Energy Efficiency in Municipal Water and Wastewater Works

Overview*

Water and wastewater infrastructure is one of the major consumers of energy within municipal operations and service delivery. Figures differ widely (particularly as many municipalities still do not routinely collect or monitor all sites of municipal electricity consumption), but the indications are that on average water and wastewater accounts for some 17% of energy consumption in a South African metro. In terms of electricity consumption alone (i.e. excluding liquid fuel use for vehicles), the proportion is far higher – often representing as much as 25% of the entire municipality's electricity bill.

As electricity is a critical input for delivering municipal water and wastewater services – usually representing around 30% of the costs of running the service – such costs often represent a high and even unsustainable operating cost (Feng et al. 2012[1]). This sector has been shown to hold the greatest electricity savings potential within municipal operations and is thus a high priority for energy efficiency investment by municipalities (SACN, 2014[2]). Efficiency measures can achieve savings of up to 25% within this area (Feng et al. 2012).

Operational cost savings are even more critical when considering future urban energy demand. Cities are growing and demand for water and wastewater services will increase into the future. New technologies, aimed at meeting stricter water treatment quality requirements, are often more energy intensive. South African electricity prices are predicted to grow at a steep rate in the coming years. Efficiency offers an important opportunity to achieve greater levels of long-term environmental and fiscal sustainability.

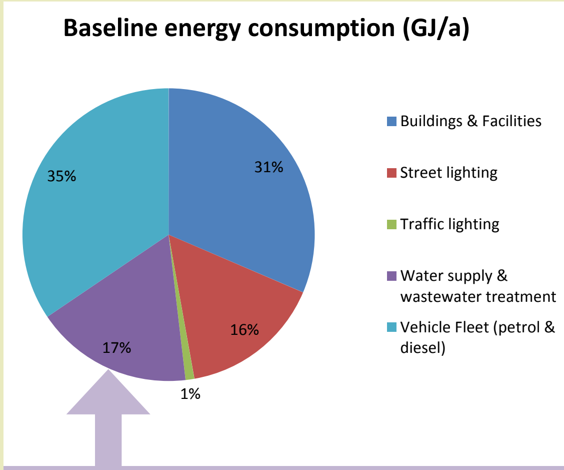
Energy is consumed at a number of points in the water and wastewater treatment infrastructure cycle.

1 Feng L et al. (2012) A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities. Energy Sector Management Assistance Program, technical report 001/12. World Bank, Washington, DC.

2 SACN (2014) Modelling Energy Efficiency Potential in Municipal Operations in the Nine Member Cities of the SACN, produced by Ndlovu, M, and SEA

* Much of the information in this chapter is taken from: Feng L et al. (2012). A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities. Energy Sector Management Assistance Program, technical report 001/12. World Bank, Washington, DC. The text of this publication may be reproduced in whole or in part and in any form for educational or non-profit uses, without special permission provided acknowledgement of the source is made.

Figure 1: Average metro baseline energy consumption per sector (GJ)



In terms of electricity consumption alone, Water Supply and WWTW represent around 25% of all municipal electricity consumption and offer the greatest energy efficiency savings opportunities.

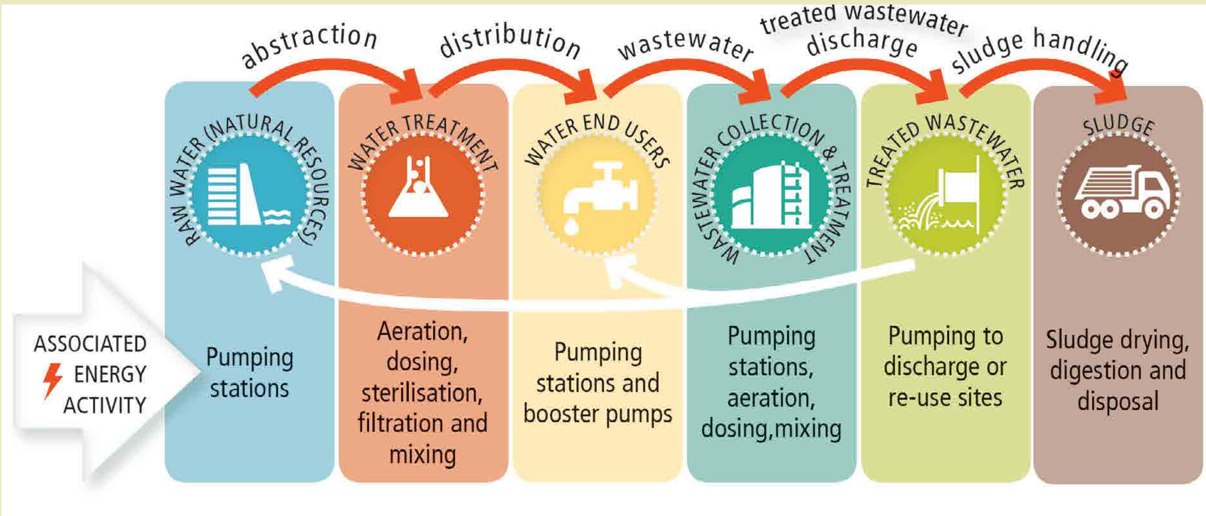
Source: South African Cities Network (2014) Modelling Energy Efficiency in the Nine Member Cities of SACN.

As electricity is a critical input for delivering municipal water and wastewater services – usually representing around 30% of the costs of running the service – such costs often represent a high and even unsustainable operating cost.

Establishing baseline costing for energy within the Municipal Water Services Sector

Financial ring-fencing of water services provision is a legal requirement in terms of the Water Services Act (1997: Section 20 (1)). The Department of Water Affairs quality assurance benchmarking initiative (the Blue and Green Drop) and the SALGA-WRC Municipal benchmarking initiative are focusing more attention on this compliance parameter. Establishing baseline costing for energy, given that it is usually the single highest cost in delivering the service, is good management practice and will provide a strong basis from which to calculate and motivate the financial opportunities that efficiency measures may provide.

Figure 1: The water services cycle



Source: Adapted from SALGA Energy guideline series (see references)

The relative energy consumption of a water supply system will differ substantially depending on the location of the raw water and the terrain in which the bulk supply must be distributed. Gravity-fed systems will obviously substantially reduce pumping costs. Ground-water supply systems are more energy intensive than surface water-based systems. However, groundwater usually requires much less treatment than surface water, often only the chlorination of raw water, which requires very little electricity.

By far the most energy using activity in all areas of water supply, whether ground or surface, is that of pumping.

Energy usage in wastewater treatment plants will also vary substantially, depending on treatment technologies which are often dictated by pollution control requirements, land availability and budgets. Advanced wastewater treatment with nitrification can use more than twice as much energy as the simple trickling filter system. Pond-based treatment is low energy but requires large land area. In wastewater treatment plants most of the electricity is consumed by the aerators and mixers.

Administrative and production buildings of water and wastewater treatment plants use a small percentage of the total electricity consumed within these facilities.

The table below provides a guide to the relative energy intensities of the different elements of the water supply and distribution infrastructure system for South Africa. For optimal interventions a municipality would need to have a good idea of what the most energy intensive aspects of their system were.

Table 1: Energy consumption range for the South African water supply chain

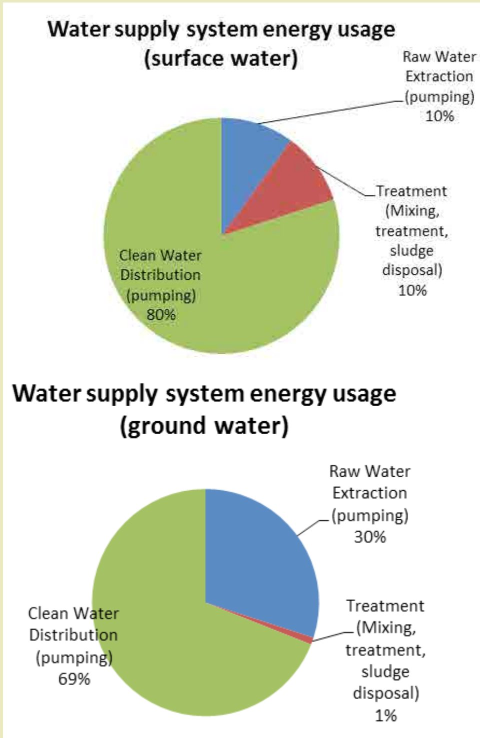
Process	Min (kWh/Ml)	Max (kWh/Ml)
Abstraction	0	100
Bulk distribution	0	350
Water treatment	150	650
Reticulation (potable and waste water)	0	350
Wastewater treatment	200	1,800

Source: Swartz et al. (2013) in SALGA Guideline Energy Series EE and RE in Municipal Water and Wastewater Treatment.

Energy efficiency approaches: technologies and interventions

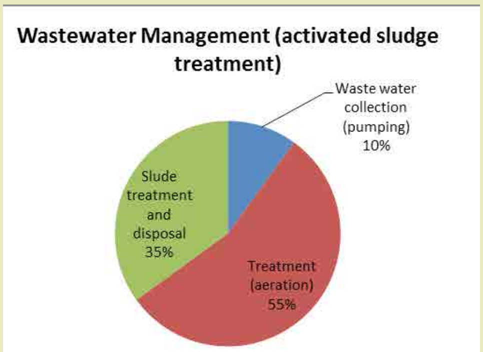
The major technologies that consume energy within the water services system are those related to the activities of pumping and water treatment. However, approaches to efficiency within the sector increasingly emphasise that a system approach is important for maximising cost-effective energy savings. This requires optimisation of system architecture (right-sizing of systems – and dynamically as they adapt to new demand regimes) and operation (energy management systems), rather than just focussing on specific equipment or technologies in isolation. Establishing best practice and ongoing monitoring and maintenance is a vital element in maintaining efficiency of systems.

Figure 3: Water supply energy usage for surface and ground water systems, noting that figures are global rather than local



Source: SEA adapted from Feng L et al (2012). A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities. Energy Sector Management Assistance Program, technical report 001/12. World Bank, Washington, DC.

Figure 4: Wastewater management energy usage noting that figures are global rather than local



Source: SEA adapted from Feng L et al (2012) A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities. Energy Sector Management Assistance Program, technical report 001/12. World Bank, Washington, DC.

Most of this chapter concentrates on the water service system (water supply and wastewater treatment), however working with water demand management is also important as reduced demand for water will translate into reduced energy required to operate the system. In addition, the water system also offers opportunities for renewable energy generation. These include biogas to energy from wastewater treatment and microhydro or mini hydropower generation from within the water distribution system.

Energy Efficiency in Water and Wastewater Treatment Works: Key elements

The 'system' approach aims to minimize energy throughout the varied elements of the system and in such a way that the entire system is optimised for water, energy and cost effectiveness. This also requires a dynamic approach whereby demand and supply elements are integrated to ensure system is constantly adjusted to new demand levels post efficiency achievements.

Figure 5: Energy efficiency in water and wastewater treatment works: key elements

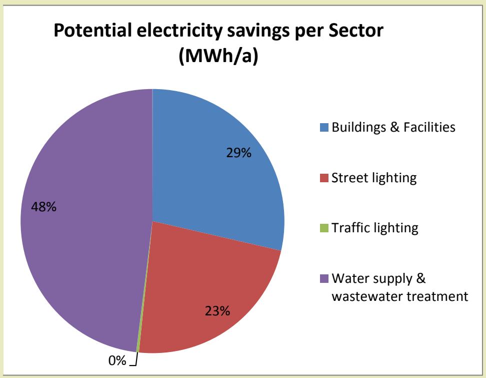
Water Supply-Side Efficiency Measures	**Water Demand-Side Efficiency Measures**	**Wastewater treatment and Renewable Energy Generation**
		
Network pressure management (leak and loss reduction) Operations and maintenance Pumping systems (improving, bringing in new technologies and and continuous right sizing pumping systems – using VSD for example – after reducing demand) Water treatment (upgrading aeration blowers, etc.)	Water efficient household appliances Industrial water reuse Leak and water waste reduction in household and industrial sectors	Wastewater treatment processes (most efficient within given context and sanitation requirements) Anaerobic digestion of sludge Biogas to energy (15% or more of power requirements) Micro or mini hydro power generators in water distribution pipelines

Source: SEA, adapted from Feng et al. (2012) A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities. Energy Sector Management Assistance Program, technical report 001/12. World Bank, Washington, DC.

Implementation

When all potential efficiency interventions are considered, the area of water and wastewater treatment in municipalities offers the greatest electricity savings opportunities. A study on South African metros indicated that this sector could contribute 48% towards all known electricity efficiency opportunities within the operations of a municipality (SACN, 2014). Given this savings potential, this sector should be viewed by municipalities as a high priority for energy efficiency investments, with the potential for high returns – saving the municipality money within a short period of time.

Figure 6: Potential electricity savings per sector (MWh/a)



Source: SACN (2014) Modelling Energy Efficiency Potential in Municipal Operations in the Nine Member Cities of the SACN, produced by Ndlovu, M, and SEA.

According to Feng et al. (2012) review of existing literature, most of the common technical measures applied to address energy efficiency in water and wastewater treatment plants generate 10 to 30 percent energy savings per measure and have 1 to 5 year payback periods. The financial viability of energy efficiency in wastewater works is dependent on a couple of factors including: conditions of the facility, technologies used at the water works, energy prices and other factors affecting the technical and financial operations of the individual plants. Feng et al. (2012) identify two areas with most potential – pumps of most types and functions, and aerobic wastewater treatment systems. Potential energy savings include:

Pumps and Pumping (Common potential ranges: 5 – 30%):

- 5 – 10% by improving existing pumps
- 3 – 7% through improvement to new pumping technology (pump technology is generally mature)
- Gains up to 30% are possible through maintenance improvement and closer matching of pumps to their duties (such as, using VSDs).
- More complex and large-scale pumping energy savings are feasible but frequently show marginal payback using current financial analysis.

Aerobic Sewage Treatment (Up to 50%)

- Simple gains of up to 50% are possible on some aerobic wastewater systems by aligning control parameters with the discharge standard
- Up to 25% in activated sludge process wastewater plant

Benefits of energy efficiency within a Water and Wastewater Treatment Works process include:

- Lower cost to consumer: these cost savings come in the form of direct electricity savings as well as savings in maintenance and replacement costs
- Ability to serve new and growing urban populations
- GHG mitigation
- Energy security
- Long-term fiscal stability for municipal services
- Enhance a municipality's Blue Drop/Green Drop status

Table 2: At a glance: remedial actions to improve energy efficiency

Typical short term remedies, all low cost giving quick payback and savings of up to 15%	Longer term remedies, larger investments, but with savings potential of 30 – 40%
• Visibility of individual pump efficiencies allows improved scheduling • Wherever possible run most efficient pumps, particularly in peak tariff periods • Do not run pumps in parallel into same column • Remove redundant / mismatched units in parallel • Change motor speed or trim the impeller • Replace low cost components e.g. by-pass flow assemblies • Reshuffle pumps to ensure unit matches requirement	• Refurbish pump • Replace impeller • Replace pump • Pump / system coating • Install VSD • Overhaul system – pipes, valves etc. • Improved maintenance planning • Develop best practices operations manual

Source: John Schulkins, Business Development Director TAS Online, presentation to Urban Energy Network meeting, October 2015.

Additional cost savings can be achieved through efficiency interventions

The installation of high efficiency motors may provide the following benefits over standard motors:

- Cooler operating temperatures due to lower heat generation, resulting in lower maintenance and a longer life.
- Improved tolerance to voltage variations and harmonics.
- Extended manufacturers' warranties.

Aerator-use pattern optimization provides:

- Reduced maintenance costs and extended life span of aerators where the aeration hours are reduced.

Source: SACN (2014) Modelling Energy Efficiency Potential in Municipal Operations in the Nine Member Cities of the SACN, produced by Ndlovu, M, and SEA.

Although the data is already relatively old and many new interventions have taken place in the intervening years, the assessment done on metros for efficient pumps and VSD retrofits (SACN, 2014) indicates that substantial energy, carbon and financial savings are possible.

Table 3: Indicative potential energy, carbon and financial savings from energy efficiency retrofits (efficient pumps and VSDs) in water supply and wastewater treatment plants in South African metros

Water supply and wastewater treatment plants	Total current consumption p.a.	%saving	Existing retrofit penetration	Proportion of energy consumption by retrofitted plant	Proportion of energy from unretrofitted plants	Total remaining saving potential for full retrofit	Potential carbon savings from retrofits	Financial saving
Units:	MWh/yr	%	%			MWh/yr	tCO_2e/yr	R/yr
Buffalo City	10,208.50	22%	7%	5%	95%	2,078.29	2,140.64	R 1,143,062
Cape Town	237,392.17	22%	0%	0%	100%	51,039.32	52,570.50	R 28,071,624
Ekurhuleni	58,764.96	22%	0%	0%	100%	12,634.47	13,013.50	R 6,948,957
Ethekwini	71,839.02	22%	0%	0%	100%	15,445.39	15,908.75	R 8,494,964
Johannesburg	180,000.00	22%	0%	0%	100%	38,700.00	39,861.00	R 21,285,000
Mangaung	121,576.66	22%	0%	0%	100%	26,138.98	26,923.15	R 14,376,440
Nelson Mandela Bay	50,447.09	22%	0%	0%	100%	10,846.12	11,171.51	R 5,965,368
Tshwane	47,684.00	22%	0%	0%	100%	10,252.06	10,559.62	R 5,638,633

Municipal focus areas

Broadly, typical system inefficiencies that will require addressing include inadequate pump specifications, change in operating conditions and lack of regular and structured maintenance. Identified solutions include installing variable speed drives (VSDs) for large pumps and replacing inefficient pump sets for all water pumping systems and upgrading aeration blowers for optimising efficiency in wastewater treatment. Network Pressure Management is important for efficiency and loss minimisation. Establishing and implementing a maintenance regime with the associated, necessary budgetary resources is vital.

The following areas of implementation will be outlined:

- Pumping systems and motors
- Network pressure management and leak and loss reduction
- Aeration in wastewater treatment
- Anaerobic digestion in activated sludge wastewater treatment
- Load shifting opportunities in water and wastewater works

(Key sources in the implementation steps below include: The Energy Trust of Oregon, 5/12[3], Feng et al. (2012[4]) and the WRC Research Report TT 565/13.)

Pumping systems and motors

It is important to ensure hydraulic system equipment is suited to load and equipment is receives regular maintenance. Pump efficiency is critically dependent on maintenance and operational aspects. Development of a best practice operations and maintenance manual will ensure these activities are regularly conducted.

Operations and maintenance measures to improve pumping system efficiency, which can deliver a simple payback of less than one year:

- Determine pump system efficiency over the range of pumping requirements and stage pumps for optimum energy use.
- Adjust basin fluid levels to decrease pump head and reduce pump load. Wet-well levels can be raised in pumping stations to reduce pump head.
- Identify and adjust poorly calibrated valves that decrease pump efficiency.

Capital improvements to pumping systems:

- Pumping accounts for as much as 67% of the energy used to operate a typical municipal treatment facility (water and wastewater). Improvements can substantially reduce facility energy use and costs.
- Install VSDs on pumps that move varying volumes of fluid to adjust speed to match pumping demand in real-time. When less pump flow or pressure is required, pump speed and accompanying energy use will be reduced.
- Replace worn or inefficient pumps with new, high-efficiency pumps that use less energy and operate with less maintenance and downtime.
- Oversized pumps that operate at constant flow are good candidates for impeller trims. Trimming the impeller is frequently a lower-cost alternative to making larger capital investments in pumps, motors or control technology.
- Install different sized pumps in new plants or during plant expansion. As seasonal flows change, controls can bring different pump combinations online to match pumping need.
- Improve piping and valves to decrease friction losses

3 Energy Trust of Oregon: Water and Wastewater Treatment Energy Savings Guide, 5/14: www.energytrust.org/industrial-and-ag.

4 Feng L et al. (2012). A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities. Energy Sector Management Assistance Program, technical report 001/12. World Bank, Washington, DC

Evaluating pump efficiency:

Standard practice in evaluating pump selection on the basis of efficiency should be a comparison of pump options under specific operating conditions prior to pump selection, i.e. density and type of medium, flow velocity, pipe design, spares availability, maintenance and repairs skill at hand, etc. It is possible that initial higher capital cost pumps may have a longer life cycle and lower operations and maintenance costs associated, thus the full lifecycle costs should be compared (WRC Research Report TT 565/13).

Water distribution:

The efficient management of water distribution across the supply system is an important opportunity to achieve energy and cost reductions. This is a complex area and the optimisation of water distribution of large systems needs to be automated. Any modelling required to achieve optimal performance needs to be based on extensive historical records. If minimum emergency levels are not maintained in all reservoirs it may become necessary to pump during peak periods which will negate any energy savings achieved (WRC Research Report TT 565/13).

Managing seasonal peaks:

Design and implement a flexible system that allows facilities to adjust to high and low seasons, ensuring that the system does not have to run at a maximum demand capacity throughout the year.

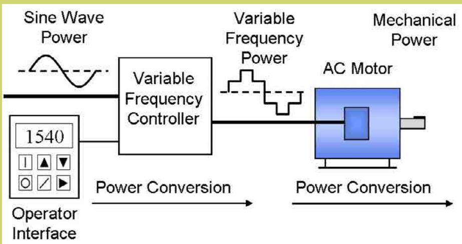
Variable Speed (or Frequency) Drives

Optimal energy savings are achieved by combining newer, more efficient pumps with variable speed drives. Without the variable speed drives, optimal energy savings cannot be achieved.

Variable Speed Drive (or adjustable speed drive) is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage. Over the past 40 years power electronics has greatly improved the cost, size and performance of this technology through advances in semiconductor switching devices, drive topologies, simulation and control techniques, and control hardware and software.

Variable Speed Drives improve pump and fan efficiency by reducing motor shaft speed to the minimum revolutions per minute, rpm, necessary to satisfy flow requirements. The flow produced by a pump or fan is directly proportional to shaft speed, while the power requirement for that flow is proportional to shaft speed cubed. For example, at 80 percent of full-load flow, a pump or fan operates at 80 percent of full load rpm, but uses only 51 percent of full-load power, yielding a steady state energy cost reduction of 49 percent. At 50 percent of full-load flow, the pump or fan operates at 50 percent of full-load rpm, but uses only 13 percent of full-load power, yielding an energy cost savings of 87 percent.

A variable-speed (or frequency) drive consists of the following three main sub-systems:



The **AC electric motor** used in a VFD system is usually three-phase induction motor. The VSD **controller** is a solid-state power electronics conversion system consisting of three distinct sub-systems: a rectifier bridge converter, a direct current (DC) link, and an inverter. The **operator interface** provides a means for an operator to start and stop the motor and adjust the operating speed. The operator interface often includes an alphanumeric display and/or indication lights and meters to provide information about the operation of the drive.

Source: C J Cowie at the English language Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9890713 and curid=3139500

An operations and maintenance guide to identifying the sources of energy waste and possible corrective measures within water and wastewater pumping systems

Mechanical problems in the Pump

Pumps wear out over time. This can be seen by viewing the original pump efficiency curves and comparing them with current data from the field. If the pump is no longer running on its curves, there are a number of reasons that must be investigated:

- worn or modified impeller
- excessive roughness in the casing
- worn bearings
- clearances that have drifted out of tolerance
- pump not running at stated RPM

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

Inefficient motors

Recent improvements in motor technology have resulted in motors that are substantially more efficient than old, standard efficiency motors. It is easy to compare the efficiency of a new motor with that of an existing motor and determine the savings in energy. In general, large motors that run most of the time will have a short payback period while motors that only run occasionally, such as stormwater pumps, will have a much longer payback period and are not likely candidates for replacement.

Poor pump selection or a change in the system

Sometimes a pump may not have been sized correctly, or may have been sized correctly but the system may have changed, which affects the operating point. This may occur when the system head is higher than expected at that flow rate due to smaller pipes that the pumps was sized for (or pipes becoming rougher over time or an important valve mistakenly closed), or a tank water level that was not considered – or has since changed – in design. A quick indicator of this is a pump that is not running at its nominal flow, such as a 2000 litre/ minute pump that is running at 1500 litres/minute.

Incompatible pump combinations

A pump which is efficient when running alone may run poorly when in combination with other pumps. An indication of this problem would be were a nominal 4500 litres/min pump that usually produces roughly 4500 litres/min when running by itself only produces 3400 litres/min when run in combination with other pumps. This usually indicates a lack of capacity in the piping system as the pumps 'fight' with one another. The pump with the highest head wins. The long term solution usually lies in adding piping capacity (i.e., flattening the system head curve). However, in the short run, avoiding bad combinations, usually by pumping at a steadier rate, can reduce energy waste.

Pumping through control valves

In some cases a pump may be producing too much pressure for the desired system, especially for a system with no storage. The pressure can be reduced using a control valve (pressure reducing or manually controlled). However this is not energy efficient. Reducing the pump speed with a variable speed drive (VSD), trimming the impeller or installing a lower head pump will all result in energy savings when compared with a throttled valve.

Pumping through undersized or rough pipes

More energy is required to pump water through pipes with high lead loss than lower head loss. Excessive head loss could be due to undersized pipes or pipes that may have been correctly sized at one time but have lost carrying capacity due to tuberculation or scale. Incorrectly closed valves can also have the same effect. Increasing the system by adding piping, cleaning pipes, or opening valves can reduce energy use. This problem of inadequate pipe capacity is usually not severe in water distribution piping since most of the energy is used to raise the water from one pressure zone to the next and system head curves are relatively flat. It is usually most critical in long transmission mains and sewage force mains (rising mains) where more of the energy is directed to overcoming head loss rather than lift.

Poor layout of pressure zones

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

Oversized pumps

Engineers are taught to be conservative in their design, but oversizing of pumps can lead to energy waste. If a pump is sized to efficiently produce 100 litres per second (L/s) at peak flow but the normal demand is 20 L/s, the pumps will not be efficient. Right sizing of pumps so that they will be operating near their best efficiency points is the optimal solution. For example, where the (rare) peak demand is 100 L/s, the lowest capital cost design may be two 100 L/s pumps, but if the average flows are much lower, it will be better to three 50L/s pumps, which can still meet peak demands with one pump out of service, but will normally be operating near their best efficiency points.

Source: Walski T and Andrew T (2015). Energy Savings in Water and Wastewater Systems, A Bentley White Paper.

Network pressure management and leak and loss reduction

Rehabilitation of leaky networks and active leakage control through pressure management offers important efficiency opportunities. These should be identified and brought together in an holistic and proactive Leakage Management Strategy, with associated water loss reduction targets. Actions include:

- Undertake pressure reduction management in water distribution systems/networks. Integrate and consider peak demand needs and that of adjacent supply zones in the design.
- Replace redundant or aged water distribution infrastructure and do ongoing repairs and maintenance (asset renewal projects).
- Install metering to check and monitor supply zones for losses, and minimise repair times for visible and detected leaks.

- Where an unanticipated supply or pressure problem arises (e.g. unexpected changes in flow or pressure from a burst pipe) a rapid, reactive pressure control should be undertaken.

Managing leaks and losses also requires engagement with water users. Best practice in leak and loss reduction within the broader water user community indicates positive outcomes can be achieved through:

- Implementing monitoring system to detect leakage and reconcile unaccounted losses combined with a leak repair programme.
- Extensive community and council consultation of the causes and interventions proposed to reduce water losses. Use a multi-disciplinary approach that involves the water technicians, meter readers from the finance department, billing department, GIS staff, councillors and community.
- Use local skilled and unskilled labour to repair and replace faulty or dilapidated plumbing fixtures.
- The introduction of a rising block tariff for water consumption can save water and related energy costs. There are many other water demand management approaches that should be considered, including awareness campaigns, promotion of low flow plumbing fixtures and engaging high volume users to jointly identify potential water savings operations modifications.[5]

Aeration in wastewater treatment

Aeration uses between 40 – 60 % of the energy consumed in a typical wastewater treatment plant in typical activated sludge treatment processes. Much of the remaining energy consumption is pumping related – and the section of pumping above pertains.

Development of new or alternative wastewater treatment processes and systems (both centralized and decentralized) should aim towards low-energy processes, especially regarding the high energy requirements for aeration in biological systems (WRC TT565/13).

Simple operations and maintenance, O&M, adjustments to existing aeration equipment can pay back quickly in reduced energy costs:

- Optimise the dissolved oxygen (DO) set point to reduce the amount of blower energy. It's not uncommon for systems to operate with DO levels that exceed what is required.
- Adjust the position of DO sensors to provide a more accurate assessment of DO levels.
- Adjust control systems to optimise mechanical mixing and bubble diffusion.
- Implement the Most Open Valve strategy in which the aeration zone with the highest oxygen demand is opened fully to reduce pressure at the blowers. DO levels in remaining aeration zones are controlled by valves that maintain the proper DO set point for each zone.
- Adjust the placement of mechanical mixers for more efficient oxygen transfer.

Possible upgrading of aeration basin technology:

- Upgrade from coarse bubble diffusion to fine bubble diffusion to increase the efficiency of oxygen transfer and reduce blower load while maintaining proper DO control.
- Install automated DO controls to reduce aeration energy by up to 40% compared to control systems that use manual sampling. Systems that rely on manual DO sampling often operate at levels that are much higher than necessary. Installing a DO sensor with integrated aeration control allows levels to be maintained within a narrower band, thereby reducing blower load.

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5 Swartz et al. (2013) Energy Efficiency in the South African Water Industry: A compendium of best practices and case studies, Research Commission Research Report TT 565/13.

- Add DO probes to different zones of the aeration basin to provide more accurate DO readings and optimise aeration for each zone.
- Upgrade systems that use mechanical mixing by installing controls that cycle on and off in response to process control parameters.
- Retrofit mechanical mixers with variable speed, or frequency, drives (VSDs) which adjust the speed of the mixer motors to match the process needs in real-time. Typical simple payback of 2 – 7 years.

Improve the efficiency of the blower system through operations and maintenance measures:

- Adjust controls to optimise blower staging.
- Optimise DO set points to allow for blower system flow reduction.
- Find and reduce obstructions to blower airflow to decrease the pressure in the blower system, with accompanying energy savings.

Capital improvements to blower system:

Up to 75% of the lifecycle cost of a blower system is attributable to energy use. When replacing an existing blower system, select a blower appropriate for the application.

- Install controls that allow staging of systems that have multiple blowers. Control systems optimise blower staging based on system requirements.
- Upgrade to a high-efficiency turbo blower system, which uses very high-speed motors and air-bearing technology to efficiently produce airflow. Turbo blower systems are typically VSD-equipped, and are capable of providing a range of airflow based on DO sensor feedback. Typical simple payback of 2.5 – 7 years.
- Add VSDs with sensor control to existing centrifugal blower systems to adjust the speed of the blower to system demand, thereby reducing energy use when oxygen demand is lower. Typical simple payback of 2 – 6 years.
- Identify oversized blowers and investigate purchase of more appropriately sized blowers.

Figure 7: Aerator at Kelvin Jones, Nelson Mandela Bay

Source: Energy Cybernetics (2008) SACN, 2014

Anaerobic digestion in activated sludge wastewater treatment

Anaerobic digestion accounts for some 14% of the energy used at a typical activated sludge wastewater treatment plant (Oregon Energy Trust, 5/14[6]).

Improve the efficiency of the digester mixing (reducing energy demand and improving digester gas yields):

- Adjust existing digester mixing systems to use the minimum number of mixers possible for adequate mixing of influent and a high volume of gas.
- Optimise mixer speed in systems with VSD-controlled motors to reduce energy use while maintaining a high output of digester gas.
- Replace mixing systems that are not functioning correctly or operating inefficiently with higher efficiency systems.
- Upgrade existing systems such as gas lance or draft tube systems to a linear motion mixing system.

Further energy savings can be realised from reducing pressure on the water feeds and also through power factor correction.

Load shifting opportunities in water and wastewater works

While municipalities can realise energy and financial savings from energy efficiency interventions in the water treatment system, load shifting holds an additional significant financial saving. Financial savings of up to 40% can be realised by running the water pumps and reservoirs during off-peak hours, when electricity costs substantially less (Energy Cybernetics, 2008 in SACN 2014).

Pumping stations can be run at their highest possible capacity during off-peak periods in order to build reservoir capacity. During peak electricity demand periods, the reservoir would be full enough to switch off some of the load. Customers will continue being supplied by the stored capacity provided by the destination reservoirs.

In wastewater treatment plants load shifting cannot be done in the pre-treatment chambers as they have to operate 24-hours a day. Flexibility exists in the aeration and mixing chambers which can be switched off for a longer period-up to 12 hours (Energy Cybernetics, 2008, in SACN, 2014). Load shifting can therefore be focused on this section of the wastewater treatment works. Load shifting can be more easily done in a plant with VSDs than those without. It might not be possible to switch off all extra pumping manually, but VSDs can be used to over-aerate the effluent during off-peak periods and then be switched off during peak hours or periods of constrained electricity supply. If load shifting is considered in wastewater treatment plants, microbial loads may be an issue and they would need to be monitored.

For load shifting to work municipalities or wastewater utilities will have to do the following:

- Install meters to monitor the exact operation of the aerators (real time metering) and an energy management system;
- Draft detailed designs of load shifting opportunities: identify units with high energy consumption during maximum demand periods when high tariffs apply and shift work periods to time spans when lower tariffs apply.
- Maintain supply MVA against set point MVA and load shed when exceeding set point.
- Gather dissolved oxygen data from the wastewater plants to determine how the aerators typically aerate the plant i.e. whether they over, under or just aerate to the required level.
- Lighting and air conditioning efficiency in offices and control rooms

6 Energy Trust of Oregon: Water and Wastewater Treatment Energy Savings Guide, 5/14: www.energytrust.org/industrial-and-ag.

Building energy consumption within municipal water services provision is a relatively small component of total energy consumption. These areas of efficiency are looked at in more detail in the chapter on Energy Efficiency in Buildings. Major areas for consideration include:

- Use occupancy sensors to turn off lamps in unoccupied spaces.
- Upgrade lighting systems to more efficient technologies, notably T5 (high-bay) or T8 (task lighting) fluorescent lamps. This can reduce energy use by up to 50 percent. Consider installing LED lighting.

Establishing an energy management process

Institutionalising energy management within water and wastewater utilities will provide the greatest chance of successfully achieving the energy efficiency potential of this sector. An Energy Management Strategy that links water, energy and other areas of facility management into an integrated approach will provide a strong policy basis. Municipalities should develop energy efficiency targets within their strategic planning processes, and include specific targets for energy efficiency in their operations in the Water Services Development Plans (WSDPs). Energy audits should be undertaken on a yearly basis. It is anticipated that targets for the South African water sector will be developed, encouraged and regulated through the Department of Water Affairs' Blue Drop and Green Drop programs (Swartz et al., 2013[7]).

Energy efficiency should form a major criterion when planning new water supply and sanitation projects, and funding programs should use specific targets in the decision-making process. In addition to the energy efficiency measures discussed in this chapter, wastewater treatment facilities should be encouraged to implement biogas energy production projects and water supply and distribution projects should investigate the feasibility of mini-hydropower generation in water distribution systems.

As water demand management programs also result in energy savings, energy efficiency should be included in water services providers' water demand management and water conservation programs. Water supply and sanitation processes that use no energy, should be actively encouraged. Examples of these systems are on-site sanitation, slow sand filtration and rainwater harvesting (use of storage tanks).

Development of new or alternative wastewater treatment processes and systems (both centralized and decentralized) should aim towards low-energy processes, especially regarding the high energy requirements for aeration in biological systems (Swartz et al., 2013).

Energy Management Process Steps

1. Establish organisational commitment and an energy management team (EMT)

- Commitment must come from senior management to establish an EMT.
- EMT must include representation from different units within a utility (from engineering to accounting), to ensure coordination across division boundaries.
- A committed and enthusiastic champion should be identified to drive the work.
- The EMT must have clear responsibilities that are embedded within the performance management system and regular reporting of progress is required.
- The EMT must have resources to support viable initiatives.
- A training budget is important to ensure training is facilitated at all levels.

7 Swartz et al. (2013) Energy Efficiency in the South African Water Industry: A compendium of best practices and case studies, Research Commission Research Report TT 565/13.

2. Conduct a facility energy assessment: Baseline, EE opportunities and Prioritisation

- A basic understanding of energy use and cost of the utility must be obtained to help identify energy efficiency and related cost savings opportunities.
- The initial baseline analysis need only involve a walkthrough audit of the facilities, staff interviews and desk analysis of metering and billing data to reveal areas for immediate improvement and those for further investigation.
- Limited audits may be conducted to confirm key efficiency opportunities.
- Identify and prioritise opportunities based on: identified energy efficiency measures, technical feasibility, cost and rate of return, available funding. Focus on the most promising systems for quick initial wins.

3. Develop an Energy Management Plan

Once an initial set of priorities have been identified and remedies proposed (contained in an assessment report) and Energy Management Plan will facilitate translating priorities into actions. This would include:

- Goals/targets: State your goals and quantify the reductions you aim to achieve (energy and cost-wise).
- Activities based on priorities: list the interventions to be undertaken.
- Implementation arrangements: will it be done by the municipality or through contracted services, outline procurement schedules and financing plans.
- Responsibility and Time frames.

4. Implementation of planned activities, monitor, evaluate and verify results

- Implementation of projects will require the business case for each intervention to be developed and, as required by a financier, investment grade energy audits.
- Arrangements for implementation will need to be determined: will the project be done in-house, or through contracted services; will it be financed through own-funding (budget or loan), or developed as a stand-alone project, with a project developer who brings their own financing.
- Set up monitoring for ongoing visibility of the impact of interventions and measure effectiveness (savings) against the baseline. Savings may be used to finance further improvements.
- Continue with ongoing training of staff to ensure operations and maintenance continue to achieve the required efficiencies.

Identified EE Measures

- Installing VSD for large pumps
- Replacing inefficient pump sets
- Upgrading aeration blowers
- Establishing and implementing a Maintenance Regime
- Network Pressure Management

Energy efficiency should form a major criterion when planning new water supply and sanitation projects, and funding programs should use specific targets in the decision-making process

Developing the project: business models, financing and contracting

Business models

Own-executed: this would involve a municipality drawing on their own staff to design and implement the necessary changes.

Consultant with fixed payments: here a consultant would be appointed to help the municipality design and implement the project. The consultant would receive a fixed lump-sum fee for services. This is a very low risk model, but may also be low service in that the consultant is not incentivized to ensure that the systems bring maximum savings.

Range of Energy Service Performance Contracting options: a range of options (increasing in risk, but also in service level) in which a consultant or energy services company (ESCO) receives performance based or savings based payments, depending on contract terms. These contracts may involve Public Private Partnership arrangements.

Financing

Internal financing/municipal budget is an important, though given constraints, often limited funding source. With a good Energy Management Plan in place, internal funds can be used to phase in pumping station retrofits.

External financing instruments can assist with more capital-intensive projects, or projects with relatively long payback periods. The following are some financing instruments to partially or fully fund EE investments:

Deferred payment financing: also considered an internal financing source, is a short-term borrowing process where the utility makes payments to the vendor soon after receiving supplies and services. Such arrangements may allow utilities to purchase high efficiency equipment to upgrade facilities if the incremental cost can be recouped quickly through operational savings.

Energy Service Performance contracting: here the service provider covers the project cost using its own funds or arranging for third party financing. Repayment is through energy savings resulting from the project. Specifics will depend on contract terms.

Partial risk guarantee programmes, reduces risk by guaranteeing a portion of any default by the utility to the lender.

Municipal bonds: these are sometimes used for large investments. To be effective the municipality needs to have a good credit rating, but if so this can be a low-cost, tax-exempt, long-term financing option for energy efficiency investments. The City of Johannesburg has issued a successful "Green Bond" for financing of its environmental/ climate response projects.

Barriers and opportunities

Barriers range from institutional and regulatory, knowledge and know-how and accessing finance. Much however is currently underway in this area and many of these barriers are being addressed and/or new opportunities are arising.

Water and wastewater tariffs are often not based on real costs of supply and municipalities struggle to cover maintenance and infrastructure renewal. Financial ring-fencing of water services provision is a legal requirement in terms of the Water Services Act (1997: Section 20 (1)). The Blue and Green Drop initiatives are focusing more attention on this compliance parameter.

Municipal budgets are separated between capital and operational and the fiscal system emphasizes upfront cost rather than lifecycle cost. This makes it difficult to motivate for more expensive equipment, even though it will save money over its lifetime. In addition the responsibility for payment for energy consumed usually sits elsewhere in the municipality and water utility officials handling day to day operations may be entirely divorced from this aspect of management.

A well-developed business case for each efficiency remedy or technology will help to motivate to procurement officials; and those involved in procurement should be trained to select the best pumps. This approach must include lifecycle considerations.

Energy efficiency is often not a required element for assessing the performance of water utilities. Protecting public health is of such critical importance that this aspect of water management trumps most other interventions.

Municipal 'champions' wishing to take energy efficiency forward should thus start with interventions that also enhance the water treatment and distribution operations. The Department of Water Affairs 'Green Drop' and 'Blue Drop' monitoring and achievements programme have now also brought in energy efficiency as a 'point scoring' management element within the evaluation system. Undertaking efficiency interventions will enhance municipal scores.

Knowledge and Know-how of officials: Many water utility managers and officials don't have the necessary information about energy efficiency opportunities and their costs and benefits, or the capacity to undertake efficiency optimisation. This includes not having adequate access to information or skills relating to sourcing financing and engaging contractors to undertake the interventions.

The sharing of information, particularly peer to peer learning, through such portals as SALGA, the Urban Energy Network meetings and Website, SACN's Water Management Group and other forums is important in addressing this. Benchmarking status, such as the Blue/Green Drop systems, and recognition of achievements will also enhance knowledge on this area of management. Tools to support rapid assessments would also be beneficial.

Access to and availability of finance: Few municipalities have ready budget to invest in detailed audits, optimization studies and new, energy efficient equipment. Although the interventions can be shown to be financially viable, producing quick returns on investment, few municipalities have sufficiently high credit ratings to obtain commercial financing (loans) to undertake the investments.

In order to avoid piecemeal interventions a municipality should undertake an initial scan and identify priorities. Thus, even if interventions must be staggered over time in order to not exceed budget, they can be done in a synchronized manner.

Initiatives to assist this barrier include guarantee funding programmes. This helps to reduce risk to lenders through a guarantee facility that pays the lender an initial loss amount or portion of the full payment default.

It may also be possible to structure the project as a viable project separate from the finances of the municipality and could therefore attract private sector investment. The Emfuleni case study provides an example of a shared savings scheme (structured as a 'build, own operate, transfer scheme) was undertaken in the Metsi-a-Lekoa municipality.

Figure 8: Potsdam wastewater treatment plant, Cape Town

Source: Aurecon

Figure 9: Amatola Water , Eastern Cape

Source: http://www.amatolawater.co.za/gallery

Case Study 1: Polokwane Municipality energy efficiency water pumping retrofit: Matching water pumps to their duties

Figure 10: Secondary clarifiers at Polokwane Municipal WWTW

Photo: Jerome Bob

Source: Polokwane Municipality, 2014.

Polokwane Municipality, in 2013, embarked on a project of retrofitting its existing water pumps in both its bulk water supply and wastewater treatment systems. The project was funded through the fifth-round (2013/14) of the Department of Energy's EEDSM fund. Polokwane municipality has participated in the DoE's programme since its inception in 2009/10. Implementation of EEDSM programmes within the municipality is managed by the municipality's Electricity Planning and Design Department. The energy saving interventions in water pumping systems comprised of the replacement of existing, re-wound energy inefficient IE1 graded motors with more efficient IE2 and IE4 motors coupled with variable speed drives (VSDs). The addition of VSDs was aimed at controlling the speed of the motors, thereby allowing them (the motors) to be operated at the ideal speed for every load condition i.e. matching the pumps to their duties. This has an impact of reducing energy consumption by the motors instead of using other control methods e.g. use of restrictive valves, on/off control, or by-passing etc. Energy efficient motors have an impact of reducing energy consumption by 5% and a further 15% of energy savings was realised from the impact of VSDs, taking the overall energy savings per pump to over 20%.

A total of 38 water pumps were retrofitted, and these pumps are located at one of the sewer works and in 9 pump stations. The expected impact of the project is a reduction in demand (24 hour average) of 0.262 MW and energy savings of 2,404 MWh per year during weekdays and weekends. The most significant benefit of the programme is that it reduces the municipality's energy consumption. In addition the pumps are now being operated during off-peak hours resulting to significant cost saving impact within the water and waste treatment system, and overall cost saving to the municipal finances.

Case study 2: Using Energy Savings Performance Contract (ESPC) for Water Loss Reduction and EE Improvement in Emfuleni*

The municipal water utility Metsi-a-Lekoa of Emfuleni, South Africa, distributes water to 70,000 households in Evaton and Sebokeng. Due to deteriorating infrastructure resulting from many years of low investment and poor maintenance, about 80 percent of potable water was leaking through broken pipes and failed plumbing fixtures. Leakage for a well-managed system is typically below 15%. A technical investigation determined that by adopting advanced pressure management in the distribution network water loss could be reduced dramatically while also lowering pumping costs.

* This case study draws extensively from the report: ESMAP, 2010, Good Practices in City Energy Efficiency, http://www.esmap.org/esmap/ node/231. Unless referenced otherwise, information is sourced from this document.

Metsi-a-Lekoa, however, lacked the required technical expertise to prepare and implement the project and was short of funds to finance the investment. A shared savings Energy Services Performance Contract (ESPC) could help address both issues. Emfuleni engaged the Alliance to Save Energy as the technical advisor to help Metsi-a-Lekoa design and prepare the project, as well as procure engineering services, and monitor and verify savings.

Through a competitive bidding process, Metsi-a-Leoka signed a water and energy performance contract with WRP Engineering Consulting Company under a Build-Own-Operate-Transfer arrangement for a period of five years. WRP acted as an ESCO—providing turnkey services—while underwriting all financial and performance risks for which WRP was able to obtain project financing from the Standard Bank of South Africa.

Figure 11: Sebokeng/Evaton pressure management installation

Source: Mckenzie & Wegelin (2009)Implementation of pressure management in municipal water supply systems.

The project involved the design, installation and commissioning of a pressure reduction chamber with appropriate sizing, fitting and operation of the valves, pipes, meters, strainers and monitoring equipment. This consisted of cutting into existing water mains and replacing sections with smaller diameter pipes and equipment. The chamber was operated to reduce pressure during off peak periods and restore to higher pressure during high demand periods.

Under the "shared savings agreement" in this contract, WRP received remuneration for its services based on verified energy and water savings from the project over a five-year period. Twenty percent of the project's savings were to be accrued by WRP and 80 percent were retained by Metsi-a-Lekoa. After five years, operations would be transferred to the utility at no cost and the utility would keep 100 percent of the savings. The project was designed to operate for at least 20 years under this scheme.

The project achieved impressive results | 7-8 million m3 annual water savings and 14,250 MWh annual electricity savings, worth a total of US$3.8 million per year [some R30 million ZAR per year]. WRP recovered the capital cost of its investment in one year: the total return to WRP represents four times its initial investment. But the lion's share of the benefit stayed with Emfuleni Municipality.

Case study 3: Umbilo Wastewater Treatment Works, eThekwini Water and Sanitation: an Industrial Energy Efficiency Improvement Project in South Africa*

The eThekwini Water and Sanitation department of the eThekwini municipality has pioneered a number of innovations in the sector. Through their involvement in the Industrial Energy Efficiency (IEE) Project the unit embarked on the journey to establish an Energy Management System (EnMS) for each of its wastewater treatment plants. With 27 plants across the metro area, it was decided to select a pilot plant and Umbilo Wastewater Treatment Works (WWTW) was chosen as the demonstration facility.

Umbilo WWTW, located at the catchment of the Umbilo River, is made up of two distinct plants: the East Works Bio-filtration Plant and the West Works Activated Sludge Plant. Each plant has its own inlet and outlet.

* This case study draws extensively from the report: Industrial Energy Efficiency Project: Municipal Wastewater Treatment 2014/15: www.iee-sa.co.za. Unless referenced otherwise, information is sourced from this document.

In 2014 and 2015 an EnMS was implemented at a total capital investment of less than R1 000. This resulted in a total monetary saving of R280 000 and an energy saving of 287 620kWh per annum. GHG emissions were reduced by 275 tonnes of CO_2. The total payback period for the investment was less than 1 month.

Summary of energy-systems optimization interventions: Activated Sludge Plant-aerators

The major energy-systems intervention was **aerator-use pattern optimisation** within the activated sludge plant aerator system. This intervention resulted in the reduction of use of four 75kW aerators from 59h per day to 46h per day (the aeration tank at Umbilo WWTW consumes about 83% of the total energy of the West Plant).

Savings achieved, based on a 19-day trial: 11% of total plant electricity consumption (19% of aerator kWh x 83% of West Plant x 70% of Total Plant) = 287 620/annum.

Implementation of an Energy Management System

An EnMS consultant was appointed to guide the development of the EnMS, after which an energy team was appointed. The energy team, with the help of the consultant, conducted an energy review with limited access to energy data (only West Plant energy consumption data was available), to identify and understand the significant energy users, their drivers and management.

After the review the team identified opportunities to improve energy performance. They compiled an EnMS Manual as a high-level management document to define the EnMS and its rollout. An agenda for management review of energy performance was also set.

Implementation Challenges

Time and priorities had to be re-aligned. Demands on the time of top managers and prioritizing EnMS roles while at the same time attending to urgent water treatment concerns proved to be very difficult.

The appointment of an energy team where all key roles were represented was a challenge, especially as an EnMS had to be driven without regular meetings to ensure sustainable progress between consultant visits.

Data management was initially difficult because of the lack of any kWh data for the East.

Creating general awareness to support behaviour-based energy performance also had to be prioritized. Initially there was limited awareness of EnMS in the plant.

The Future

- *Confirm chemical oxygen demand (COD) impacts on quality of outflow effluent and consolidate the aeration pattern, taking cognizance of peak tariff times and provide training in operator aerator efficiencies.*
- *Install on-line dissolved-oxygen probes to enable aeration times to be COD-based and install a seasonal setting on the aerators as less aeration is required during cooler months.*
- *A new energy-efficient screw pump to be installed.*
- *Investigate the viability of routing more flow to the East Plant that is more energy efficient.*

Lessons Learnt

If energy performance is integrated into performance indicators for key management members, it increases the profile and likelihood of success. Unless energy management is integrated, there will always be other priorities that take precedence. There is need for increased ownership of energy management.

An active energy team and sound and current energy data are critical success factors.

Non-energy benefits of energy interventions should also be considered when developing energy business cases. For example, reduced maintenance costs and extended life span of the aerators if the aeration hours are reduced.

Case study 4: WRC Research Report TT565/13: Short case studies – City of Johannesburg and eThekwini Metro

Cost reflection in City of Johannesburg

Johannesburg Water operates and maintains six wastewater treatment works. Johannesburg estimated that the cost of electricity for the treatment of wastewater would have risen from R97 million per annum in 2010 to over R300 million per annum by 2020, making the existing wastewater treatment operation possibly unaffordable. Failure of the wastewater treatment operations would have a devastating effect on the economy, environment, health services and social activities of the City. Energy has been recognized as a key driver in the wastewater treatment value chain of Johannesburg and efforts have been made to reduce power consumption and produce renewable energy.

Energy efficiency improvement has been achieved by the City of Johannesburg through:

- *Power factor correction installed.*
- *Targets set for an annual reduction in power use.*
- *Automation of the aeration systems.*
- *Control of the maximum and minimum dissolved oxygen concentrations.*
- *Hydraulic balancing of bioreactor influences.*
- *Guidelines and best practices in demand side management (energy conservation) within the Utility operations.*

Off-peak pumping and pressure management in municipal water distribution systems: Durban

The Durban water distribution network is operated by Durban Metro Water Services (DMWS) and includes some 250 reservoirs, each of which has a level signal which is transmitted to a central SCADA system. Some pumps and valves in the network can be actuated remotely from this control point.

Optimisation of the operation of the distribution system by pumping at off-peak periods, while ensuring minimum emergency levels in all reservoirs, will not only effect an energy savings in terms of electrical energy used for pumping, but may also delay upgrades to the distribution system. Energy gains are entirely dependent on management of the system. Optimising the system for example to gravity feed from one reservoir to another to cater for high demand periods during peak tariff periods and then replenishing both reservoirs by pumping during low tariff periods can realize significant savings in electricity costs.

Advanced pressure management was implemented in the Durban Central Business District (CBD). The objective of this initiative was to promote responsible management and usage of potable water. The commissioning of a pressure management system in the Durban CBD reduced the water loss levels in this area by 18.7 ML/day – representing approximately 2% of the daily treated water purchases from Umgeni Water, the bulk water provider. Annual water purchase savings have been R20.8 million for a capital investment of just 10% of the annual benefit (i.e. a payback of less than 2 months).

Support organisations

Department of Energy – EEDSM Programme, including water and wastewater efficiency measures
www.doe.gov.za

Institute of Municipal Engineering South Africa (IMESA)
admin@imesa.org.za

National Cleaner Production Centre
www.ncpc.co.za