

# GREENHOUSE GAS REDUCTION AS AN ADDITIONAL BENEFIT OF OPTIMAL PUMP SCHEDULING FOR WATER UTILITIES

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## Abstract

*Operations Optimisers, and their subset Pump Scheduling Systems for water utilities target load movement from peak to off-peak periods chasing the tariff differential to achieve energy cost savings. Derceto Aquadapt is a holistic solver and also chases energy efficiency improvements achievable from operating pumps at more efficient points on their pump curves. Energy efficiency gains of 6% to 11% have been consistently achieved in client installations. A side benefit of efficiency improvement is a consequent reduction in the Green House Gas footprint of the utility. These savings are not trivial; the US water utility could reduce its CO<sub>2</sub> footprint by 1.5 million tonnes per year or more. Savings from energy efficiency improvements and load management for 4 utilities are presented. These use the Derceto Aquadapt operations optimisation software package, a complex real-time and fully automatic production, pump and valve scheduling system designed to minimize energy cost while maintaining water quality. .*

## Keywords

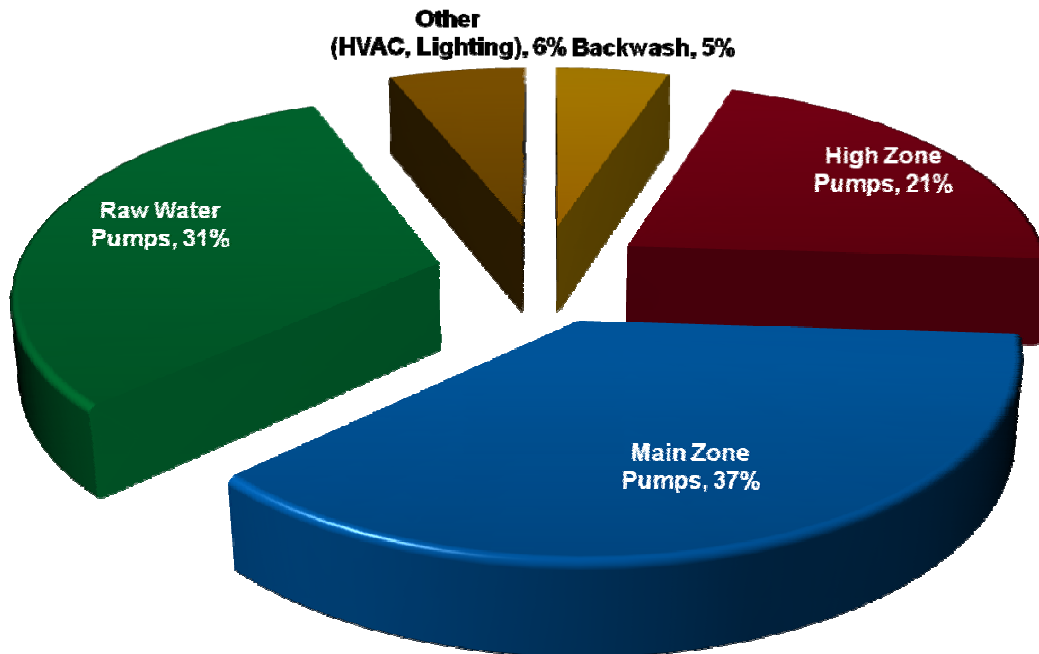
Green house gases, pump scheduling optimisation, carbon footprint

## 1. INTRODUCTION

Total US electricity production for 2006 was 4,104,900,000,000 kWh according to the CIA World fact Book. The more than 60,000 water systems and 15,000 wastewater systems in the United States are among the country's largest energy consumers, using about 100 million MWh/yr nationally – about 3 % of the annual U.S. electricity consumption.<sup>1</sup> Pumping is the prime user of power, typically 90% to 95% of the total energy purchases for water utilities are used by pumping plants. Water demand tends to peak in the same diurnal profile as energy demand thereby increasing the need for pumping during peak energy periods and consequently increasing the need for less efficient electricity generators to enter the market to supply energy. These tend to be high green house gas emitting thermal peaking stations driven by coal, diesel, oil or gas. During the off-peak night periods a greater proportion of energy production comes from base-load hydro, wind and nuclear power plants that have zero green house gas emission. Shifting energy use from peak to off peak therefore can significantly reduce the green house gas foot print of a water or wastewater utility with environmental benefits over and above cost savings achieved by purchasing cheaper energy.

Reducing this energy consumption for water and wastewater utilities through efficiency improvements of 6% to 11% would lead to a similar reduction in greenhouse gas emissions, with the actual tonnages dependent on the mix of fuel types used by each state. The US average CO<sub>2</sub> emission rate for electricity production is about 0.5 tons per MWh so a 6% reduction overall on the 100 million MWh would lead to a CO<sub>2</sub> reduction of 3,000,000 tons. Up to half of this is due to potable water treatment and pumping.

If we analyse how energy is used by a potable water utility we would find that typically 90% or more is used for pumping, the balance being offices, lighting and small power. Some treatment processes are energy intensive such as ozone generation and UV sterilisation but these do not feature widely in the US so we can assume a value closer to the 94% shown below (Figure 1) for a very large utility which uses the Derceto Aquadapt software.



**Figure 1 Typical electricity use by a Water Utility**

Given that at such a large percentage of the energy spend is on pumping you could assume that pumps are selected based on their efficiency. Unfortunately, this is not the case; a recent major EU study (European Commission, February 2001) found that 90% of the purchasing decision for pumps was based on the capital price of the pump with very little thought given to the operating efficiency of the pump over its lifetime.

With these three figures. The 50 billion kWh energy use for potable water, 94% being spent on pumping, and little consideration being given to pump efficiency it is likely that significant benefits could be achieved through energy optimisation of water distribution systems.

## **2. METHODOLOGY**

Derceto Aquadapt software is a real-time operations optimisation program that attaches to a Scada system to fully automate a water distribution system. 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. It achieves this in less than two minutes. Every half an hour it runs again to adapt to changing conditions, primarily demand changes and equipment failure. Controls are automatically initiated by Derceto allowing for fully automated unattended operation of even very large distribution systems.

In July 2006 a fourth implementation of the Derceto pump scheduling optimisation software was installed in the US. The first 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, WaterOne of Kansas City and Eastern Municipal Water District (EMWD) of Southern California. Each system imposed unique challenges in creating a real-time water distribution optimization solution to reduce operational costs, mainly energy, in widely varying physical distribution systems with significant customization required. The table below gives some indication to the relative size and complexity of these systems.

**Table 1 ; Statistics for Four US Utilities**

<b>System</b>	<b>Pop. Served</b>	<b>Storage tanks</b>	<b>Pressure zones</b>	<b>Pump stations</b>	<b>Pumps</b>	<b>Auto Valves</b>	<b>Demand (MLD)</b>
<b>East Bay MUD, CA</b>	660k	28	26	20	66	4	160 to 480
<b>Washington Suburban, MD</b>	1.6m	57	15	18	81	25	640 to 900
<b>WaterOne, Kansas</b>	570k	25	3	26	84	11	190 to 400
<b>Eastern Municipal Water District, CA</b>	375k	26	13	26	62	2	88 to 170
<b>Eastern Municipal (expansion system wide)</b>	630k	68	44	58	143	9	88 to 170

In addition to the physical complexity of the distribution systems each client system had a range of unique features to optimize. WSSC operate under real-time energy pricing, EMWD have gas reciprocating gas engine driven pumps in addition to electric pumps at most stations and WaterOne have only underground storage negating much of the ability to reduce electrical load through use of elevated storage to supply pressure when pumps are off.

### **3. THE OPTIMIZATION PROBLEM**

A great deal of research and effort has gone into solving the problem of scheduling production and pumps in water distribution systems. In the 90's a group of US utilities got together to promote the idea of an Energy and Water Quality Management System (EWQMS) under the auspices of the AWWA Research Foundation. This project led to a number of trials including two companies working with EBMUD and a Nevada water system amongst others. Unfortunately none were successful and all have been subsequently abandoned. There a few add-on packages for commercial hydraulic modelling programs that use evolutionary genetic algorithms to allow a competent engineer to make informed design decisions but none of these can claim to be targeting automatic real time control of a distribution system.

Most approaches to this problem show that significant electricity cost savings could be made through appropriate pump scheduling decisions; especially when multi-objective evolutionary algorithms (MOEA) are used (Mackle, Savic and Walters, 1995), (Savic, Walters and Schwab, 1997), (Sotelo, Lücken and Barán, 2002). Typically energy cost savings of 10%, 15% or more are predicted. The problem has always been one of implementation of these systems into real-world applications. Solutions based on MOEA have always suffered from relatively slow speed of solution, especially in systems with more than a trivial number of pumps. 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) to solve the hydraulic equations. (Zhengfu Rao and E.Salomons, 2007).

Although the Aquadapt algorithm, based on a linear programming, is proprietary its speed of solution is public domain. Now with four major installations in the US there is extra supporting data on the speed of solution and the achievement of the objective to reduce distribution costs. The solution speed is phenomenal, EBMUD solves a 24-hour schedule for half hour blocks in 53 seconds, WSSC do it in 118 seconds, Eastern Municipal in 47 seconds and WaterOne in 50 seconds. These are orders of magnitude faster than MOEA based systems. Computer hardware in all cases is identical, a relatively modest Dell 1850 rack mounted server with a single XEON 3GHz CPU and 2 GB of RAM.

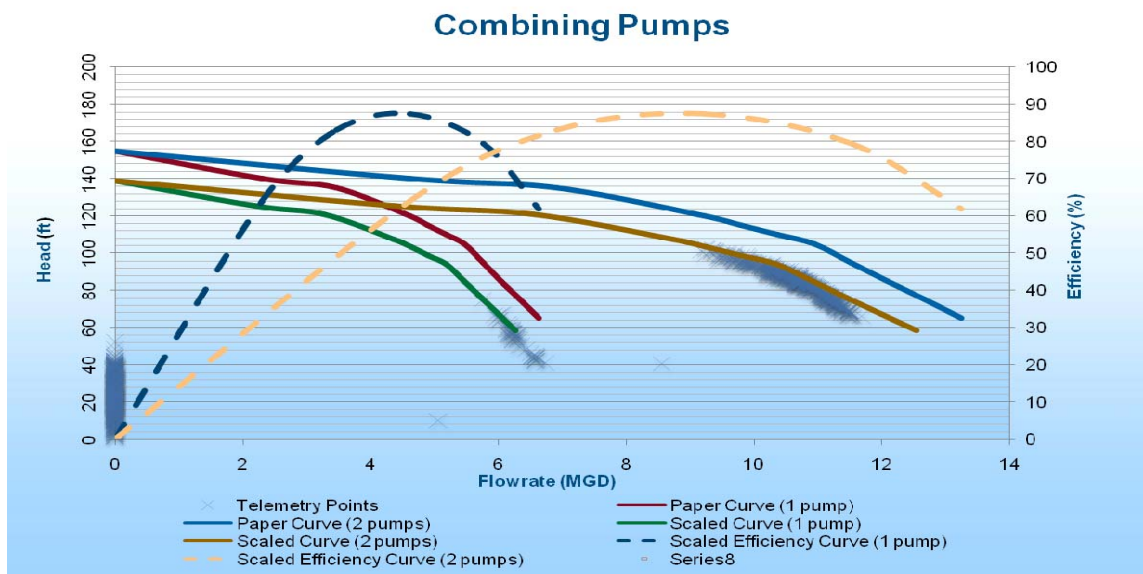
#### 4. AN UNEXPECTED OUTCOME

The Derceto Aquadapt solution is single objective, (being an LP), targeting the minimisation of cost for water production and transmission. It does this in five ways;

- Electrical load movement in time, to maximise utilisation of load tariff blocks
- Electricity peak demand reduction.
- Energy efficiency improvements from pumps and pumping plants.
- Utilisation of lowest production and chemical cost sources of water.
- Utilisation of shortest path between source and destination

Of these, energy efficiency improvements produced the most unexpected outcome. Aquadapt accurately models the non-linear hydraulics of pumps using EPANET. It is able to calculate the flow, efficiency and kilowatt hour consumption of each pump for each half hour block of time for the 24 hours ahead. It uses this information, primarily in the load shifting algorithm. However, where a utility has a differential in the tariff between peak and off-peak electricity cost which is relatively small, the solver often find it is better to improve operating efficiency at peak times rather than move load. Reducing consumption by a single kWh through efficiency improvements can be more cost effective than moving load between to time-of-use electricity tariff periods.

*In the figure above running two pumps together is 20% more efficient than running a single pump.*



**Figure 2 Pump efficiency for one pump and two pumps operating together**

This seems obvious in hindsight, but when first observed was surprising. Various pumps at pump stations would operate during peak energy periods, much to the consternation of the operators. It was only after analysis of the solution log files that it became evident that this was indeed the lowest cost solution due to the pumps operating at higher efficiency points during these times slots. Depending on the pump curve and system curve intersection it can be better to run more pumps when a destination tank is low and reduce pump numbers as the tank fills to constantly move the pump further to the right on their curve. Of course the converse can also be true if pumps are operating at the extreme right of their curve as shown in Figure 2.

There are of course benefits other than just simple cost savings from this strategy. It should be the goal of all water companies to improve the energy efficiency as good corporate citizens. Reducing the amount of kilowatt hours required to pump the same volume of water through improved efficiency also reduces the greenhouse gas footprint of the utility. The question then becomes "what auditable process can I use to determine greenhouse gas reduction through improved efficiency" and making sure that this process follows industry guidelines. The rest of this paper discusses the process we went through for four water utilities.

## **5. OBTAINING USEFUL ENERGY FUEL MIX DATA**

Each energy supplier uses a variety of generation sources to deliver electricity to the end user. Some sources such as Hydro generation, wind farm and nuclear produce negligible greenhouse gases. Highly efficient combined heat and power gas fired turbines produce somewhere between 0.3 to 0.4 tons of CO<sub>2</sub> per megawatt hour produced. Coal-fired stations, especially old technology stations, can produce as much as 1 ton of CO<sub>2</sub> per megawatt hour. Most energy utilities have a mixture of generation sources and their outputs are reported to various state and federal agencies. If the relative percentages of each fuel mix is multiplied by the CO<sub>2</sub> contribution of each fuel type an average CO<sub>2</sub> per kilowatt hour value can be derived. It is then relatively trivial to multiply the megawatt hour savings achieved through energy efficiency improvements by the average tons of CO<sub>2</sub> to produce a value for total CO<sub>2</sub> reduction.

For each 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 by state concerns on climate change. This is particularly evident in California, where Governor Arnold Schwarzenegger has made greenhouse gas reduction in state-wide mandate. Other states are following suit in the absence of a clear directive at the federal level.

There is no one official source, and the information was not readily available on the supplier websites. As a result, estimates were made using the Energy Information Administration's (tri-agency data from EPA, EIA & FERC) eGRID 2004 database<sup>ii</sup>. This had statistics on almost every power generation plant in the US in 2004, including annual figures for MWh production and CO<sub>2</sub> emissions. Groups of power plants were selected from eGRID that were relevant to each supplier that were operated by them or in their power control area. An average annual coefficient for CO<sub>2</sub>/MWh could then be calculated by dividing the sum total emissions by sum total generation.

## 6. SOURCING CO2 EMISSION DATA IN THE UNITED STATES

The table below documents, the source of data for each of the four US water utilities.

Client	Electricity Supplier	Source of Emissions Information	Year of emissions estimate
EBMUD	Pacific Gas & Electric Company	California Climate Action Registry	2005
EMWD	Southern California Edison	California Climate Action Registry	2005
WaterOne	Board of Public Utilities (BPU)	US Environmental Protection Agency's Acid Rain Program	2005
	Kansas City Power & Light Co (KCPL)	KCPL 2006 Environment Report	2006
WSSC	PJM Interconnection	PJM Environmental Information Services	2006

Unfortunately, we found that differing sources of information gave conflicting values for CO2 emissions. Pacific Gas & Electric Co, who supply East Bay MUD for example, reported internally that the average CO2 emission was only 0.201 tons of CO2 per megawatt hour. This is inconsistent with their fuel mix and the California Energy Commission (CEC) in the September 2006 presentation to the ACS Committee on Environmental Improvement determined that the average CO2 emission per megawatt hour is 0.502 tons. Until there is an agreed independent process for determining the greenhouse gas emissions it was assumed that the independent state regulator CEC was more likely to be accurate than the generation company.

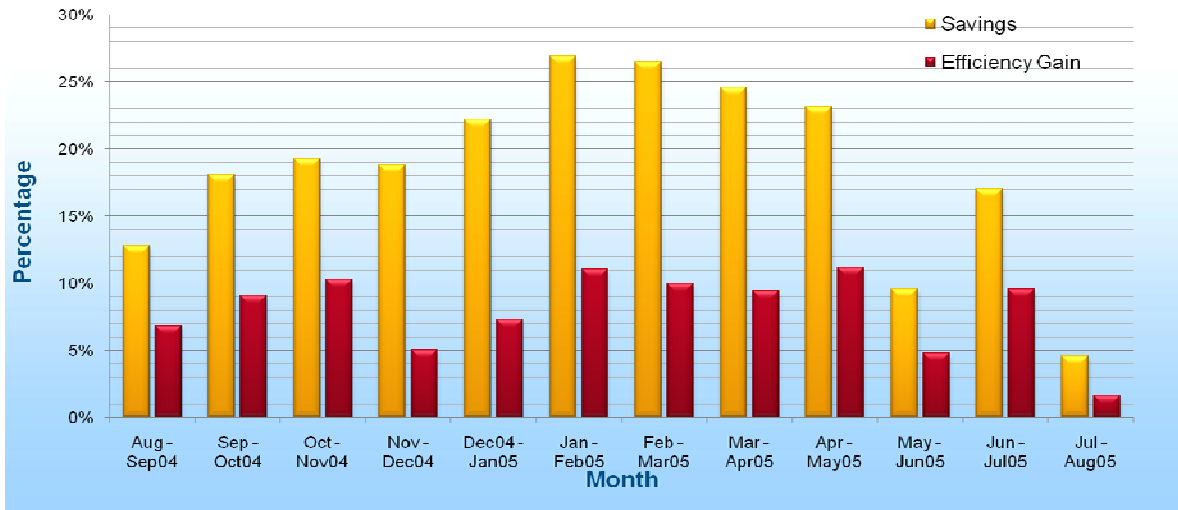
Repeating this process for each of the four utilities running Derceto Aquadapt produced the table below.

Customer System	Plant Operator Name	Selection Criteria in eGRID Database	CO2 Emissions (Tons/MWh)
East Bay Municipal Utility District, Oakland CA	Pacific Gas & Electric Co	non-utility service area	0.502
Eastern Municipal Water District, Perris CA	Southern California Edison	non-utility service area	0.515
Washington Suburban Sanitary Commission, Laurel MD	PJM Interconnection	power control area	0.547
Water District Number 1 of Johnson County (WaterOne), Kansas KS	Board of Public Utilities, Kansas City Power & Light Co	power control area	0.845

## 6.1. Results for EBMUD

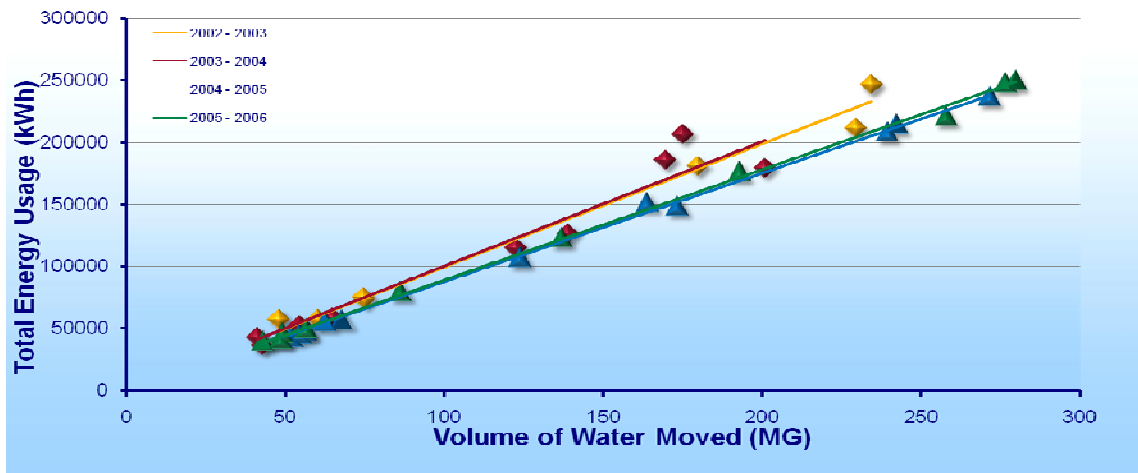
As the system has been active is the longest in the United States results for East Bay MUD now span three years. Derceto Aquadapt controls roughly 25% of the distribution system, but this one quarter consumes more than 35% of total energy spend. It contains a number of complex pump stations, where pumps of different sizes are available to deliver water at any time. This provides an optimiser with many options to deliver a range of flows into the distribution system. Aquadapt solves the non-linear hydraulic equations to determine which combination of pumps will deliver the required daily mass-balance at the highest efficiency and lowest cost.

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Even though EBMUD had spent quite a lot of effort improving pump efficiency Aquadapt was successful in reducing the total amount of MWhs required to deliver flow by 6.1 % overall. At some pump stations it improved efficiency by more than 27% purely from selecting the right pump or pumps at the right time.

**Efficiency Comparison  
Total Energy Usage v Volume of Water Moved**



*Efficiency gains of 6.1% overall were achieved in the first full year(2004-2005) of Derceto operation at EBMUD*

## 6.2. Results for all Sites

Similar analysis has been carried out for all US sites and the table below indicates the average efficiency gained under Derceto control as well as the CO<sub>2</sub> reduction per year through efficiency gains.

Customer System	Average MWh per Year	Average Efficiency Gain under Derceto	EPA eGRID 2004 CO <sub>2</sub> Emissions (Tons/MWh)	Extrapolated CO <sub>2</sub> Reduction per Year (Tons)
EBMUD	26,000	6.1%	0.502	800
EMWD <sup>iii</sup>	7,000	8.4%	0.515	300 <sup>iv</sup>
WSSC <sup>iii</sup>	99,000	11.2%	0.547	6,062
WaterOne <sup>iii</sup>	94,000	6.0%	0.845	4,800

## 7. CONCLUSION

The benefits of effective pump scheduling have been theorised, and now through Aquadapt been shown to be achievable in practice. Most academic analysis concerned the ability of the pump scheduling system to move electrical load in response to tariff prices. A true holistic optimiser however, would also consider energy efficiency, though still primarily to reduce energy cost, and this is shown to be the case for Aquadapt. In the changing focus on climate change resulting from the lead by states such as California 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 11% in this energy consumption through efficiency improvements would therefore lead to saving between 3 and 5.5 million MWh of electricity production per year. The US average CO<sub>2</sub> emission per MWh of electricity production is about 0.5 tons. The potential CO<sub>2</sub> reduction therefore, is between 1.5 million and 2.75 million tons. This is certainly not inconsequential and provides a use another compelling reason for water utilities to consider operations optimisation.

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## END NOTES

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<sup>i</sup> EPRI, Water and Wastewater Industries: Characteristics and Energy Management Opportunities, 1996

<sup>ii</sup> <http://www.epa.gov/cleanenergy/egrid/index.htm>

<sup>iii</sup> Based on 3-6 months of available data

<sup>iv</sup> Electric pumps only, gas pumps not analyzed