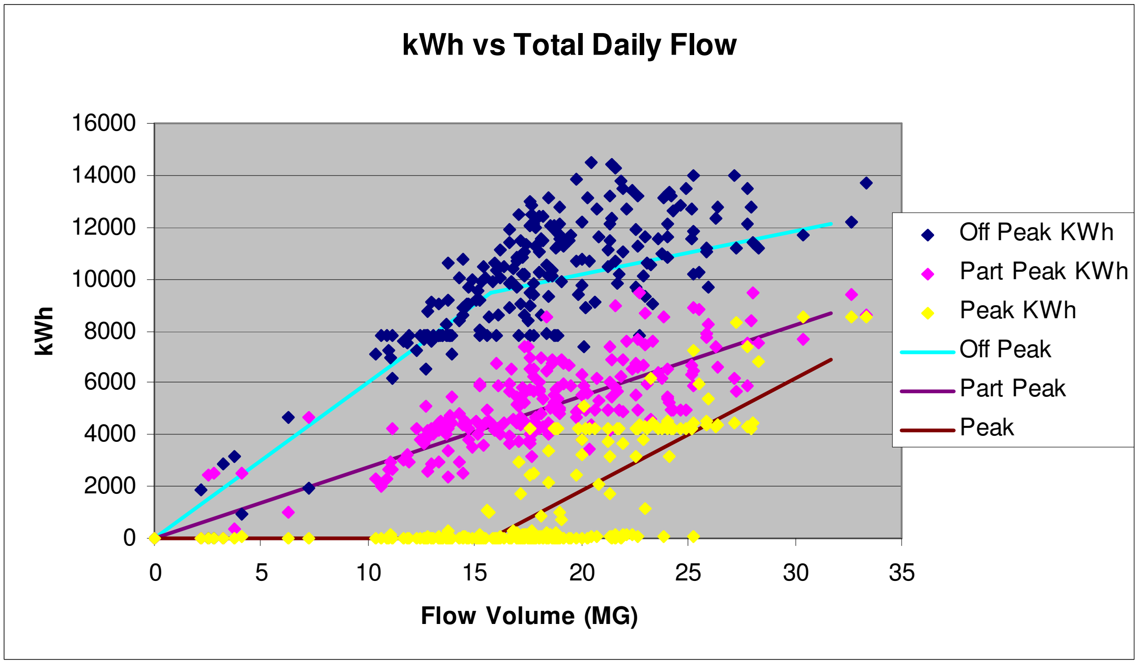

Figure 1: Example regression relationships between daily pump station flow and kWh used in each Tariff band

3. Issues Relating to Baseline Methodology

Developing a baseline methodology that accurately takes into account all possible variation in a water distribution network is not simple. There were several issues identified during the development of a baseline methodology at WSSC in 2006, and at EBMUD in 2004 during the installations of the Derceto energy management system. These are discussed below.

Energy Tariff Changes

A. Real Time Energy Tariffs

WSSC purchase more than 80% of their energy under real time energy pricing on the PJM Interconnection. The real time price changes every hour of the day and is subject to seasonal and annual variations. As the size of the PJM Interconnection has increased the prices have stabilized significantly because more generators have entered the market resulting in localized events having less effect on the local energy price. Effectively additional generators are able to take-up load requirements buffering users from short term generation shortages.

Because the average price of electricity changes every year it is not correct to measure savings based on last year costing $X and this year costing $Y to deliver the same volume of water. Instead a more detailed comparison that takes into account the hourly price of energy must be made. To create this comparison the kWh use profile on any day is compared to the kWh use profile that would have occurred in the baseline period. The difference in these profiles is multiplied by the real time price for each hour of the day to determine the savings on a day by day basis. Figure 2 illustrates an example of an hourly baseline kWh profile and actual kWh profile compared to hourly energy prices from the PJM Interchange.

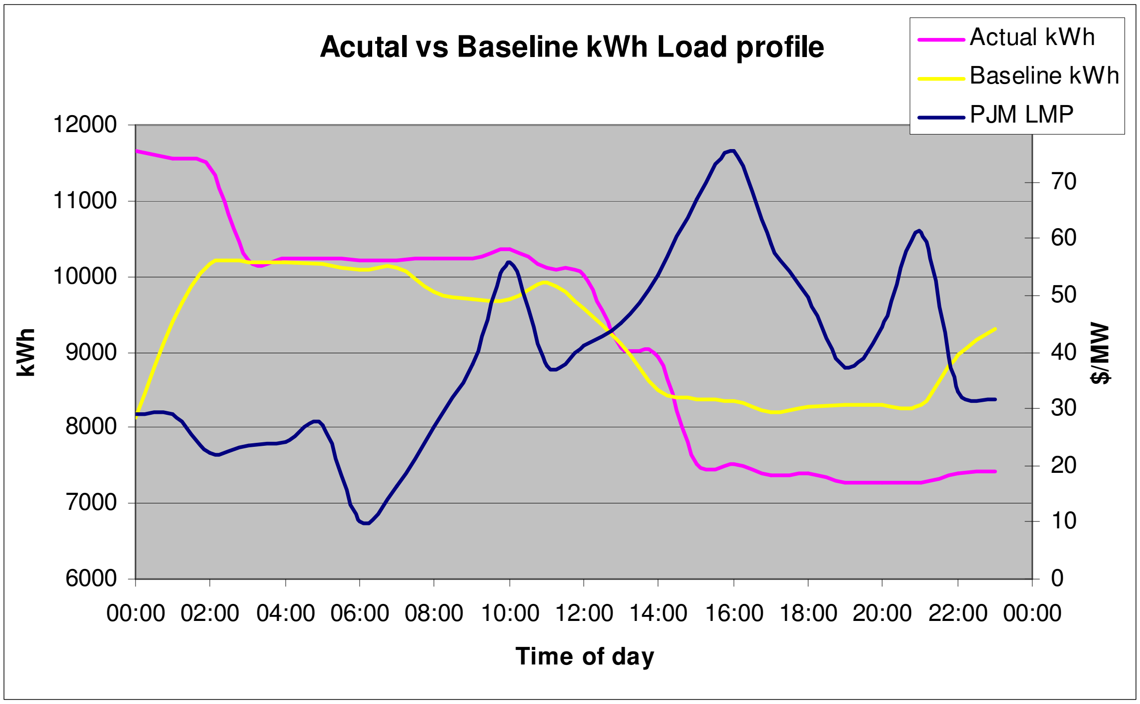

Figure 2: Illustration of Actual vs Baseline hourly kWh profile and PJM Real Time Price

B. Standard Offer of Service Energy Tariffs

Determining savings generated while using a standard offer of service tariff is more straightforward than for real time pricing. Energy providers revise standard offer of service tariffs regularly as markets change so any baseline methodology needs to account for these changes and revisions. Standard offer of service tariffs are usually set up in bands with peak, partial peak and off peak times of day with a different energy cost in each band.

To create a valid cost comparison when tariffs change the baseline energy kWh in each tariff time band is first determined based on the daily flow through the station this is then multiplied by the current tariff costs to result in the baseline dollar cost. This is next compared to the actual cost that occurred using the current tariffs from the energy bills.

Comparisons are more complicated when the time of day for each tariff band changes although this is a rare occurrence. For example if the peak energy tariff band changes from 2pm to 6pm to be from 3pm to 7pm the baseline methodology should account for the likely operational change that would have occurred in the baseline period had the change in tariff time band occurred then.

Demand Charges

Separate and distinct from energy charges which usually charge an hourly rate in $/kWh for energy use are demand charges which are usually a $/kW charge. Demand charges for standard offer of service tariffs can be generalized to typically charge

- Peak demand charge for highest instantaneous kW use during a peak time window

- Anytime demand charge for highest instantaneous kW use at any time of the day

These demand charges are often based on a 15 minute integrated kW measurement to prevent penalties for inrush current used during pump start up. The charge is usually based on the highest kW value recorded in a months billing cycle but in some cases is based on the highest recorded value over the previous 12 months making the demand charge a significant portion of the energy bill.

To estimate savings in demand charges a baseline methodology must determine the likely peak kW use at any time in a month. For fixed speed pumps this can be done using a statistical likelihood of the number of pumps run to supply a total volume over a day. Figure 3 shows the relationship between daily flow through a pump station with fixed speed pumps and maximum kW used.

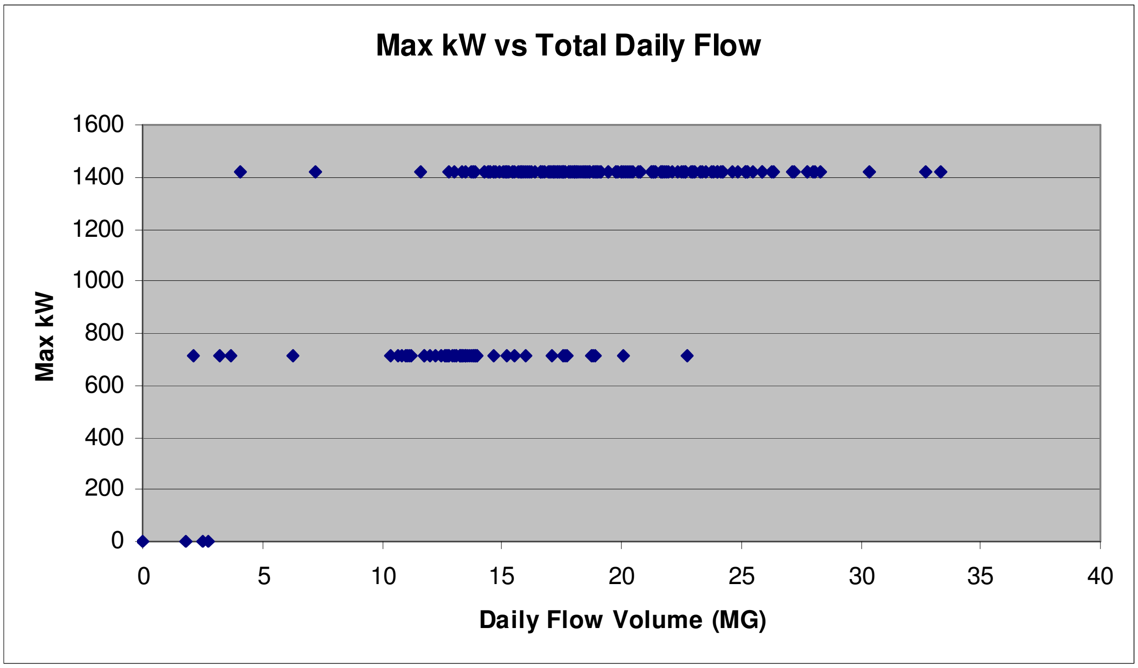

Figure 3: Example step relationship between daily pump station flow and max kW for fixed speed pumps

Efficiency Improvements

Derceto calculates the most efficient times of day to run pumps and determines which combination of pumps to run to maximize the volume of water moved through a pump station per unit of energy consumed. This is computed using pump and efficiency curves and identifying the best efficiency point [1] then choosing to run the pumps in combinations where this best efficiency point is utilized more often. Usually this result is measurable by comparing kWh usage per MG of water delivered using a linear regression type method as illustrated in Figure 4.

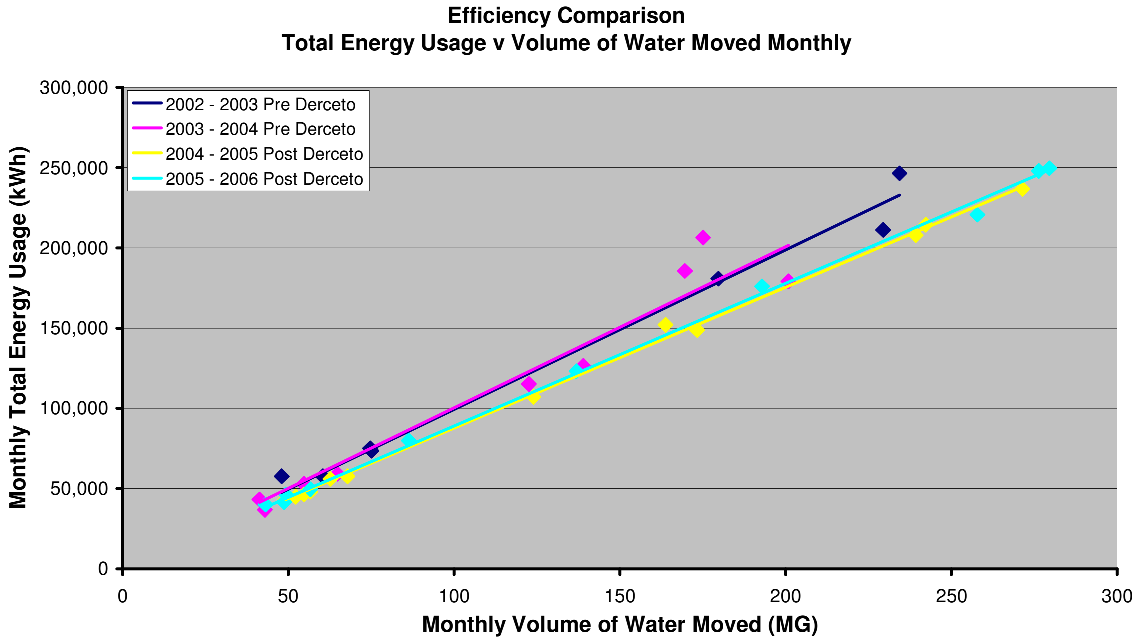

Figure 4: Illustration of Daily Pump station flow and total kWh before and after Derceto installation

Several Pump Stations Using One Electricity Meter

If there are several pump stations whose energy usage is recorded by one meter it can be difficult to determine the baseline energy use at each station from the pump station flow data. The proportion of energy used by the different pumps could change during the implementation of the energy management system thus changing the dollars per MG water supplied over the stations on the one energy meter.

Additional complications occur when pumps at one station pump to different pressure zones. If the proportion of pumping to the higher zone increases compared to the lower zone the energy use will increase per MG pumped, and conversely if more water is pumped to the lower zone less energy is used per MG. This is because pumping over a higher head is more energy intensive than over a lower head.

Gravity Supply and Shortest Flow Paths

Derceto utilizes gravity flow rate control valves to their maximum extent. Supplying a pressure zone through a rate control valve costs nothing compared to supplying it through a pump station. The difficulty in measuring the savings generated from this effect is that because a valve station would use no energy in the baseline period and will also use no energy in the operational period power bills for the valve station can not be compared. Instead when flow is moved from a pump station to a rate control valve the baseline methodology needs to account for the flow that would have been supplied through the related pump station in the baseline period. Figure 5 illustrates the increase in gravity supplied flow on days where total water supply is low enough to provide flexibility in valve use.

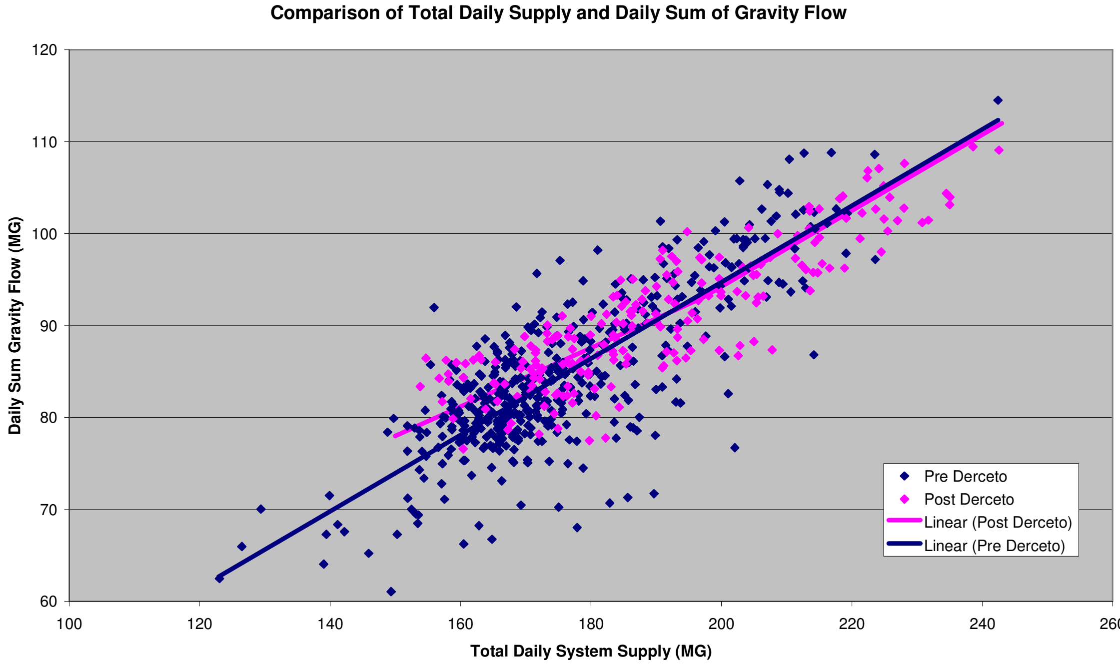

Figure 5: Illustration of Derceto using more Gravity supplied flow than pumped flow up to the limits possible when total water supply increases

Derceto naturally finds the shortest path to supply water to the distribution network reducing the number of times water is pumped to reach its final destination. This is illustrated in Figure 6 which shows total daily water supply from all sources (MG) vs volume of water pumped through pump stations during the day. On average each MG of water is pumped just less than twice before being consumed by customers.

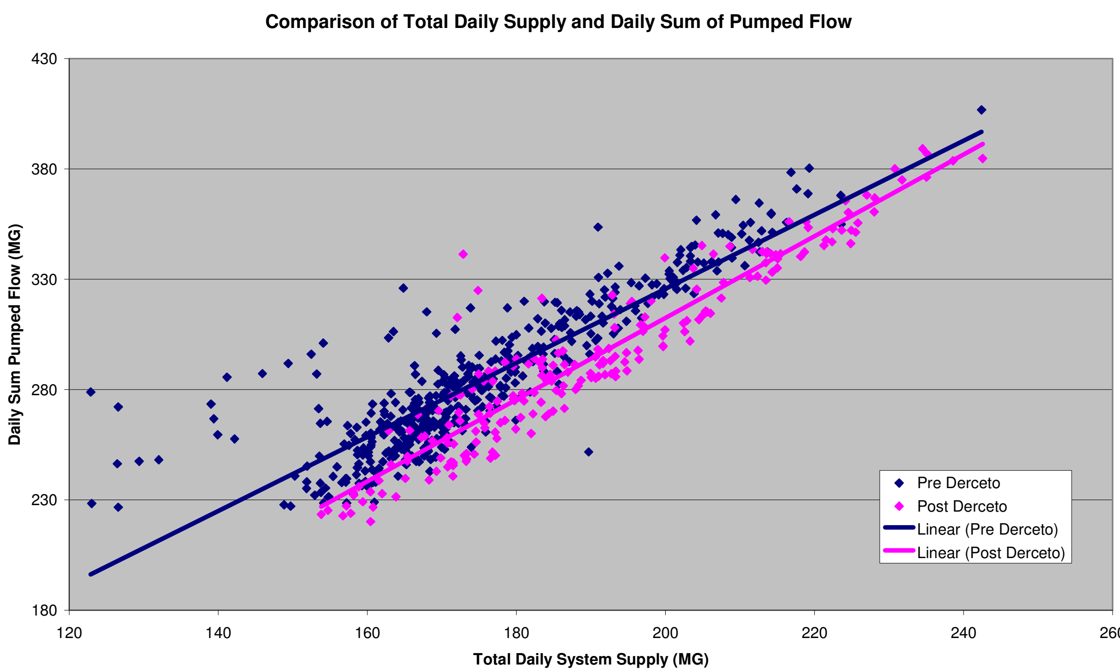

Figure 6: Illustration of Derceto using less pumped flow than in the baseline period

Moving Load Between Two Parallel Pump Stations

If two alternate routes for water exist in a network an energy management system may take advantage of the cheaper or more efficient route and in the extreme choose not to use an expensive station at all. In this case if baseline energy use at the station is calculated from the flow through the station (zero) the baseline energy use will be zero even though the station would have been used on any similar day in the baseline period. When comparing actual and baseline energy use at the station based only on flow through that station the savings are not recognized. Where these alternate paths exist it is best if the baseline methodology captures the baseline operation of each station based on the sum of the water supplied through the different paths.

Another way to look at this issue is to determine the baseline operation of each pump station based on the total daily supply of water into the network. This assumes that on a high water demand day where more water is produced and distributed the operation of each pump station is consistent to other high water demand days. This option more accurately attributes cost savings from load substitution from one pump station to another to the energy management system.

Equipment Failures, Maintenance, Capital Expenditure and Operational Changes

It was noted above that the baseline period should be based on a period of time where normal distribution system operation was observed. In reality this may be impossible to find as water utilities are continually modifying operation to cope with scheduled maintenance, unscheduled maintenance, capital expenditure, new facilities, upgrades and replacements.
Some examples of changes in the physical availability of facilities and how they may affect a baseline methodology are outlined below.

A. Pump Station out of Service

If a pump station is completely out of service in the baseline period there will be no record of the operation of the facility 'before' the energy management software installation. If the station is of significant size its operation should be estimated. One alternative is to assume the flow for the station is part of another station that could supply the same zone and adding the flows and energy use for the two stations together when analyzing savings.
When a pump station is out of service after the installation of the energy management system whereas it was normally available during the baseline period the consequences need to be considered. If there is an alternative station that can be used to move the water the increase in flow through this station should be possible without creating bias in the baseline methodology.

B. New Pump Station or Treatment Facility

When a new pump station is bought on line during the operation of an energy management system there can be no basis for baseline energy use at that station. It is simply not practical to turn the energy management system off for a year to determine how the new station would be operated in relation to the other stations in the baseline. Even less desirable is additional cost incurred from not using the energy management system during this time. A more reasonable option is to estimate savings by assuming the flow through the new facility is supplied as previously by another station. This option will only be slightly biased towards positive savings as a new station is likely to be more efficient than an older one.

C. Large Operational Changes

Occasionally events will occur in the operation of a water distribution utility that could not have been foreseen and affect the baseline methodology. In these rare cases there should be a simple process to follow to agree the likely affect on the baseline results rather than re-write the entire baseline methodology to account for a one off event. It can be advantageous to agree to use a pervious normal month of operation savings results instead of those in the month affected by the event.

One example event that had a significant affect on the baseline at EBMUD was the change in winter operation of the network. Additional bulk water was supplied through the network to another network for four months in winter. This operation effectively doubled the normal water production during those months and caused flow rates that had not been observed during the baseline period. It was simply agreed to use the baseline savings results from a normal winter month of 9% and extrapolate this result to the four months of changed operation.

Data Verification

Although it is desirable for a baseline methodology to be automated to reduce the time taken each month for data input and collation it is still important to undergo some form of regular verification. There are some simple events that can cause baseline results to be unreliable. These include raw flow data drop outs which can only have a negatively biased effect on the savings calculations. If flow is recorded as zero when the pump is actually running the kWh use will still be recorded by the energy meter resulting in what will look like high kWh per MG water supplied over a month. It is preferred if the flow data is used in conjunction with the pump on/off status data. Some automated data verification methods exist however the best results are achieved by eye-balling the flow and pump on/off status data in graphical format then back filling in missing or erroneous data with typical or average data.

If the process of verifying the data and results of a baseline tool can be incorporated into the original design labor costs can be reduced during the implementation of the baseline tool.

Derceto expects to produce energy savings from 10% to 20% of the total energy bill so an error of only 5% in the calculation of these savings can be significant.

4. Case Study – Water Utility Utilizing Real Time Energy Pricing

During the installation of the Derceto energy management system at WSSC in 2006 several events occurred that affected the development of an accurate baseline methodology.

A large 96" pipeline on the discharge side of the largest pump station in the network was closed for maintenance for a one month period. This closure had the effect of limiting the maximum flow through the station and limiting the ability of Derceto to move energy load and save on energy at this station. As a result it was agreed to begin the baseline analysis of savings after the pipeline was repaired and back in service.

Another significant event was the scheduled shut down of a medium sized pump station for seven months. The station was operating normally in the baseline period so modification of the baseline methodology was required to account for the substitution of the flow from the out of service station to another more expensive station. This was the only remaining way to supply the pressure zone. The baseline methodology was changed from determining pump station baseline flows from daily pump station flow to looking at the daily system water supply. This changed the baseline flow for the out of service station from zero flow to flow comparable with that used in the baseline period. As a result Derceto was attributed a savings credit for not using this station which partially balanced with the additional cost of using the alternative station to show an overall positive system wide savings.

5. Case Study – Water Utility Utilizing Standard Offer of Service Energy Pricing

The Derceto energy management system was installed at EBMUD during 2004. EBMUD purchase energy using standard offer of service tariffs from their supplier. The tariffs have off-peak, part-peak and peak time bands.

Several of the EBMUD pump stations have changed tariff rates from a flat daily rate to a time of use rate with peak, part peak and off peak charges. In these cases it was assumed that the operation of the stations would have remained the same as in the baseline period if the rate change had occurred during the baseline period so no modifications to the baseline methodology were required.

The baseline methodology at EBMUD is a set of equations for each pump station which convert the total daily flow through the station to kWh and peak kW that would have been used in the baseline period in each tariff band that day.

Over the first two years of Derceto operation at EBMUD the baseline methodology developed for the project has successfully demonstrated savings of over $700,000 attributed to load shifting and energy efficiency improvements. The movement of energy from expensive peak and part peak energy bands to off peak after the Derceto installation is illustrated in Figure 7 .

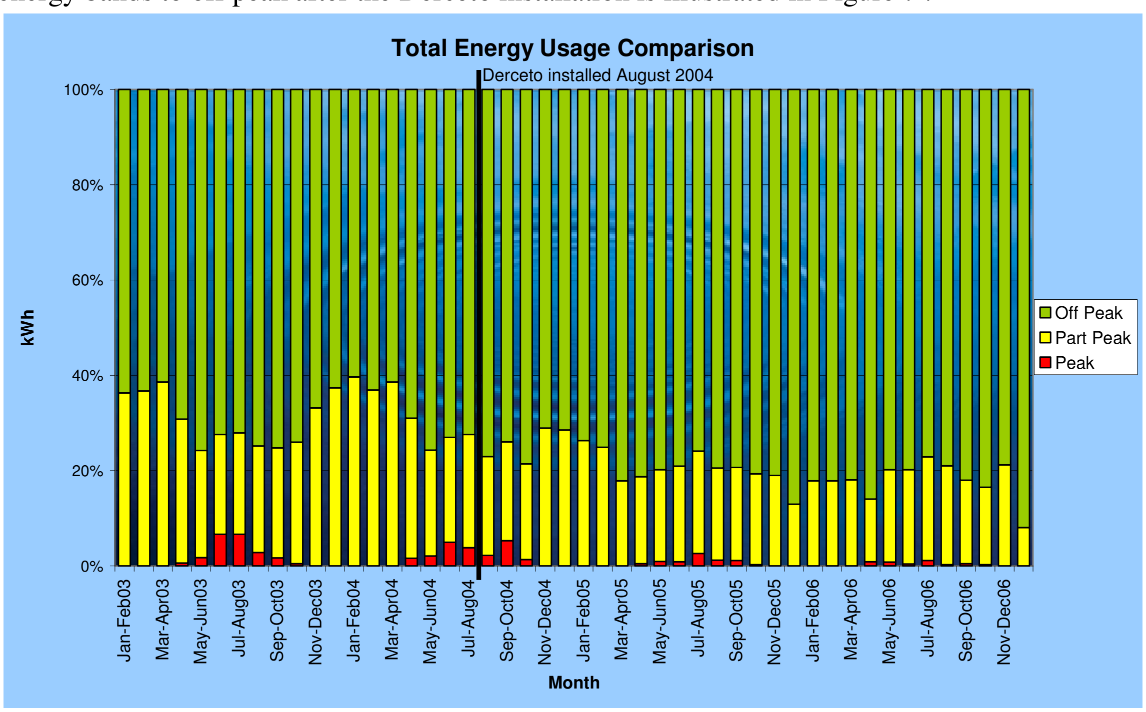

Figure 7: Illustration of Derceto kWh load movement from peak and part peak to off peak at EBMUD

6. Conclusion

A baseline methodology is a desired way of measuring savings for an energy management system to determine return on investment and success of the systems goals.

Developing and applying this methodology is not as simple as ‘calculate what it would have cost last year and the difference is the energy savings’ for several reasons.

- Energy prices are continually changing. On the real time energy market the energy price changes every hour forcing the baseline methodology to take detailed hourly data into consideration.
- The energy management system aims to increase efficiency by using less kWh to move the same MG of water.
- Gravity flow and shortest paths for water distribution will be utilized.
- Electricity and flow meters are not always physically configured to capture the ideal information at each site.
- Networks change, maintenance and upgrades and changes to operational procedures occur.
- Data must be verified during the operational period.
- Occasionally agreements will be required where unforeseen circumstances significantly affect the baseline results and no automatic way of handling them exists. The right to negotiate needs to be maintained in these cases.

7. References

[1] S. Bunn and C. Hillebrand, Energy Management in a Deregulated Market, AWWA Annual Conference and Exposition, San Antonio, TX, June 2006.
[2] S. Bunn, Pump Scheduling Optimization in Four US Cities: Case Studies, 8th Annual Water Distribution Systems Analysis Symposium, Cincinnati, Ohio, August 2006.