Energy Optimization Opportunities in Municipal Water and Wastewater Treatment

Spartan Performance Solutions

CONTENTS

1 INTRODUCTION

In an industry where the cost of electric energy is second only to its personnel costs, one would expect that energy efficiency would be an important priority in both the design and operation of its facilities. For water and wastewater utility operations, the primary objectives have focused on meeting regulatory requirements that protect the health and safety of local populations as well as the environment by treating both our drinking water and effluent to very high quality standards. Historically, water and wastewater facilities have not been designed, as a rule, with a priority on energy efficiency. Once operational, energy optimization opportunities within these assets are also traditionally overlooked by most municipal organizations.

More recently however, environmental issues linked to the consumption of energy in its many forms have all levels of government discussing policy in regard to its efficient use. Climate change linked to greenhouse gas emissions is getting more than its fair share of media attention these days with policy makers establishing their plans and priorities. One only need to visit the website for their own community to learn more about local climate change and environmental policies and ongoing programs to see that a trend has been established and it is gaining momentum. Today, consumer based water conservation, gas and electric energy efficiency and energy efficient building programs are common in many urban communities. Suddenly, opportunities to better manage energy has become an area of great interest as community managers and planners work to implement energy management strategies and programs across their municipalities.

Most interestingly however, the enormous electric loads associated with pumping water and wastewater make these utilities the largest potential opportunity for municipalities to reduce their energy consumption. With the focus of most municipal efficiency programs focusing on the consumer, their treatment facilities, piping networks and pumping stations remain excellent targets for improvement.

This paper describes how energy is used in the water treatment processes along with current consumption trends in this industry. Opportunities to reduce energy use in these operations and some of the barriers to addressing the energy efficiency issue in this industry are then discussed. Finally, a number of case studies from North American water utilities that have created and adopted an energy strategy and successfully implemented energy management programs are presented.

2 ENERGY CONSUMED IN THE WATER USE CYCLE

The illustration below shows each stage of the water use cycle in which energy is consumed. In North America, in the majority (>80%) of both water and wastewater processes, the operating energy comes from electrical sources. In the water industries, electric drives (motors) are most commonly used because of their reliability and relatively low cost to operate.

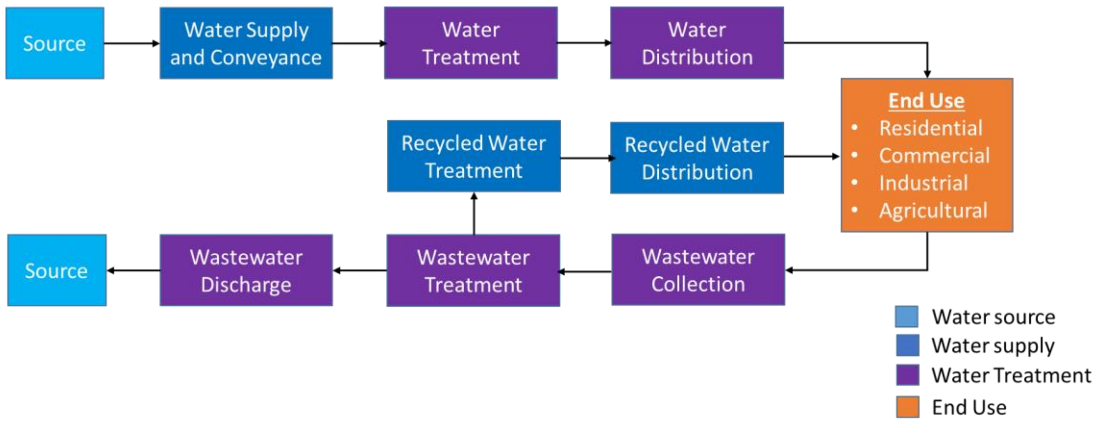


Figure 1: The Water Use Cycle (source: Klein, etal)

Referring to the Figure 1, from source to source in the U.S., it is estimated that the energy required to treat and transport municipal water supplies is approximately 3-4% of its total national electric supply [1]. The U.S. EPA has estimated that energy use in the water and wastewater treatment industries is as much as the pulp and paper and petroleum industries combined. It is also notable that the total electric energy costs associated with these operations account for as much as 30-40% of a typical municipalities total electrical energy bill. [ibid] As an example, Illustrated in Figure 2, for the City of Dallas Texas, electricity consumed in their water and wastewater facilities represents 59% of the city's total electricity costs with street lighting the next largest load at 11%. Of course, these figures will vary widely from region to region

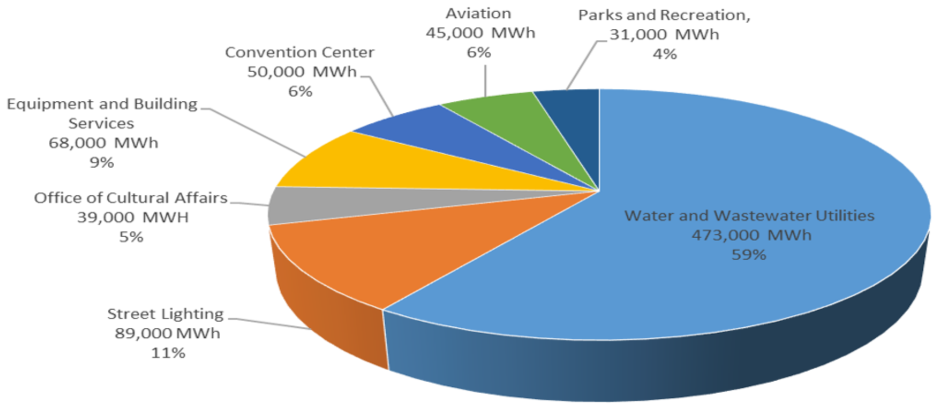


Figure 2: The City of Dallas Electricity Profile by Department – 2011
(source: WWTP Process Decisions Impacting Energy, Kaitie Bell, CDM Engineering, 2011)

with local climate, the raw water source, and the size and geometry of individual water distribution and collection systems, but without a doubt, water utilities are energy intensive operations.

As one would expect, the carbon footprint associated with the water use cycle is comparatively significant. Using U.S. figures again, in 2005, carbon emissions associated with water, including water heating were estimated to be 5% of the national total. This total is the equivalent to the emissions generated by 53 million passenger vehicles annually. [ibid]

If we breakdown the total energy consumption in these facilities, Figure 3 shows that in a public drinking water system, greater than 85% of the electrical energy is consumed by water pumping in both the treatment and distribution processes. Water distribution, including high lift pumping and booster pump stations that supply finished water to various end users, account for the largest portion at 67% of the total.

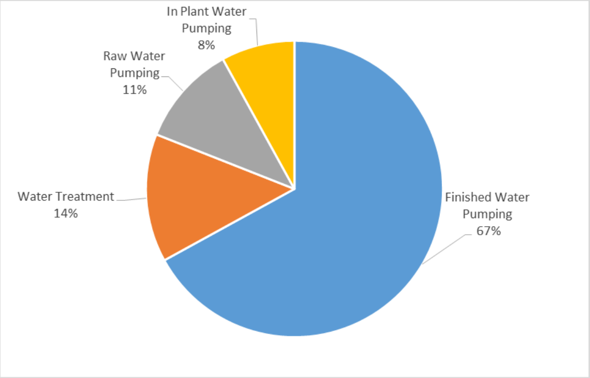


Figure 3: Typical Energy End-Uses in Public Water Systems Source: Keith Carns, EPRI Water Solutions

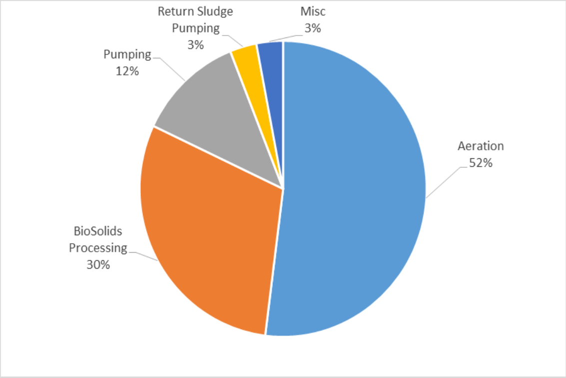


Figure 4: Typical Energy End-Uses in Municipal Wastewater Systems Source: Hazen & Sawyer

Similarly in wastewater treatment, aeration, various pumping applications, and solids processing can account for greater than 85% of the electricity consumed by these operations, as illustrated in Figure 4. Aeration blowers in the secondary waste treatment process are the largest electrical load in these operations.

Note that the numbers contained in Figures 3 & 4 are industry averages and are meant to be illustrative. They are not applicable to all water treatment systems as processing equipment and piping hydraulics vary from operation to operation. They provide however, broad context to how and where energy is consumed across the water industry.

Focusing now on the electrical cost associated with operating these loads, consider the data in Table 1. Here we show the electrical energy costs associated with operating a fully loaded 100 hp motor over

Operating Time	Electricity Costs for a Fully Loaded 100 hp Motor (assumes 90% efficiency, 365d/y, 30d/mo)			
	7 ¢/kWh	8 ¢/kWh	10 ¢/kWh	12 ¢/kWh
1 Hour	$4.70	$5.37	$6.71	$8.06
1 Day	$113	$129	$161	$193
1 Month	$3,384	$3,867	$4,834	$5,801
1 Year	$41,140	$47,052	$58,815	$70,578

Table 1: Electricity Costs to Operate a 100hp Motor

various time spans. At 7¢/kWh, over the span of one year for example, this motor would cost the operator just over $40,000 to run it continuously. A 2000 hp high lift pump could easily cost the operator 20X this figure, using $800K - $1M of power itself, over the same period.

Keeping in mind that some of the electrical loads in these operations are several hundred horsepower or larger and that large water distribution networks will contain dozens of pumps, power costs to operate municipal water and wastewater utilities for a municipality of one million people easily reaches into the tens of millions of dollars annually.

3 ENERGY CONSUMPTION TRENDS IN WATER TREATMENT

In spite of conservation efforts, the energy consumed by the water and waste water industry is forecast to grow. This is primarily the case for two reasons. First, human populations continue to grow as well as urbanize creating an ever increasing demand on municipal water treatment systems. And second, both drinking water quality and waste water effluent regulations have continued to become more stringent, necessitating the use of advanced water treatment technologies and, consequently, more energy.

Traditionally, the discharge standards for wastewater focused on only the biochemical oxygen demand (BOD) and suspended solids characteristics of plant effluent – primary treatment. Then, the bacterial properties of waste water became the focus of secondary treatment processes. More recently, contaminants like ammonia, the macro-nutrients nitrogen and phosphorous, and residuals from disinfection processes are being addressed with advanced treatment processes. Biological nitrification, ozone and UV disinfection (Figure 5), for example, successfully improve wastewater effluent quality, but not without the additional cost associated with greater electrical energy consumption by these processes.

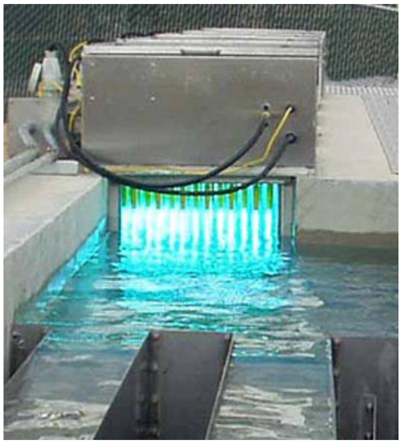


Figure 5 UV Disinfection System
(source American Air and Water)

Figure 6 Membrane Filtration
(source Arifiks Engineering)

In drinking water treatment reverse osmosis, membrane (nano) filtration (Figure 6) and ion exchange technologies have similar quality improving effects with an additional energy penalty.

4 ENERGY EFFICIENCY OPPORTUNITIES IN WATER TREATMENT

Today, there is a growing awareness of what is now termed the ‘Water-Energy Nexus’. Simply, the water energy nexus refers to the close interrelationship between energy and water. In most cases, energy cannot be produced without water consumption and conversely water cannot be produced without consuming energy. In a thermoelectric power plant for example, water is required to make steam as well as for cooling in the generation of electricity. Here in Alberta, steam is used as a means of mobilizing heavy oil deposits before they can be lifted to the surface and processed. Both these forms of energy require the consumption of significant quantities of high quality water in their production. Each is dependent on the other and today, an awareness that saving water saves energy, and saving energy saves water, is growing.

Going forward, municipal water and waste water treatment operators will continue to be faced with the mounting pressures associated with the increasing water demands of growing populations as well as the increasing quality requirements of health and environmental regulators. On top of these demands, water operations will be expected to deliver their product and service at reasonable costs to consumers with minimal environmental impact. We argue that meeting all of these objectives will necessitate water utilities exploiting all means necessary to conserve both water and energy.

Going forward, energy efficiency is poised to become a far greater issue in water utilities.

The list below is not exhaustive, but it represents perhaps the largest opportunities for water utilities to both conserve energy and lower their cost of operations.

4.1 Strategic Energy Management Policy

The factors which impact energy price are beyond the control of any organization, with market forces, the economy, and government policy acting as primary drivers. However, organizations can control how they manage the energy they consume and how they respond to market forces and government changes in energy policy. As is described in some detail below, improving energy performance can provide significant benefits for these organizations but experience has shown that effective energy policy and plans are necessary in order for gains to be lasting. Even though a water and wastewater organization may have tackled energy efficiency as a means of controlling cost, they have not always done so in a comprehensive structured manner. The International Organization for Standards (ISO), familiar to most water organizations, has developed an international standard for energy management. ISO 50001 establishes a comprehensive framework to manage all forms of energy use, organization wide. The standard uses a familiar management systems model, shown in Figure 7, that has been adopted by most organizations in similar Quality (ISO 9000) and Environmental (ISO 14000) management programs.

Strategic energy management initiatives engage the broader organization in a planned and structured way in order to make lasting energy efficiency improvements.

These programs typically involve:

- Gaining executive management buy in to a strategic energy management plan
- Creating the organizations energy management policy
- Identifying energy management opportunities and setting priorities

- Creating and committing to energy reduction goals
- Benchmarking facility performance and tracking energy reduction targets.
- Creating and improving operational and maintenance energy "best practices"
- Creating an energy team to initiate and act on efficiency projects
- Creating organizational energy awareness and engaging employees to suggest and make energy saving improvements.

Across the process and manufacturing industries, ISO 50001 has proven successful in providing an organizational framework for managing large scale energy conservation initiatives. In water operations, it has been shown that savings of 4 – 5% over and above those associated with process, equipment or control improvements, can be achieved by adopting strategic energy management policies. [5] Note that adopting the standard and certification to it, are two different matters, with the latter viewed as optional by many.

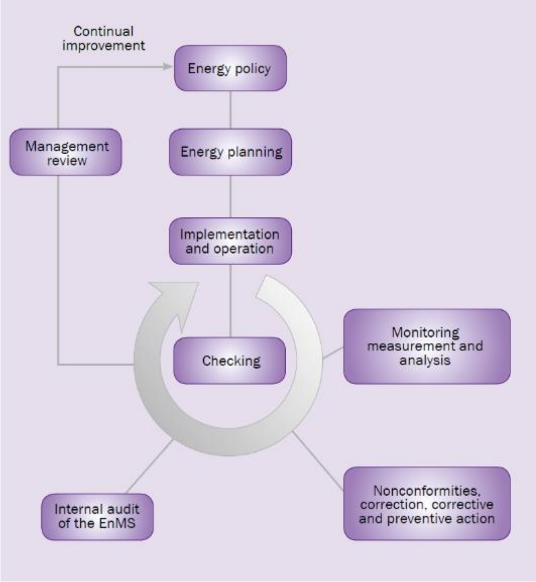


Figure 7: ISO's Energy Management Systems Model

4.2 Process Design and Equipment Upgrades

Figure 8: 21 MGD Finished Water Pumping Station **Albertville, AL, USA**
(Source: KREBS Engineering)

Figure 9: 2000hp, 90ML/d High Lift Pump
Edmonton, AB, E.L. Smith Water Treatment Plant
(Source: Edmonton Journal)

Designing with Energy Efficiency in Mind: Proper system design is the single most important factor in minimizing the lifecycle cost of a pumping or blower system, yet it is typically the least considered in this industry. In a study of 20 plants in Finland with 1690 pumps, it was revealed that pumping efficiency was lower than 40%, with 10% of all pumps operating at efficiencies below 10% [6].

This is the case because, historically, pumping systems are normally selected based on lowest first cost rather than lifecycle costs. The energy costs required to operate it or the maintenance cost required to keep it running are typically ignored during the system design and selection of the equipment.

Estimates by both equipment manufacturers and end-user organizations show that in large pumping system applications like the ones in water utilities, as high as 85% of the total lifecycle cost is electricity consumption. As little as 5% of the total lifecycle cost of a large pumping application is its capital expense in fact. [7] See Figure 10.

Given this cost imbalance, one would expect that greater consideration for energy efficiency would be given in the design and equipment selection for these systems. Unfortunately, single-speed pumps and motors are typically selected and oversized in order to meet the maximum flow rate that is required by the process. Control valves or bypass lines are then used to throttle the process pressure and flow in order to meet the requirements of the process at specific conditions.

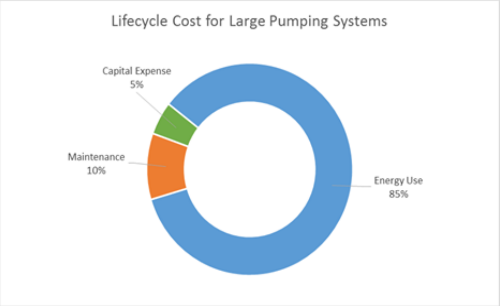


Figure 10: Lifecycle Cost for Large Pumping Systems (source: Grundfos Pumps, Thames Water)

Though in some cases unavoidable, logically, to raise the process pressure to a high level with a pump and then let it down across control devices to satisfy lower flow rates required by the process under normal operating conditions is very expensive from an energy standpoint. Unfortunately this is a common design practice as it is often least expensive from a capital cost perspective.

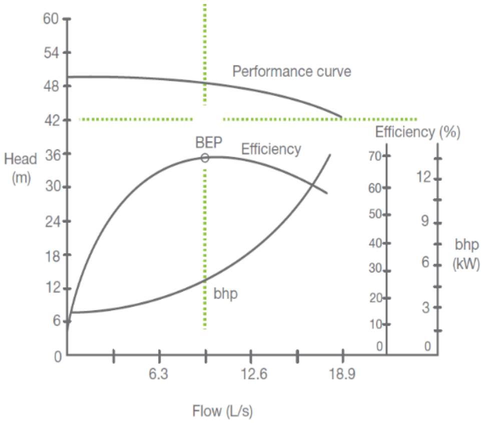


Figure 11: Best Efficiency Point for a Pump
(source: State of Victoria: Energy Efficiency Best Practice Guide)

Figure 11 illustrates a typical pump curve which provides a graphical representation of how a pumps key operating parameters (head, power, efficiency) vary with flow. A pump operates most cost effectively when it is close to its Best Efficiency Point (BEP). Pumping continuously at the BEP is impractical however because of the changing flow and head requirements of typical processes.

An alternative pumping system design strategy to the current practice then is to use multiple centrifugal pumps. The most energy efficient pump is used to meet the normal base flow conditions of a process, and a supplemental pump(s) is started to manage peak flows.

This is a far more energy efficient design practice and will result in significant electrical energy savings. Admittedly, this design will have a higher capital cost, but the total lifecycle cost for the system will typically be much lower when energy and maintenance costs are also considered. Examples of energy efficient and inefficient pumping systems are given in Figures 12 and 13 below.

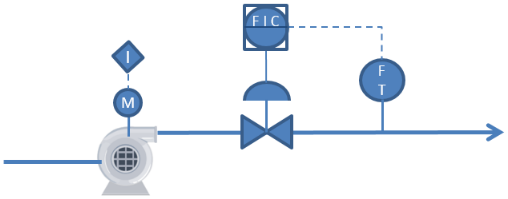


Figure 12: Energy Inefficient Pumping System Design

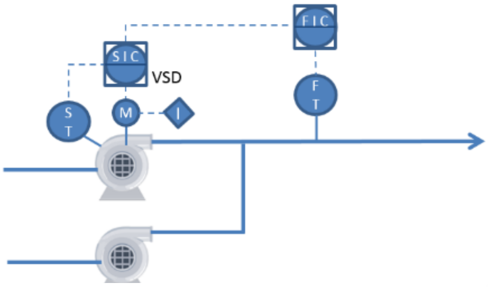


Figure 13: Energy Efficient Pumping System Design

Figure 14 illustrates this point by comparing the lifecycle costs between efficient and inefficient pumping system designs. Note that in the low efficiency design, the initial capital expenses to design and install the pump are lower than a more efficient design. Over time however, the initial cost benefit of selecting the less expensive equipment is lost to much higher operating and maintenances associated with operating less efficient equipment.

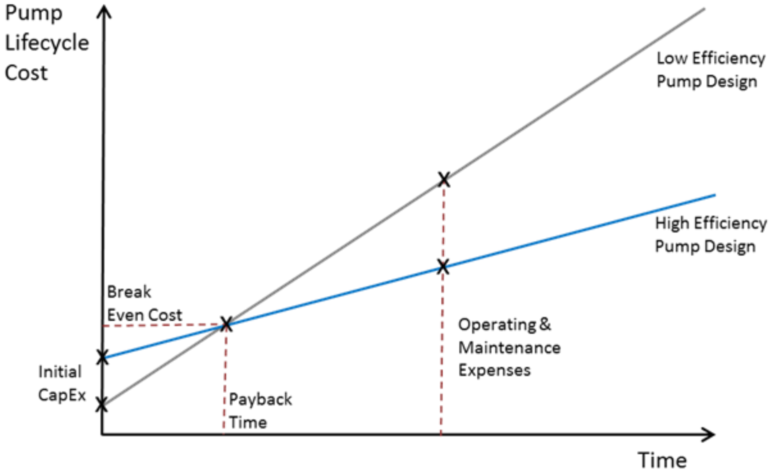


Figure 14: Lifecycle Cost of Pumping Systems using Efficient and Inefficient Design Practice
(Source: Grundfos Pumps)

Note that although we have used a liquid pumping example, identical argurments apply to other electrical loads where the torque changes with the speed of the equipment. Blowers, fans and centrifuges are additional examples of variable torque loads commonly used in water utilities.

Payback of course is dependent on many factors associated with the details of specific installations including the system design, selected equipment efficiency and local power contracts.   As a reasonable estimate however, case studies throughout North America routinely report payback times of a few years associated with large pump and blower upgrade projects. [5, 6, 7,] Given the operating life of these assets can be 25 years or more, profitable projects such as these should be carefully considered in both brown and greenfield applications.

Variable Speed Drives (VSD): Variable speed drives are devices which modulate the voltage and frequency that is being supplied to an electric motor and therefore control the speed of the motor and the machine it is driving. VSD's deserve specific mention because they generate energy savings over and above those created through better design or a move to high efficiency equipment and motors.   VSD's allow the equipment speed to be adjusted to match the required flow demanded by the process and in some cases allow designers to eliminate bypasses or throttling devices such as valves, dampers and guide vanes.   Because many of the typical applications in water and wastewater (i.e. pumps and blowers) are variable torque loads, they are ideal candidates for VSD's.

How Do VSD's Save Money ?: The physical laws governing centrifugal loads are called the 'affinity laws' and briefly, they state that flow will change linearly with speed, pressure will change with the square of the speed and power will change with the cube of the speed. Referring to curves in Figure 15, a centrifugal pump with a VSD operating at maximum speed (100%) will produce the maximum flow rate, the highest pressure (head), and will consume the greatest amount of energy doing so. If the pump speed is reduced to 50% of its maximum, the flow rate also drops to half, but the pressure generated will drop to: 0.5^2 = 25%, and the power consumed to: 0.5^3= 12.5% of their respective full ranges. In this example then, a 50% reduction in speed results in a 87.5 % reduction in power consumption because of their cubic relationship.

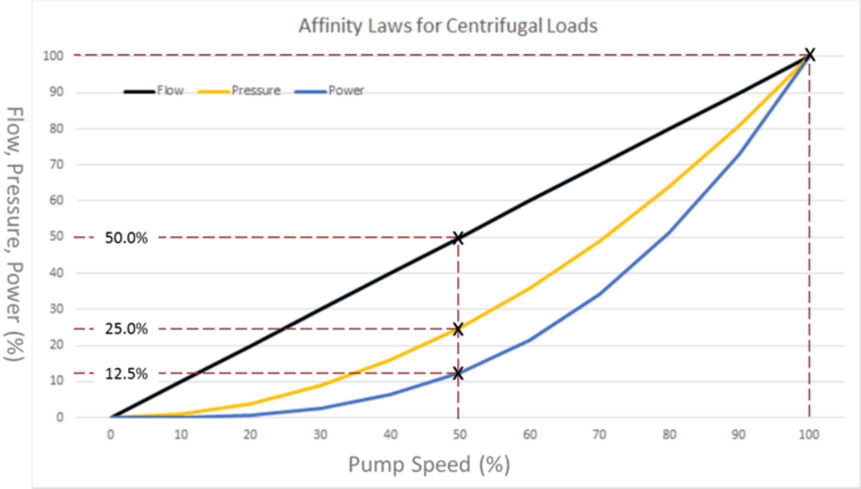


Figure 15: Flow, Pressure and Power at 50% and 100% of VFD Speed
(Source: pump affinity laws)

The affinity law between speed and power for a VSD controlled device is the source of the energy savings potential generated by VSD's.

VSD's are not appropriate for every pumping application, but EPRI estimates 30 – 50% energy savings can be achieved when VSD's are implemented in large centrifugal, variable torque applications with high annual operating hours and widely variable flow rates (i.e. distribution pumps, aeration blowers). Across the public water industry, VFD's alone could reduce the energy requirements by 10 – 20% and to date, it has been estimated that only 5% of motors used in water supply applications are currently VSD controlled. [3]

Another benefit associated with VSD's is improved process control. Matching the pump output flow or pressure directly to the process requirements and correcting variations in closed loop control, ensures flow or pressure surges are minimized, improving process performance. From a reliability perspective, it has also been shown that VSD's have a major benefit in reducing pump wear (bearings and seals) in relation to reductions in speed that can be achieved with these devices.

Turbo Blowers for Wastewater Aeration: Wastewater aeration is required in secondary waste water treatment, where a biological process is used to consume dissolved and suspended organic compounds.

Figure 16: Multistage Centrifugal Blower
(Source: waterworld.com)

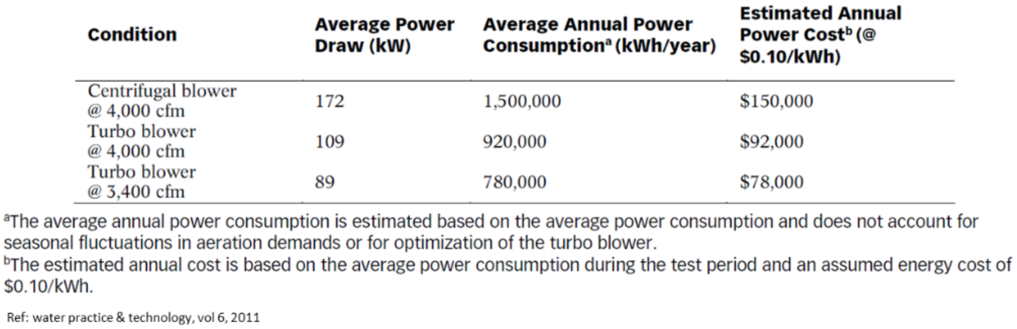
Figure 17: Turbo Blower
(Source: Sulzer.com)

Oxygen is necessary to support the aquatic micro-organisms in this aerobic habitat. Positive displacement, multistage, and single stage centrifugal blower technologies have traditionally been installed in wastewater aeration applications. Prior to the introduction of direct drive turbo blower technology into the wastewater market, single stage centrifugal blowers were the last major improvement in blower technology and were introduced in the early 1980's.

The primary advantages of direct-drive, high speed turbo blowers include: significant energy savings, higher surge margins, greater durability, higher reliability, less maintenance, ease of installation, compactness, light weight, and reduced noise [8]. A comparison of blower technologies is reported in Table 2. High speed turbo blowers can be 10-20% more efficient than multistage centrifugal or positive displacement blower technologies. They are able to operate at much higher speeds (up to 40,000 rpm) and consume less energy when compared to other blower designs. To illustrate, Table 3 compares the energy consumption of a conventional single stage centrifugal blower with a high speed turbo blower tested at a wastewater facility in Ft. Meyers, FL. [10]

Blower Type	First Introduced to Market	Nominal Efficiency Range
Positive Displacement	Mid 1800's	45-65%
Multi-Stage Centrifugal	1950's	50 – 70%
Single Stage Centrifugal	1980's	60 – 80%
Single Stage High Speed Centrifugal (TURBO)	2007	70 – 80+%

Table 2: Typical Aeration Blower Efficiencies
Source: CDM Engineering



Condition	Average Power Draw (kW)	Average Annual Power Consumption[a] (kWh/year)	Estimated Annual Power Cost[b] (@ $0.10/kWh)
Centrifugal blower @ 4,000 cfm	172	1,500,000	$150,000
Turbo blower @ 4,000 cfm	109	920,000	$92,000
Turbo blower @ 3,400 cfm	89	780,000	$78,000

[a] The average annual power consumption is estimated based on the average power consumption and does not account for seasonal fluctuations in aeration demands or for optimization of the turbo blower.

[b] The estimated annual cost is based on the average power consumption during the test period and an assumed energy cost of $0.10/kWh.

Ref: water practice & technology, vol 6, 2011

Table 3: Energy Consumption by Wastewater Blowers (source: Water Practice and Technology, 2011)

Fine-Bubble Diffuser Technology: For many decades, mechanical aeration and coarse-bubble aeration technologies (Figures 18 & 19) have been in use in secondary wastewater treatment processes. The development of fine-bubble diffuser technology (Figure 20) in the 1970's has been shown to reduce aeration energy consumption because of the increased oxygen transfer rates afforded by the increase in surface area of vast quantities of tiny bubbles. It is commonly reported that fine-bubble diffusion can reduce aeration energy consumption from 30% to 40% when used in a closed loop dissolved oxygen control strategy. [8]

Figure 18: Mechanical Air Delivery System
Source: biogest.com

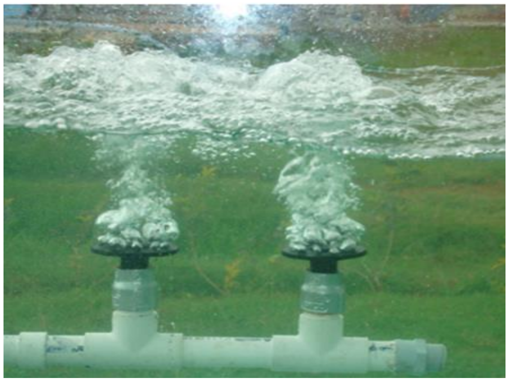


Figure 19: Coarse Bubble Air Diffusion Systems
Source: southern cogen systems PVT. LTD.

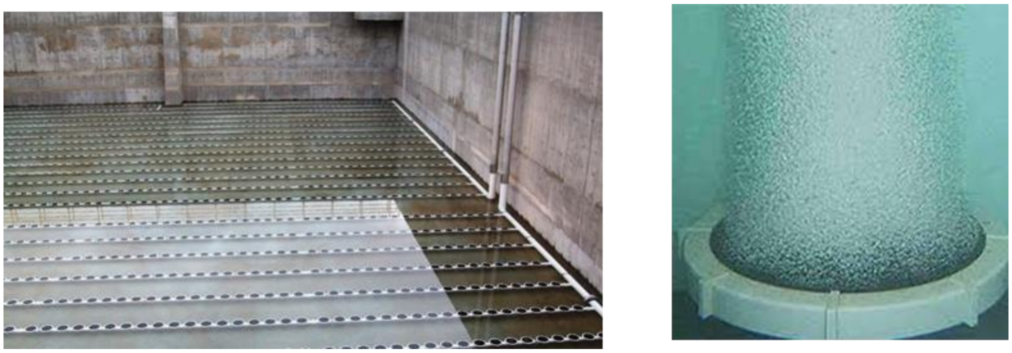


Figure 20: Fine Bubble Diffusion System
Source: Aquarius technologies.com, Tepcro Energy Systems

4.3 Water Conservation

Water conservation lowers water demand and reduces the volumes of water taken from public water supplies and in turn reduces the energy required to pump and treat the water provided to consumers. Lower freshwater demand automatically translates to reduced demand for wastewater collection treatment and disposal making water conservation an excellent energy saving strategy.

Consumers: Many municipal water organizations have well established water conservation initiatives which focus on creating greater consumer awareness in regards to both indoor and outdoor water use. In effort to manage demand, consumers are encouraged to invest in low flow taps, showerheads and toilets in their homes and, outdoors, to water lawns and gardens on specific days for example. Some utilities are now providing timely information on usage patterns for water, gas and electricity in order to increase awareness and transform consumer behavior. ‘Smart’, automated meter reading technology and acoustic leak detectors are now making their way into homes and businesses to identify leaky toilets, garden hoses or taps being left on accidentally.

Considerable opportunity exists to improve the performance of commercial and residential irrigation systems with estimates showing that up to 50% of water is wasted due to inefficient practices. [11] Storm water collection and reuse are also growing areas which reduce the demand on public water supplies.

Note that though very effective, this type of water conservation is challenging as it relies on gaining small improvements from large numbers of participants. Measuring the impact of large scale conservation programs across a municipality is a difficult task.

Water Utilities: In a Canadian study released in 2011, it was estimated that on average over 13% of treated drinking water is lost from distribution systems across the country. Similar figures are reported in the U.S. [9]. On the wastewater side, infiltration into the collection systems leads to significant flow increases into the treatment facilities, particularly during spring run-off or rain events. Not only must the additional volume be pumped and treated, but a potential source of fresh groundwater also is lost.

Projects which address drinking water loss or better isolate wastewater collection systems from ground water sources are both water and energy savings investments. The size and complexity of the distribution and collection networks and the capital required to find and repair the leaks makes addressing this problem very challenging.

Additional metering and implementing an acoustic sensing network can help pinpoint significant losses in large water networks in preparation for line repairs or replacement.

4.4 Process Control Optimization

Advanced Process Controls and Real Time Optimization:

In most process industries, plant process control systems are fully leveraged to optimize production efficiency and lower operating costs in order to maximize company profit margins. In the 1980’s the field of advanced process control (APC) exploded with many of the process industries recognizing the commercial opportunity associated with moving and holding their production processes at desired optimums. These technologies are now commonplace in many process industries with the benefits of advanced control widely reported to provide bottom line benefits of 2-6% of operating costs. (10) Today, it would be unusual <u>not</u> to see these technologies widely deployed in a typical world scale refining, petrochemical or pulp and paper complex for example. Outside of the water industry, greater attention has been given to leveraging process control technology in effort to reduce the energy intensity and increase efficiency of operating facilities.

In general, energy efficiency is widely accepted as a key cost containment strategy that generates greater financial returns for industrial process operations. It is not uncommon to see an organizations 'energy policy' effectively realized through its plant process control systems in many of the process industries. 'Peak-shaving' for example, is a control strategy that reduces the amount of power consumed in an operation by automatically turning off, non-essential electric loads and where possible, turning down others, during periods of peak demand when electric energy charges are the highest. Peak shaving not only reduces consumption charges, but can also reduce costly peak demand charges for the consumer.

To date, as primarily public utilities, the water industry has placed a greater focus on improving process reliability and water quality than on optimizing the production and distribution processes. Advanced process control technologies such as model based control, fuzzy systems and heuristics are in use in water and wastewater treatment operations, albeit limited in North America, and more broadly in Europe for example. Tremendous results have been generated in water utilities in specific applications, but in general, under-investment in modern process control and optimization technology has left the water industries behind other process industries in regards to optimization and energy efficiency of their process operations.

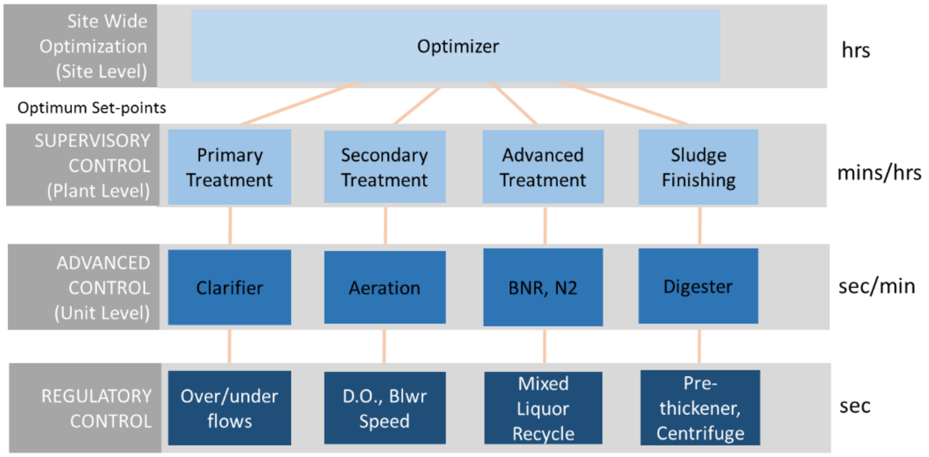


Figure 21: Advanced Process Control Hierarchy

The diagram in Figure 21 represents a typical layered process control hierarchy that is used in many operating process organizations and conceptually, can be used just as well in water and wastewater operations. Beginning from the bottom and moving upward, in any plant, regulatory controls are implemented to maintain individual control parameters at desired set points. Their purpose is to regulate the process within a safe set of boundaries. Above the regulatory controls, advanced controllers are able to move individual process units to their optimum operating points with individual advanced controllers used to stabilize specific equipment or portions of individual unit operations. In addition, APC helps coordinate control responses across specific units.   Supervisory controllers are used to coordinate the control actions across plant areas and finally, a site wide optimizer can be used to meet a specific economic objective function for the entire facility as well as coordinate the control between plants. A process optimizer is able to compute the optimum set points for each process in order for the entire operation to run with maximum efficiency for example.

The advantages associated with the above architecture are many, including:

- More stable operation under a wide variety of process conditions
- Improved disturbance rejection with a quicker return to steady state
- Automatic coordinated control responses within and between process units
- Optimized site-wide responses to changes in plant economics (i.e. power cost)

Successful advanced control strategies implemented through such an architecture remove the burden from the operator having to manage individual equipment, freeing them to manage the entire process. Good control ensures a stable, more responsive, and more efficiently operated process while facilitating broader site wide optimization objectives such as energy efficiency.

As has been stated, optimizing the pumping systems in water utilities is a large opportunity because of the magnitude of electricity consumed by these operations, yet few organizations have adopted advanced controls or optimization technology of any kind. In water utilities, advanced controls can be used for system-wide control of complex water systems, including: multiple water treatment plants, booster pumping stations, and water reservoirs in schemes which conserve energy while still meeting the needs of the process and consumers.

Coordinated pump controls can manage 'peak' electricity usage by staggering the duty cycles of large loads such as finished water and booster pumps. By leveraging reservoir capacity to avoid starting and using these pumps during periods of peak electrical demand, the system may be able to coast through the heavy demand periods without starting additional pumps. Often, periods of peak water demand will coincide with high electric rates, so predictive control is a key strategy that can be used in reducing electricity costs in water utilities. EPRI has estimated that an additional 5-10% reduction in energy consumption could be achieved across all US public water utilities through the adoption of better pumping and water treatment control. [12]

In wastewater utilities, the aeration blowers in the secondary treatment process can account for over 50% of the total electric energy consumption in these facilities. For good reason then, the largest optimization opportunity to improve energy efficiency in wastewater is associated with optimizing the performance of the aeration blowers. It is widely reported that using advanced process control strategies to continuously optimize the dissolved oxygen concentration in activated sludge treatment processes can reduce blower energy consumption by 10-20%. In 2004, Amand published a summary of various advanced blower control strategies deployed and their associated results in the wastewater industry. [11]

Optimizing the pumping operations as well as bio-solids equipment is another opportunity in wastewater. As with drinking water treatment, peaking controls can be used to manage pumping duty cycles and avoid pumping, when possible, during periods of peak electrical demand. Waste sludge pumping and dewatering processes, for example, are typically operated only as needed and are logical candidates for this type of optimization.

Demand Management Strategies:

Demand Management (DM) strategies involve changes in electrical usage by power consumers from regular consumption patterns in response to changes in the price of electricity or incentive payments by the electric system operator to the consumer in order to induce lower electricity consumption at times of high wholesale market prices or when the reliability of the electricity grid is jeopardized in some way. Implementing a DM strategy can result not only in reducing electricity cost but, in jurisdictions where the Electric System Operator (ESO) is incented to pay the consumer for reducing their load on the electric grid, it can in fact be a means of offsetting total energy costs.

Load shedding, load shifting, or switching to onsite generation are all strategies that can be implemented for cost avoidance in a demand response strategy. Load shedding involves shutting down non-critical electric loads while load shifting involves modifying when the equipment is used and therefore shifting the load from one time period to another. Sites with power generation capabilities may choose to bring on power in response to a DM event rather than load shed or load shift. A combination of these strategies can be effectively used in water utility operations to lower energy costs.

Again, water and wastewater utilities are good candidates for DM because of their energy intensity. As described, if planned effectively, water storage capacity can provide some flexibility in the operation of large loads like distribution and lift pumps. Figure 22 below shows the change in electrical demand by a wastewater operator by shedding two effluent pumps on a day when the facility was able to reduce its electric demand by approximately 540kW or 30% of its total load.[13] The facility operates with an average demand of 2MW with peak demand reaching 2.5MW. The red line represents the demand response (DR) baseline and the blue line shows the reduction in demand associated with shedding the load of the effluent pumps.

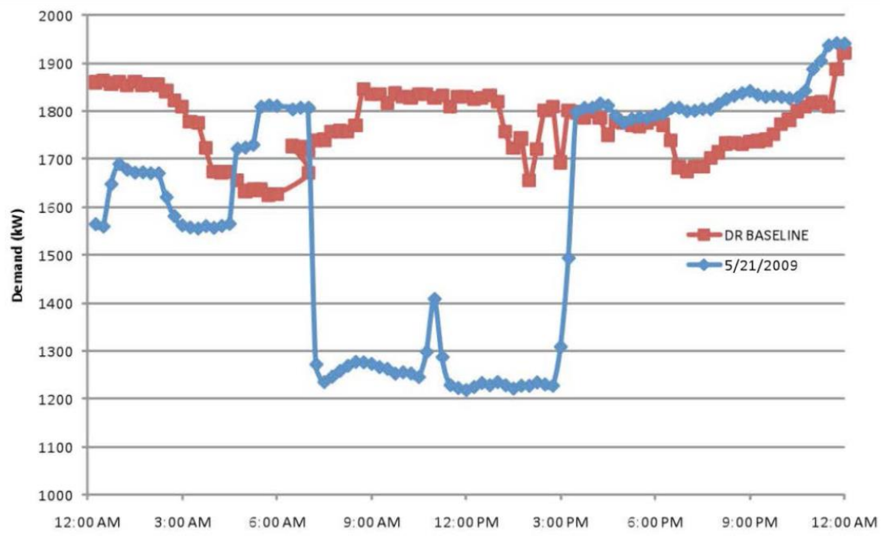


Figure 22: Load Shedding at a Wastewater Treatment Facility in California
(Source: Lawrence Berkeley National Laboratory)

DM strategies can be automatically or manually initiated. In some jurisdictions, the ESO is able to provide notification to the water utility that a demand response is required by the site. This can be in the form of emails or phone calls for example and then the facility operator physically initiates the strategy. Automatic DM requires no human intervention, with an automated signal sent to the facility control system, building automation system or other controls in order to automatically curtail loads in response to price or other system triggers. This signal can be generated internally or through the ESO or 3rd party companies specialized in DM response.

Note that 'Smart Grid' technologies, such as Smart Power Meters (smart meters), are now widely deployed at industrial and large commercial facilities in many jurisdictions in Canada. Not only do these meters record real-time power consumption as well as peak usage, but they also can be equipped with outputs that allow the customer to connect the meter to plant control systems. If desired, the data can be used in conjunction with power pool price information to reduce consumption automatically, as per the sites demand management strategy.

Note that in 2011, the Alberta Electric System Operator selected EnerNOC, a 3rd party demand response aggregator, to provide 150MW of automated demand response through its 'DemandSMART' application for example [14]. John Mansville's manufacturing facility in Innisfail, AB currently participates in this program [15].

4.5 Onsite Energy Generation

Because of the energy intensity associated with operating water utilities, it is becoming more common to see wastewater facilities generate energy on site in order to offset electrical energy costs. Energy can be recovered from municipal waste in the form of bio-gas, and consumed to generate electricity or provide fuel for hot-water boilers used to heat plant processes and buildings. Some wastewater operations have modified their operations in order to accept higher strength waste from disposed food sources like fats, oils and greases (FOG) or milk products such as whey. These additional waste streams raise the level of methane production and are used for additional power and heat generation.

Natural gas engines have been most commonly used in this type of generation application, but micro gas turbine technology has emerged as a very energy efficient alternative. Micro-turbines are typically installed in combined heat and power applications (CHP), where the waste heat is recovered and used within the facility for other purposes. They have some distinct advantages in that they can use a wider range of fuels, they are far more energy efficient, and produce a fraction of the NOx emissions generated by natural gas engines.

As one example, the City of Sheboygan wastewater treatment plant in Eastern Wisconsin, reduced their energy intensity by over 1 million kWh by recovering and burning their bio-gas in micro gas turbines. This facility generates ~80% of their total electricity and heat required for their U.S. operation. [16] Today, there are actually several net-zero energy wastewater operations now operating in the U.S. that are leveraging micro turbine technology. Given the energy intensity of these facilities, this is a notable achievement indeed.

Figure 23: Micro Turbine Power Generators
(Source: decentralizedenergy.com)

Figure 24: Micro Turbines at the Sheboygan WWTP (Source: City of Sheboygan, WI website)

5 BARRIERS TO MAKING ENERGY EFFICIENCY IMPROVEMENTS

In spite of the tremendous opportunities which exist to improve the energy efficiency of water and wastewater operations, several barriers prevent many operations from moving forward and addressing the issue. Some of these include:

Policy Coordination: Today, many municipalities have structured environmental policies, some following the ISO 14000 guidelines which commit to improvements in energy efficiency and greenhouse gas reductions. Fleet management, municipal building energy efficiency, and water conservation initiatives for homeowners are typical targets for municipal program planners. Energy policy however, in many municipal organizations, is either non-existent, being formed, or simply not coordinated with existing environmental policy framework. The interrelationships between water, energy, and the environment suggests that these policies should be thoughtfully coordinated together in any organization.

Business Culture: Many municipal organizations tend to be risk adverse, reluctant to change practices and hesitant to adopt new technology. Unlike commercial enterprises, the business driver of profit does not exist in public water utilities with operating costs borne by local rate payers. Historically, little incentive has existed to investigate energy efficiency, with those consuming the energy disconnected from those paying the bill. In addition, many water utility operations were constructed decades ago in times when energy costs were of no concern to most.

Without necessary incentives or business drivers, there has been little impetus for the industry to change existing practices or business culture. We believe however, growing environmental pressures and the resulting policy changes at all levels of government will be the required catalyst for water utilities to address their energy efficiency challenges.

Upgrade Costs: As with any industrial operation, capital and operating budgets are always constrained and, in spite of typically strong business cases, the capital costs associated with energy efficiency projects can be significant. Without a properly defined business case, it is much easier to follow the status quo than fund projects that by some are considered risky. Without a proper engineering study to quantify the return on investment for these projects, planners have been reluctant to fund optimization and efficiency projects.

Note that in some Canadian markets, provincially owned power producers are funding energy efficiency projects as a means of avoiding the capital expense of bringing on additional supply. B.C. Hydro is one example of a Canadian utility which works closely with industry to assess and fund good energy efficiency projects under their 'Power Smart' program. SaskPower has similar programs to help offset the cost of energy efficiency projects.

6 CASE STUDIES

The following case studies have been taken directly from a document published in 2013 by the Water Research Foundation and EPRI (Electric Power Research Institute). [5] The purpose of including this information is to demonstrate the success of similar operations in the water and waste water space as well as provide legitimacy to the arguments we make in this paper.

Wastewater Case Study: Eugene/Springfield Regional Wastewater Pollution Control Facility has a Comprehensive Energy Management Program[5]

The Metropolitan Wastewater Management Commission is the governing body for the Regional Wastewater Pollution Control Facility located in Eugene, Oregon. The facility services the cities of Eugene and Springfield and the surrounding areas (population 240,000). The treatment facility uses a four-stage step feed anoxic selector activated sludge plant designed to treat an average daily dry weather flow of 49 MGD. The treatment process includes an influent pump station with bar screens and grit removal, odor control scrubbers, four primary clarifiers, eight aeration basins equipped with five 1,000-hp centrifugal blowers and two 350-hp turbo blowers, ten secondary clarifiers, and chlorine contact tanks for disinfection and de-chlorination. Sludge conditioning and anaerobic digestion are the main elements of the solids treatment process. Solids removed in primary treatment are pumped directly to anaerobic digesters. Sludge from secondary treatment is thickened by a gravity belt thickener process and is then fed to the mesophilic anaerobic digesters, each with a capacity of 1 MG.

The regional wastewater treatment facility is ISO 14001 Certified. An Environmental Management System (EMS) manages the environmental impacts of the activities, products and services of the facility, mitigates adverse environmental impacts, and continually moves towards a more sustainable facility. Energy management is a key component of the EMS, as plant staff continuously looks for innovative ways to reduce power use while meeting regulatory requirements. Although capacity of the facility has been significantly expanded in recent years, energy use has remained relatively flat. This is due to strategies such as:

- Evenly distributing equipment operation throughout the day
- Partnering with the local utility provider to change to more efficient equipment
- Purchasing premium efficient motors and VFDs where applicable
- Turning down HVAC equipment when spaces are not occupied
- Instituting behavioral changes, such as turning off lights and computers when not in use, stop before start when rotating equipment

The facility is successfully capturing methane gas from its digesters and beneficially uses the biogas to supply heat and power for the plant. Specifically, methane is used to fuel engines for power generation. Heat also is recovered from the engines in a closed loop hot water supply system that provides the heat necessary for the sludge digestion process. Energy efficiency projects at the plant began in 1996 with the conversion of coarse bubble diffusers in the aeration basins to fine bubble diffusers. These improvements have continued each year by capitalizing on the ongoing utility incentive program to offset equipment costs. The most recent energy savings project is the replacement of one of the existing multi-stage blowers with an energy-efficient turbo blower. The cumulative energy savings for 1996-2013 are summarized in Table 7-4 below.

Table 7-4
Eugene/Springfield Regional Wastewater Pollution Control Facility Energy Efficiency Project Summary, 1996-2013

Annual kWh Savings	Utility Incentives	Project Cost	Annual Cost Savings
10,572,860	$958,377	$3,293,945	$655,517

Source: Bob Sprick, Operation Supervisor, Eugene/ Springfield Regional Water Pollution Control Facility

Figure 7-6 presents the total annual electric use of the plant and how it has changed since 1994. The normalized energy use (in kWh/MG) includes power purchased, generated, pump stations.

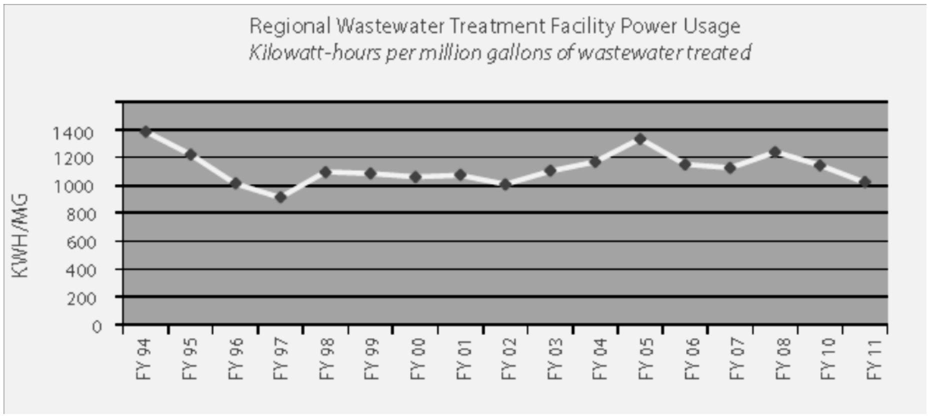


FIGURE 7.6: Annual Electricity Use for the Eugene/Springfield Regional Wastewater Pollution Control Facility
Source: Metropolitan Wastewater Management Commission Annual Report, 2011

Methane gas is sent to an 800-kW generator which supplies 53% of the onsite power as well as hot water for digester heating. The generator is connected to the plant SCADA system and can trigger a mechanism to drop the blowers off the grid should the generator set fault. Table 7-5 illustrates the amount of energy generated onsite from the methane recovery equipment.

Table 7-5
Energy Generated from Methane Recovery

Year	kWh Generated
2008	6,359,645
2009	5,094,612
2010	6,345,866
2011	5,613,758
2012	5,374,490

Water Case Study: Las Vegas Valley Water District Relies on an Energy and Water Quality Management System for its Energy Conservation Efforts [3]

The Las Vegas Valley Water District (LVVWD) delivery system consists of several different types of facilities that pump and store water around the valley. Since 2002, when a drought response plan was first developed, Southern Nevada has reduced its water demand by 29%, from 314 gallon per capita day (GPCD) to 222 GPCD in 2011. While this reduction in water use can be attributed to community conservation efforts, recent economic conditions also may be a factor in the GPCD reduction.
The LVVWD facilities include:

- 68 reservoirs and tanks with more than 900 MG storage capacity
- 46 pumping stations
- 76 production wells capable of producing 175 MG of water per day
- More than 4,500 miles of water transmission pipelines
- Six facilities generating up to 3.1 MW of power from onsite solar array panels

Once water has been treated or has gone through the delivery system, it is pumped uphill through 24 pressure zones. High service pumps at pumping stations force water through the transmission pipelines, usually at night when the cost of electricity is less. Pump stations move water from reservoirs starting at elevation 1,845 feet, with portions ending at elevation 3,550 feet. Reservoirs store the water until it is needed, and gravity then delivers water from the reservoir to the community.

Due to the complexity of LVVWD’s distribution system, it was recognized (in retrospect) that both energy and water quality improvement opportunities were being overlooked or lost in the day-to-day operations. In April of 2002, the District embarked on the development and installation of an Energy and Water Quality Management System (EWQMS) for the District’s distribution system. This system, as installed, somewhat emulated the WaterRF’s direction for implementing a prototype EWQMS. It integrates equipment availability, energy requirements, time-of-use energy costs, water quality parameters, and historical water delivery data to develop daily operations schedules optimized for energy savings. It is a collection of software applications and operational processes focused on efficiently operating a water system.

Since 2005, the current system, as installed, has proven to be effective in reducing energy costs while improving water quality. Electric demand and facility charge costs are reduced by balancing groups of pumps in optimized strategies giving consideration to time of use and variable group efficiencies. The EWQMS process aims to improve water quality by limiting limit the age of the water within the distribution system, thereby, limiting the time that the disinfection by-products can form. The system balances water quality with energy use using heuristic programming and hydraulic modeling.

Figure 7-1 illustrates how the Las Vegas Valley grew and the average weighted elevation went from 2,436 to 2,488 feet. Electricity cost for pumping typically increases as the weighted elevation increases. However, a review of the data presented in Figure 7-2 shows the electricity cost dropped due to the EWQMS process starting in early 2006. Although the total lift continued to grow, the kWh/MG has remained level since 2006.

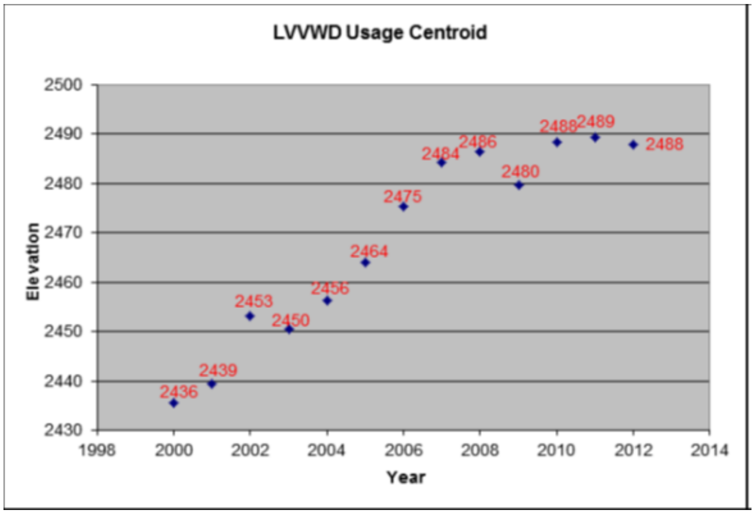


Figure 7.1
Weighted Elevation Increase of the LVVWD System
Source: Kevin Fischer, LVVWD, 2013

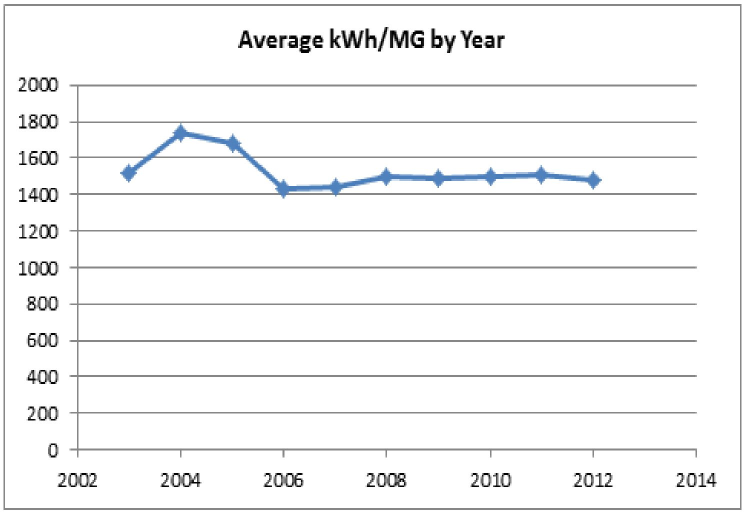


Figure 7.2
Electric Power Use of the LVVWD System
Source: Kevin Fischer, LVVWD, 2013

The EWQMS approach has helped the District achieve the following process and energy goals:

- Improve water quality by minimizing the age of water in the system
- Optimize energy use
- Optimize equipment use
- Achieve optimization faster and more accurately
- Make optimization decisions more objective than subjective
- Increase its ability to flexibly respond to future changes in the energy market

Demand Response Case Study: Eastern Municipal Water District of Southern California Receives Annual Demand Response Payments of $600,000[5]

The Eastern Municipal Water District (EMWD) is one of the largest water providers in Southern California, serving a population of more than 758,000 in a 542 square-mile area. The district provides water service to approximately 136,000 retail customer accounts and also provides sewer service to 228,000 customer accounts located within its service area. In addition, the district supplies water on a wholesale basis to other water agencies, and recycled water to certain customers, such as agricultural sites, golf courses, and landscape irrigation sites. The district is a major consumer of electricity, costing it more than $14 million a year from an annual operating budget of $224 million. The EMWD facilities include two water filtration plants, two brackish groundwater desalting plants, five wastewater treatment plants, over 70 water storage tanks, over 100 pump stations, 47 sewage lift stations, and 29 water wells. As part of a balanced energy portfolio, EMWD uses a variety of renewable energy and alternative energy sources, including the following:

- Biogas-fired fuel cells (1,500 kW) Biogas-fired engines (1,465 hp)
- Natural gas-fired engines (20,000 hp)
- Natural gas-fired microturbines (540 kW)
- Photovoltaics (500 kW)

As an alternative to running costly backup power plants, power providers can use larger energy users to relieve the grid of excess demand at critical times. To meet this challenge, EMWD designed an energy curtailment plan to reduce non-essential energy use during critical periods of imbalance between electricity supply and demand on the grid. The electric curtailment potential for its operations is maximized to minimize impact on day-to-day operations.

During critical power need periods, a DR dispatch is triggered, and utilities and grid operators call upon energy reduction plans. DR programs are administered by utility companies, independent system operators (ISOs) or third-party aggregators that contract with utilities or ISOs. EMWD's DR activities are managed through three distinct DR programs. EMWD has 16 accounts enrolled with a third-party aggregator (EnerNOC, Inc.) to manage a portion of their load. They also have 3 accounts enrolled in the California Base Interruptible Program and 20 accounts enrolled in the California Agricultural/Pumping Interruptible Program. EMWD achieves demand reductions by shutting down major electricity-using equipment (e.g., pumps) at various treatment plants and pumping facilities, and by utilizing its biogas-fired and natural gas fired onsite generators. By participating in DR programs, EMWD helps to stabilize the electric grid and gets paid for the energy not used, and is provided an incentive year-round simply for being on call.

EMWD has currently 12.2 MW enrolled in the various DR programs in California, representing approximately 33% of its peak demand. Table 7-6 summarizes the EMWD's DR portfolio for 2013. The district has experienced several events and routine tests, all of which have proceeded smoothly. During a DR event, EMWD receives a thirty-minute advanced notification, and then manually shuts down a portion of its facilities, such as water treatment plants and pumping stations. EMWD has redundant resources available for supplying water, so the system reserves enable operators to run at reduced capacity temporarily. Financial payments through the DR programs have exceeded $600,000 annually, which are credited back to the facilities participating. The payments help offset electricity cost.

The most important benefit of DR is that it can be easily implemented by EMWD without requiring major changes or affecting its core mission of providing clean water to its constituents. Under the program terms, EMWD can choose to participate in an event at varying levels by choosing to run its equipment at lower levels or shutting them down completely. And it always has the option of manually restarting whenever necessary, although any financial benefits would be lost.

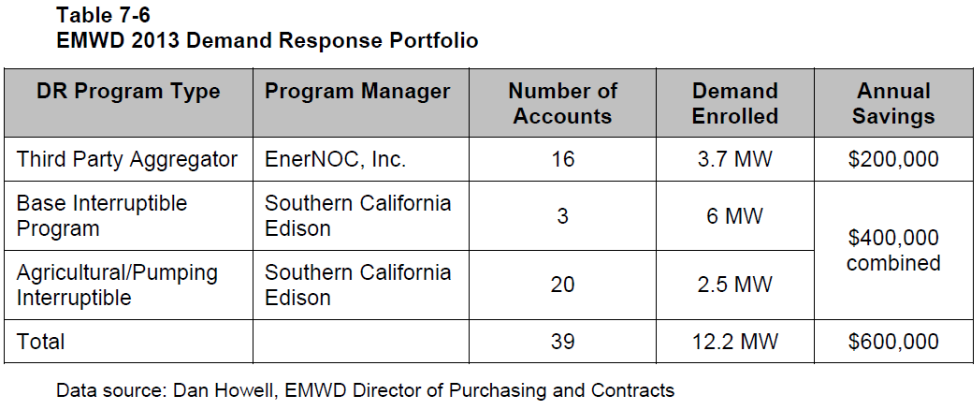


Table 7-6
EMWD 2013 Demand Response Portfolio

DR Program Type	Program Manager	Number of Accounts	Demand Enrolled	Annual Savings
Third Party Aggregator	EnerNOC, Inc.	16	3.7 MW	$200,000
Base Interruptible Program	Southern California Edison	3	6 MW	$400,000 combined
Agricultural/Pumping Interruptible	Southern California Edison	20	2.5 MW	
Total		39	12.2 MW	$600,000

Data source: Dan Howell, EMWD Director of Purchasing and Contracts

Initial testing of DR at two of EMWD's facilities has proven successful, so the district is evaluating other likely DR candidates among its 250 additional facilities. In addition, EMWD is investigating if some facilities can participate through an Auto-DR system. Auto-DR automates the implementation of DR events, enabling greater enrollment in DR programs and enhancing EMWD's ability to participate in other utility pricing programs, such as critical peak pricing, demand bidding, scheduled load reduction, and real time pricing.

7 SUMMARY

Clean drinking water and efficient wastewater treatment are vital services which ensure the health and well-being of communities everywhere. Meeting necessary regulatory requirements to ensure the health and safety of municipal populations while minimizing damage to local natural water supplies have been key industry priorities, with process optimization opportunities such as energy efficiency perceived as optional. More recently however, environmental concerns associated with climate change and carbon use have policy makers at all levels of government closely examining energy use across their organizations.

Unknown or misunderstood by their leadership, improving the energy efficiency of the water and wastewater treatment processes remains one of the largest energy efficiency opportunities for municipalities. These operations account for the greatest portion of the total electrical consumption in most municipalities by a large margin, and yet, are not targeted for efficiency improvements in most cases.

We recommend that municipalities create and implement strategic energy management policies that are synchronized with existing environmental and water use policies in order to bring needed visibility to the water-energy nexus across these organizations. Understanding where and how energy is used in an organization is the first step in successfully managing it. From there, energy policy can be created to effectively manage this valuable resource in all of its forms, including electrical.

With a clear energy picture established, closely studying the opportunities to lower electrical energy costs across departments, including water utilities, is recommended. As shown, 85% of electrical energy consumed in water and wastewater utilities is for pumping, wastewater aeration and bio-solids handling via variable torque rotating machines. In addition, it was established that greater than 80% of the total lifecycle cost associated with large pumps and blowers is the electrical energy cost required to operate them throughout their life. These two facts make these devices the largest target for energy efficiency improvements in water utilities today.

The benefits associated with better pumping system design, upgrading to energy efficient motors, variable speed drives, turbo-blowers and fine bubble diffusion technology was discussed in detail - each, a potential opportunity to significantly lower energy costs. Implementing advanced process control and optimization technologies was also discussed as was leveraging plant systems in the implementation of a demand management strategy in these operations. Combined heat and power (CHP) energy generation opportunities in wastewater applications was touched on briefly.

Finally, some of the barriers to making energy efficiency improvements that exist in most water organizations were explored, citing policy coordination, business culture and upgrade costs as fundamental road blocks.

We conclude by saying that going forward, human populations will continue to grow, and we fully expect regulators will demand that water be treated to ever higher standards for both human consumption as well as for discharge into our natural ecosystems. These conditions guarantee that greater amounts of energy, not less, will be required by water utilities in the future. Add new electricity cost pressures associated with carbon pricing and meeting more stringent emissions regulations, and most would agree, addressing the energy efficiency gap in water and wastewater utilities would be both prudent and wise.

We hope that city managers and planners agree by joining many of their colleagues in other industries in harnessing this significant business opportunity in their water utilities.

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