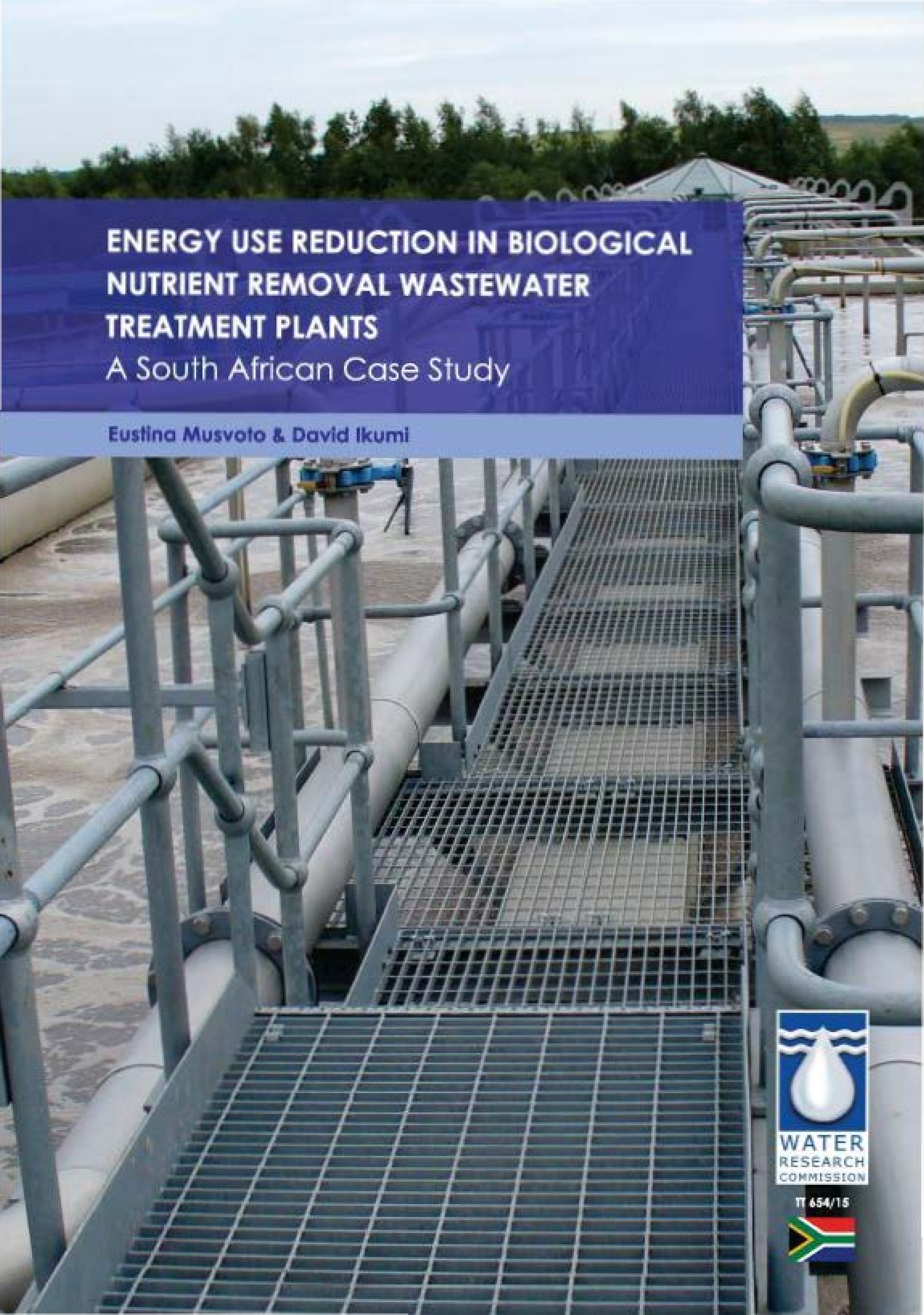

ENERGY USE REDUCTION IN BIOLOGICAL NUTRIENT REMOVAL WASTEWATER TREATMENT PLANTS

A South African Case Study

Eustina Musvoto & David Ikumi

WATER RESEARCH COMMISSION

TT 654/15

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Report to the
WATER RESEARCH COMMISSION

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EXECUTIVE SUMMARY

Similar to the global industry, the South African wastewater sector has historically focused on achieving the primary objective of wastewater treatment of protecting the environment and compliance with the Department of Water and Sanitation regulatory standards. Energy costs have been viewed as simply part of the cost of doing business and no significant focus has been placed on mitigating cost increases. However with the sharp increases in Eskom electricity rates, which are predicted to continue increasing in the foreseeable future, energy will continue to be a significant operating cost which requires additional funding. In order to remain sustainable, it is therefore prudent for South African municipalities to follow global trends and consider energy management as an intrinsic part of wastewater operations and a de-facto secondary treatment objective of wastewater treatment.

The need for energy efficiency in the South African water sector has already been identified by previous research funded by the Water Research Commission over the past 5 years. The most prominent of these is the recently completed "Energy Efficiency in the South African Water Industry: A Compendium of best Practices", undertaken as part of the Global Water Research Coalition. The study developed a compendium of best practices in energy efficiency technologies and approaches in the South African Water sector and recommended a three-pronged approach to energy efficiency consisting of demand side management (conservation), supply side management (generation) and regulatory incentives.

The study also identified that wastewater treatment uses about 55% of the energy consumed in the South African water sector. The bulk of this energy (50-75%) is used for aeration at biological nutrient removal activated sludge plants which are widely employed for municipal wastewater treatment in order to meet the Department of Water and Sanitation`s strict final effluent discharge regulations. Focusing on aeration energy use reduction therefore yields the most savings in energy cost.

This project was funded by the Water Research Commission as part of the energy efficiency in the water sector initiative and is focused on aeration energy conservation in wastewater treatment. The project investigated feasible practical aeration energy conservation measures that can be implemented at biological nutrient removal activated sludge plants that not only result in energy use reduction, but also ensure final effluent compliance with discharge regulations; thus satisfying both the primary objective of wastewater treatment as well as energy conservation. The main objectives of the project were to:

- Identify and evaluate in detail practically feasible aeration energy conservation measures suitable for a typical South African biological nutrient removal activated sludge plant. Measures should also ensure final effluent compliance with discharge standards when implemented.
- Establish aeration energy use benchmark figures that can be applied for national and international comparison.
- Conduct knowledge exchange workshops to disseminate project findings.
- Produce a report in the format of a manual that can serve as a practical guide for local municipalities to develop and carry out aeration energy conservation programs.

Two biological nutrient removal activated sludge plants were selected as case studies: (i) Zeekoegat wastewater treatment plant owned and operated by the City of Tshwane with a design capacity of 85 Ml/d average dry weather flow and utilising fine bubble diffused aeration and (ii) JP Marais wastewater treatment plant operated by the East Rand Water Care Company, with a design capacity of 15 Ml/d and utilising surface aeration.

The scope of work for both plants covered collection and analysis of plant data, determination of 2014 baseline energy use and benchmarking, identification of feasible aeration energy conservation measures, application of advanced process modelling and simulation to determine optimal process and aeration control strategies and economic evaluation of feasible measures.
Feasible aeration conservation measures were classified into three categories:

- Simple measures that only require changes to process operation and control to optimal levels, with little to no additional capital investment apart from operator training
- Low to medium capital measures that involve upgrading aeration and control strategies requiring investment in new monitoring equipment and control systems
- Complex measures that involve (i) redesigning and replacing less efficient aeration systems with more efficient technologies (ii) introduction of influent flow balancing.

Zeekoegat is a fairly new plant with the second module and aeration upgrades commissioned in 2013. The plant was designed to minimise aeration energy use with highly efficient fine bubble diffused aeration systems. Influent flow is balanced after primary clarification and the plant aeration control system is also optimised to minimise energy wastage. Final effluent complied with all parameter limits except for nitrate/nitrite. For the 2014 baseline year:

- Total annual power consumption was 11,240 MWh at a cost of R9, 8 million. Aeration accounted for approximately 42% of the total at 4,750 MWh and a cost of R2.9 million.
- The baseline aeration energy use intensity, which serves as a benchmark for the plant was 22 kWh/peCOD$_{100}$/yr (0.7 kWh/kgCOD treated).

The following feasible aeration energy conservation measures were identified:

(i) Simple measures utilizing existing process and aeration equipment
Optimal process and aeration control resulting in potential cost savings of 9%.
(ii) *Low to medium capital investment*
Upgrading the current aeration control strategy from traditional dissolved oxygen based control to ammonia based control with potential cost saving of 17%. Preliminary financial analysis indicates a payback period of 1.7 years.
(iii) Complex High capital investment
Replacing the existing Module 1 single stage centrifugal blowers with more efficient turbo blowers similar to Module 2. Potential savings of 19-23% can be achieved with payback periods of 5.2-5.5 years.

JP Marais is an old plant constructed in 1990. The design of the activated sludge process is typical of most activated sludge processes of this era that were not designed for energy efficiency. The plant uses traditional slow, single-speed surface aerators which have low energy transfer efficiency. In addition the aeration design is not tapered and aeration control was designed to be semi-automated but was manually controlled in 2014 due to equipment breakdowns.

- Total annual power consumption at the plant was 3,340 MWh at a cost of R3.1 million. Aeration accounted for 74% of the total energy usage at 2,465 MWh/yr and a cost of R2.3 million.
- Aeration energy use intensity, which serves as a benchmark for the plant was 31 kWh/pe COD$_{100}$/yr (0.9 kWh/kgCOD treated). The value is 41% higher than that for Zeekoegat

Feasible aeration energy conservation measures were as follows:

(i) *Simple measures utilizing existing process and aeration equipment*
Optimal process and aeration resulting in potential cost savings of about 14%.

(ii) *Low to medium capital investment measures utilising the existing aeration equipment*
Fully automating aeration control and implementing advanced process control with ammonia based aeration control. Potential cost savings of 21% and a payback period of 1.1 years.

(iii) *High capital investment – replacing existing surface aerators*
This measure requires a complete redesign of the aeration system and replacing the surface aerators with either fine bubble diffused aeration, hybrid aerator/mixers or dual impeller surface aerators. Potential cost savings of 31-39% can be achieved with payback periods ranging from 5.8 to 6.4 years.

(iv) *High capital investment – installing an influent balancing tank*
Installing a balancing tank combined with an efficient aeration system similar to the one at Zeekoegat plant will yield maximum energy savings greater than 40%. Flow balancing also results in simplified more efficient process and aeration control systems.

For both plants implementing advanced process control strategies resulted in optimal process and aeration control which improved both denitrification and enhanced biological phosphorus removal. Model predicted final effluent nitrate/nitrite and Ortho Phosphate values were significantly lower than the baseline measured values as well as licence discharge limits.

Two workshops were in Pretoria and Durban to discuss the findings of the project. The workshops were publicised through Water Institute of Southern Africa's branches and attended by members of the public from municipalities, water utilities, government organisations, universities, as well as consultants. Attendees ranged from operational staff, senior managers, design engineers, academics and students. Input was received from participants on the experience and challenges faced by South African municipalities in implementing energy management programs at their wastewater treatment plants. Some of the challenges identified which are also similar to challenges experienced globally were:

- Unreliable technology
- Poor designs
- Limited funding, technical expertise and top management commitment
- Restrictive/poor supply chain management practices
- Lack of or misleading incentives to stakeholders.

The following recommendations and conclusions are made based on the findings from the case studies:

1. The approach of applying advanced process modelling to evaluate aeration energy conservation measures yields other benefits, the most significant of which is ***to ensure that final effluent compliance with regulatory requirements is met satisfying the primary wastewater treatment objective of protecting the environment.***
2. Model predicted energy and cost savings might not be realised in practice due to both technological and human challenges that have been identified as hindering the implementation of efficient process and aeration control systems in practice.
3. Before practically implementing aeration energy conservation measures identified from desktop studies of this nature, the following is recommended:

- A more detailed investigation of market available options for aeration technologies as well as process and aeration control technologies. The quality and costs including maintenance requirements are of critical importance to the success of the aeration energy conservation measures.
- Application of a superior economic evaluation technique such as life cycle cost analysis, which takes into account all the costs incurred during the project life, so that the most cost effective measures can be selected for implementation.
- Detailed engineering design support for medium to high capital measures that require significant modifications to existing infrastructure as well as new treatment units and equipment.

The South African water sector could benefit from an aeration energy use benchmarking exercise for activated sludge plants to guide municipalities in planning for energy management initiatives.

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LIST OF ABBREVIATIONS

AAF	average annual flow
ADF	average daily flow
ADWF	average dry weather flow
ASIM	activated sludge simulation
ASP	activated sludge plant
BNR	biological nutrient removal
BO	biodegradable organics
BPO	biodegradable particulate organics
BSO	biodegradable soluble organics
CFD	computational fluid dynamics
CHP	combined heat and power
COD	chemical oxygen demand
DAF	dissolved air flotation
DO	dissolved oxygen
DSVI	diluted sludge volume index
DWA	department of water affairs (South Africa)
DWS	Department of Water and Sanitation (South Africa)
EBPR	enhanced biological phosphorus removal
ECM	energy conservation measure
EMP	energy management program
EPA	Environment Protection Agency (USA)
ERWAT	East Rand Water Care Company
FB	feedback
FBDA	fine bubble diffused aeration
FF-FB	feedforward feedback
FSA	free and saline ammonia
GHG	greenhouse gas
GWRC	Global Water Research Coalition
IWA	International Water Association
KPI	key performance indicator
kW	kilowatt
kWh	kilowatt hour
MDF	maximum daily flow
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
MMF	maximum monthly flow
MWF	maximum weekly flow
N	Nitrogen
O&M	operation & maintenance
Ortho P	Ortho phosphate
p	person; also depicted as capita (c) or head (hd)
pe	population equivalent
P&IDS	piping and instrumentation diagrams
PFD	process flow diagram
PLC	programmable logical controller
PST	primary settling tank

PWWF	peak wet weather flow
RAS	return activated sludge
ROI	return on investment
SAC	specific absorbance coefficient
SCADA	supervisory control and data acquisition
SRT	sludge retention time
SST	secondary settling tank
$SSVI_{3.5}$	stirred specific volume index at 3.5g MLSS/l
TCOD	total chemical oxygen demand; also represented as COD unless specified otherwise
TKN	total Kjeldahl nitrogen
TN	total nitrogen
Total P	total phosphorus
ToU	time of use
TSS	total suspended solids
UCT	University of Cape Town
UPO	unbiodegradable particulate organics
USO	unbiodegradable soluble organics
VFA	volatile fatty acids
VFD	variable frequency drive
VSS	volatile suspended solids
WAS	waste activated sludge, also surplus activated sludge (SAS)
WRC	Water Research Commission (South Africa)
WSDP	water services development plans
WWTP	wastewater treatment plant

1. Background

1.1 ENERGY EFFICIENCY IN WASTEWATER TREATMENT – A GLOBAL PERSPECTIVE

Historically the design and operation of wastewater treatment plants focused on achieving the primary objective of protecting the environment and public health as required by regulations with no special attention paid to energy efficiency. Low energy costs meant that this could be achieved at reasonable municipal budgets as well as fair and affordable rates to the public.

However in recent years global energy prices have continued to increase placing greater financial burden on municipalities whose budgets are already under pressure to finance not only other aspects of wastewater treatment, but meet other civic responsibilities. In South Africa where historically electricity used to be much cheaper than other countries, the national electricity shortages have resulted in sharp increases with rates doubling from 2009 to 2014 and expected to triple by 2018 as Eskom bids to raise finance for additional power stations. Unmitigated energy usage will therefore affect municipal budgets and threaten the long term sustainability of wastewater treatment operations. In addition to increasing energy costs, the wastewater sector, like other industries, has to face the challenges of climate change as well as increased public sentiment on carbon footprint reduction and sustainability. As a result of these challenges, energy efficiency and energy management is now of great importance and viewed by the industry as a de-facto secondary objective of wastewater treatment

1.1.1 Global Studies

A number of studies have been carried out globally to position the water sector with regards to energy consumption. The most prominent of these studies is “Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies” commissioned by the Global Water Research Coalition (GWRC), a partnership represented by four continental coordinators; Australasia (Australia and Singapore), Europe, South Africa and the USA. Each continental group has produced a report of best practices and case studies from water and wastewater utilities in their region. A global report was compiled in 2010.

The key findings from the global case studies with respect to wastewater were

- Pumping represents about 70% of potable water supply energy while for wastewater it’s at least 30%
- Aeration demands the most energy for wastewater treatment, accounting for upwards of 60%
- Up to 15% of wastewater energy demand can be offset by biogas generation and combined heat and power (CHP). This can be higher in places where uptake is still low
- Although there was limited demand information to accurately split between water and wastewater cycles, the perception was that 45% is for water and 55% for wastewater
- By adopting the best practices identified in the global case studies, energy efficiency gains of between 5 and 25% appear realistic in the water cycle. However lower potential savings of 5 to 15% are more realistic in places where energy prices have already had a significant impact.

Two areas were identified as having the most potential for energy savings viz:

- ***Pumps and pumping***: Savings of 5 to 10% on existing pumps and 3 to 7% through improvement in pump technology. It was also identified that savings of 5 to 30% may be realised in pumping situations where the operational setup was changed from the design condition.

- ***Aerobic wastewater treatment***: Savings of up to 50% can be achieved on some aerobic wastewater systems through aligning control parameters with final effluent quality standards and up to 25% for activated sludge processes.

Thus based on case studies from various regions, the GWRC global report concluded that by focusing on high energy demand areas i.e. pumping and aerobic wastewater treatment, water and wastewater utilities can achieve reasonable energy efficiencies. However the energy efficiency gains will depend on specific circumstances.

1.1.2 South African Studies

.In response to the increased need to improve energy efficiency in South Africa as well as globally, the Water Research Commission (WRC) has, over the past 5 years, been funding a number of water sector energy-related studies (e.g. Burton et. al., 2009; Van Vuuren, 2010; Frost & Sullivan, 2011 and Swartz et.al. 2013). The most prominent of these is the recently completed "Energy Efficiency in the South African Water Industry: A Compendium of Best Practices" (Swartz et.al, 2013), undertaken as part of the GWRC study.

The study made a number of recommendations based on the energy efficiency case studies and best practices form South African utilities. A summary of these recommendations which covered both supply and demand side management as well as the regulatory side to incentivise the sector to adopt energy efficiency measures is as follows:

Supply Side (Energy Generation)

- Wastewater treatment facilities should be encouraged to implement biogas energy production projects, and incentives should be provided for this purpose
- Similarly, water supply and distribution projects should investigate the feasibility of mini-hydropower generation in water distribution systems.
- Feasibility of using alternative renewable energy technologies with relation to initial capital costs, site conditions, specific climate conditions and return-on-investment should be investigated. Financial incentives should be provided for such investigations and projects.

Demand Side Management (Energy Conservation)

- Energy efficiency should form a major criterion when planning new or upgrading existing water supply and sanitation projects, and funding programs should use specific targets in the decision-making process.
- "Toolboxes" should be developed to provide water and wastewater treatment plant supervisors and process controllers with technical solutions and support for improving energy efficiency in their facilities.
- 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.
- Implementation of water supply and sanitation processes that use no energy, should be actively encouraged
- 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.

Regulatory and Incentives

- The guidelines and best practices should be used as a basis for development of energy efficiency and energy conservation targets for the South African water sector. These targets can then be implemented, encouraged and regulated through the Department of Water and Sanitation (DWS) Blue Drop and Green Drop programs.
- Municipalities should already start using the guidelines for energy conservation and energy generation in 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.
- Loose liaison should be established and maintained with energy suppliers (Eskom), and water services providers and authorities should be aware of and pursue the offerings in the rebate program.

1.2 ENERGY USE IN ACTIVATED SLUDGE PROCESSES

1.2.1 Overview

In biological wastewater treatment, aeration consumes the most energy accounting for anything between 50 to 65% on nitrifying activated sludge plants. Figure 1-1 shows an example of electricity requirements for an activated sludge plant based on data from the USA (Crawford & Sandino, 2010). Table 1-1 gives wastewater treatment plant energy consumption figures for other selected countries which further confirm the high energy consumption by aeration.

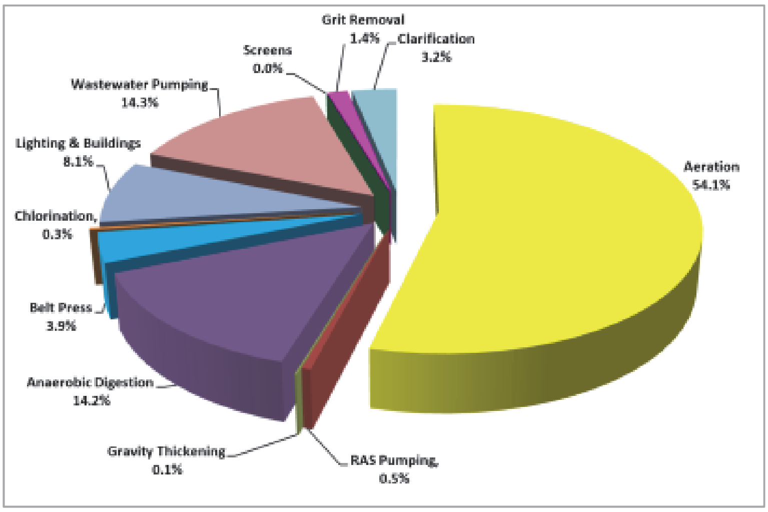

Figure 1-1: Example of Electricity Requirements for Activated Sludge Wastewater Treatment (Source: WERF, 2010)

Table 1-1: Energy Consumption at Wastewater Treatment Plants for Selected Countries based on data from NEWRI (2010) (Source: Swartz, 2013)

% Energy Consumption	Austria	Austria (Strass)	Sweden	China (Beijing)	Japan	Iran
Preliminary & Primary	13	21	28	38	4	5
Aeration	70	57	48	57	46	77
Sludge Thickening, Dewatering & Digestion	13	13	14	5	31	7
Pumping	4	9	10		19	11

1.2.2 Energy Conservation Measures for Aeration Systems in Activated Sludge Plants

Because of the high energy use associated with aeration, energy conservation measures (ECMs) that focus on reducing aeration energy consumption have been universally found to yield the most energy efficiency gains at wastewater treatment facilities that use the activated sludge process. Not all the energy used is required to meet process demand as some of it is wasted due to non-optimal operation and/or inefficient mechanical and electrical equipment. Some of the ECMs that have been identified to reduce aeration energy use are:

- ***Installation of most efficient aeration system*****:** A decision on which aeration system to install during the design of a plant has huge implications on the whole life cycle energy costs at a plant. Careful choices on the aeration system taking into account efficiency as well as capital and long term operating costs need to be made at design stage e.g. choices between using fine bubble diffused aeration (FBDA) as compared to surface aeration. The type of aeration equipment is also important and needs to be carefully made as efficiency differs between types of blowers; diffusers as well as mechanical aerators. Selecting the most efficient combination of blower and diffuser type is also important.
- ***Proper sizing and configuration of aeration system:*** Many treatment plants have more capacity in their aeration systems than needed to meet the process oxygen demand. This is due to a combination of factors e.g. long design horizons, reduction in anticipated design loads as well as inefficient design procedures with unnecessarily high peak oxygen demand factors. Also, using the aeration system to supply parasitic loads (e.g. grit removal systems, air lift pumps, odour control) inflates the design capacity and makes it difficult to optimally control the aeration system in practice. In addition, poor determination of minimum oxygen requirements during design as well as use of few large aeration units particularly blowers results in inefficient turndowns during low load periods thus wasting energy. It is therefore important to size and configure aeration systems at design stage to ensure optimum energy use across the design horizon.

- ***Optimum process and aeration control***: Optimum control of both the process and aeration system is critical for conserving energy and ensuring compliance with final effluent quality requirements. Oxygen demand for aeration is proportional to the organic and ammonia load into the plant and these fluctuate with time of day and sometimes on a weekly and seasonal basis depending on the plant. The two most important operating parameters in activated sludge i.e. sludge retention time (SRT)/sludge age) and dissolved oxygen (DO) not only impact process performance but also aeration energy requirements. Implementing optimum process operating parameters as well as automatic aeration control systems results in substantial saving in aeration energy. Usually, plant operating parameters are set based on design guidelines (which are typically conservative) or on historic or conventional practices thus optimization after commissioning will ensure optimum energy use.

Therefore energy savings can be gained by designing and operating aeration systems to match, as closely as possible, the actual oxygen demands of the process. By understanding the oxygen demands of their particular wastewater and how those demands vary daily, weekly and seasonally wastewater treatment plants (WWTPs) can implement process and aeration systems control strategies that can ensure long term efficient energy use.

1.2.3 The Role of Advanced Process Modelling in Evaluating Energy Conservation Measures for Aeration Systems

The last two decades has seen not only the introduction of very sophisticated and accurate biological models for activated sludge processes e.g. ASM1, ASM2 (Gujer, 1994), ASM2d (Henze, 1999) and ASM3 (Gujer 1999) but also commercial simulation programs (simulators) that incorporate the biological models as well as other treatment units at a WWTP (e.g. BIOWIN, GPSX, WEST, SIMBA). These tools have been proven to be very useful for design, research and optimization of WWTPs and their application has been increasing over the years. At the same time, automation process control technologies have been developing rapidly and with the availability of more reliable and affordable sensors, automation is now extensively used at more and more WWTPs. This has led to the development of more efficient control strategies.

To keep up with growing automated control, commercially available wastewater simulators have recently been incorporating modules that can simulate control strategies e.g. for aeration, pumping systems as well as chemical dosing. Thus the simulators can now be applied in the optimization and design of both treatment processes and automated control strategies. This is particularly important in the investigation of optimum aeration ECMs because aeration requirements are driven by biological process oxygen demand. Hence using process driven modelling will result in more efficient measures being adopted as compared to the traditional approach which focuses on changing electrical/mechanical equipment (i.e. focusing on directly changing blowers, aerators, pumps, sensors etc.) based on generally expected performances without using the process oxygen demand and its diurnal/seasonal variability as a driver. Also this combined modelling approach ensures that the ECMS that are implemented do not upset the biological process and/or result in violation of final effluent compliance requirements. This is critical for complex treatment processes with strict final effluent discharge limits like biological nutrient removal (BNR) plants.

Use of these advanced process models and simulators has recently been proven to be an efficient engineering tool for the investigation of practical aeration ECMs while maintaining or improving the required final effluent standards. Coronias *et al.* (2009) applied modelling to optimize Val del Ges, a biological nitrogen removal plant in Spain with a design capacity of 42,000 pe. The modelling enabled various aeration control strategies as well as the long term impacts on final effluent quality to be evaluated. Energy cost savings of up to 30% were identified while maintaining the final effluent quality within the required standard.

Musvoto *et al.* (2012) also applied modelling to investigate energy saving operational measures at nitrifying activated sludge plants in the United Kingdom with design capacities of 158 Ml/d and 350 Ml/d. Wastewater treatment energy costs had increased substantially due to a change in the unit energy tariff from a flat rate to time of use. Measures identified included changes to aeration control strategies as well as implementing flow balancing/deferral using the catchment collection system and pump stations. Energy cost savings of up to 50% could be achieved depending on the measure implemented. Implementing simple changes to the aeration control strategies resulted in annual energy cost savings of 25% with no capital investment required, while complying with final effluent compliance requirements. In addition, the modelling also identified strategies for operating the plants under variable ammonia permit limits for winter and summer (which would result in further energy savings), a concept the Water Company was negotiating with the regulator.

The benefits of applying modelling to combine optimizing process operations and energy use were also identified by Rieger *et al.* (2012). They applied modelling to develop aeration control strategies as well as improve total nitrogen (TN) removal at 3 Swiss WWTPs viz: Morgental (13 Ml/d), Thurnersee (38 Ml/d) and Werdhoelzli (190 Ml/d). The identified aeration control strategies resulted in annual energy cost savings of up to 30% for the 3 plants. Total nitrogen removal improved by up to 40% with the optimized aeration control strategies.

In all the cases discussed above, application of modelling to evaluate aeration ECMs was found to be less risky and more cost effective than directly implementing generally identified ECMs at full scale. Long term effects on process performance and final effluent quality could also be predicted.

Therefore these cases have proven that a process driven optimization approach which applies modelling to evaluate aeration ECMs offers several advantages:

- Enables offline thorough understanding of the impacts of aeration ECMs on long term process performance before making commitments to capital expenditure and operational changes
- Minimizes the risk of implementing costly measures and/or measures that result in violation of final effluent quality requirements. Ensures compliance with final effluent regulations at minimal energy use as it addresses actual biological process energy requirements and performance taking into account daily/seasonal variability
- Includes and evaluates in a scientific way all the process parameters that impact energy consumption e.g. sludge age, aerated and un-aerated mass fractions
- Evaluates and optimizes most common aeration control strategies thus resulting in the most efficient being adopted
- Determines optimum blower/surface aerator turndowns under varying flows and load conditions thus allowing informed decisions to be made for changes to mechanical/electrical equipment
- Optimizes energy tariffs and determines optimum operation & control strategies to minimize energy consumption during high cost periods
- Evaluates impacts of changes to process configurations on energy consumption (e.g. flow balancing on site or in the collection system, intermittent aeration, swing zones)
- Optimizes the management of internal plant side streams that impact energy consumption such as sludge thickening and dewatering liquors
- Can easily include modelling of energy offset opportunities such as biogas generation through anaerobic digestion of sludge thus enabling combined evaluation of supply and demand sides

2. Project Overview

2.1 CONTEXT AND OBJECTIVES

Similar to the global industry, in South Africa the wastewater sector has historically focused on achieving the primary wastewater treatment objective of protecting the environment and compliance with the DWS regulatory standards. As a result energy costs have been viewed as simply part of the cost of doing business and no significant focus has been placed on mitigating cost increases. However with the sharp increases in Eskom electricity rates, which are predicted to continue increasing in the foreseeable future, energy will continue to be a significant operating costs which requires additional funding.

In South Africa it is not feasible for municipalities to indiscriminately increase user rates to finance the increase in energy costs and will thus be forced to use capital reserves in an effort to maintain fair municipal rates. This will reduce funding available for other critical areas such as maintenance and upgrade of treatment plants and process equipment. In addition municipalities might be forced to base all purchases of services and equipment solely on lowest initial capital cost rather than considering the level of expertise as well as the life-cycle cost of owning and operating the equipment. In order to remain sustainable it is therefore prudent for South African municipalities to consider energy management as an intrinsic part of wastewater operations and a de-facto secondary treatment objective of wastewater treatment

Apart from reducing energy costs, the South African wastewater sector is also obligated to reduce energy consumption in order to contribute to the national energy conservation agenda to alleviate the current energy shortages in the country.

A study by Frost and Sullivan (2011) showed that wastewater treatment consumed about 55% of the energy consumed in the South African water sector. The bulk of this energy is used for aeration at BNR activated sludge plants which are widely employed for municipal wastewater treatment in order to meet the DWS`s strict final effluent discharge regulations. Thus most municipalities face the pressure of employing the highest energy consuming process (and the associated electricity costs); while at the same time having to comply with strict nitrogen and phosphorus final effluent standards. Targeting aeration energy use reduction in activated sludge process will therefore yield the most significant savings for most municipalities.

This project forms part of the WRC's energy efficiency in the water sector initiative. The project investigated through case studies, feasible practical aeration energy conservation measures that can be implemented at BNR activated sludge plants that not only result in aeration energy use reduction but also ensure and/or improve final effluent compliance with N and P standards.

The main objectives of the project were to:

- Identify and evaluate in detail practically feasible aeration energy conservation measures suitable for a typical South African BNR activated sludge plant that also ensure final effluent compliance if implemented
- Establish aeration energy use benchmark figures that can be applied for national and international comparison
- Conduct training workshops on aeration energy conservation measures based on project findings

- Produce a report in the format of a manual that can serve as a practical guide for local municipalities to develop and implement aeration energy conservation programs

Based on international experience, advanced process modelling and simulation was applied in evaluating aeration ECMs to determine both optimum process and aeration control strategies ensuring energy use reduction as well as compliance with the strict final effluent N and P regulations applicable to most of the country.

The South African Energy Efficiency Study (Swartz et.al 2013), recommended that demand side management particularly implementation of energy efficiency at both existing and new wastewater treatment plants be adopted by wastewater utilities. The study also recommended carrying out of energy audits as well as development of technical solutions and tools for water and wastewater treatment plant supervisors and process controllers to use in improving energy efficiency in their facilities. This project not only contributed to finding energy use reduction measures but also provide energy efficiency improvement tools to wastewater treatment operations personnel thus progressing the demand side management recommendations made in the South African Energy Efficiency Study.

2.2 APPROACH AND METHODOLOGY

In order for the outputs of the project to be applicable on a broader scale, two BNR activated sludge plants were selected as case studies viz:

- Zeekoegat WWTP owned and operated by the City of Tshwane. The plant has a design capacity of 85 Ml/d average dry weather flow (ADWF) and uses a fine bubble diffused aeration (FBDA) system
- JP Marais WWTP operated by the East Rand Water Care Company (ERWAT), with a design capacity of 15 Ml/d ADWF. The plant uses surface aeration

The project was carried out in 5 main tasks applicable for each plant as follows:

Task 1: Collection and Analysis of WWTP Data

A baseline period for the study was selected. Data to enable capture of diurnal and seasonal variation of influent flow and loading, model calibration and validation as well as establishing baseline energy use was collected through:

- Analysis of historically measured/recorded data at the plant i.e.
  - influent raw and settled wastewater flows and loads
  - operating parameters for the ASP and other treatment units as well as final effluent quality
  - power usage by different treatment units
  - energy tariff structure and energy costs

- Additional 24 hour composite sampling and analysis on the influent under both dry (winter) and wet (summer) weather conditions. Samples to determine operating parameters were also collected along the treatment process. Online instrument measurements were also recorded at the same time to determine process operating parameters as well as aeration power consumption

The City of Tshwane and ERWAT contributed through wastewater sampling and analysis for their respective plants.

Task 2: Determination of Baseline Period Energy Use
The data collected in Task 1 was used to determine actual total energy use and costs as well as split by different functional areas/treatment units for the selected baseline period.

Task 3: Evaluation of Aeration Energy Use Reduction Strategies through Modelling and Simulation
BIOWIN™ simulator (by Envirosim Associates) was used for modelling and simulation. The historical wastewater data as well as additional data collected under Task 1 for summer and winter was used to calibrate and validate the models. Simulations were then carried out using the calibrated models to evaluate aeration energy use reduction strategies and corresponding process operational and control parameters that ensure final effluent compliance at minimum energy use.

Task 4: Financial Analysis and Energy Use Benchmarking
Estimated costs for implementing feasible options identified in Task 3 were obtained from local suppliers. Simple payback was applied as a financial evaluation technique. Process driven benchmark aeration energy consumption intensities based on COD load treated and population equivalent served were also calculated for the baseline period as well as for the recommended ECMs. These were compared with available international and national benchmarks and can be used as a starting point for evaluating the national energy benchmarking criteria currently being applied in South Africa.

Task 5: Knowledge Dissemination Workshops
Two workshops were held in Pretoria and Durban to discuss the findings of the project. The workshops were publicised through the Water Institute of Southern Africa's (WISA) branches and attended by members of the public from municipalities, water utilities, government organisations, universities as well as consultants. Attendees ranged from operational staff, senior managers, design engineers, academics and students. Input was received from participants on the experience and challenges faced by South African municipalities in implementing energy management programs at their wastewater treatment plants.

Task 6: Project Report
Following on the workshop and the inputs obtained from the participants as well as the nature of the project outputs, it was decided that rather than produce a conventional research oriented project report, the report should be structured in the format of a "how to do" manual providing guidance on how to implement energy management programs based on international best practices; illustrated by the outputs from the cases studies. The report is thus structured as follows:

Section 1: Background

Section 2: Project Overview

Section 3: Developing Energy Management Programs for Activated Sludge Plants – Best Practice

Section 4 Case Study 1 – Zeekoegat WWTP

Section 5 Case Study 2 – JP Marais WWTP

3. Developing Energy Management Programs for Activated Sludge Plants – Best Practice

3.1 INTRODUCTION

Achieving both the primary and secondary objectives of wastewater treatment as well as energy efficiency present a challenge for most municipalities. However international experience as well as findings from this project has shown that complying with regulatory requirements and achieving energy efficiency are not mutually exclusive. Implementing energy conservation has been found to not only reduce energy costs, but also to improve operation and control of unit treatment processes and final effluent compliance thus satisfying both the primary and secondary objectives of wastewater treatment. In addition implementing energy conservation yields other benefits such as

- Reduction of other operational cost e.g. chemicals, labour, maintenance and disposal
- Improved staff operational knowledge and understanding of the treatment process, confidence and morale
- Freeing up financial resources that can be used for other municipal services
- Ability to control rate increases for ratepayers thus improve public confidence in municipal operations
- Increasing energy available on the national grid, helping to alleviate the national electricity shortage
- Contributing to the reduction of greenhouse gas (GHG) emissions.

In order to achieve the benefits of energy conservation without compromising performance of treatment plants, it is imperative that municipalities adopt a systematic approach to energy management. International experience has already demonstrated that a systematic approach makes sound business and environmental sense and ensures setting up of a sustainable energy management program (EMP) that enables municipalities to:

- Plan – establish and prioritize energy conservation goals and targets
- Implement measures to meet the goals and targets
- Monitor and measure performance to track effectiveness of energy conservation measures
- Review and adjust energy programs as required

This Chapter gives guidelines on how to set up an EMP to minimise aeration energy use in BNR activated sludge processes, within the South African context. The guidelines and format are based on international best practices outlined in the EPA energy management guidebook[1] as well as the findings from this project's case studies. While some of the details are applicable only to aeration energy use reduction in BNR activated sludge processes, the general principles are applicable to development of EMPs for other aspects of water and wastewater collection and treatment.

[1] Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities (EPA, 2008)

3.2 BASIC STEPS IN SETTING UP AN ENERGY MANAGEMENT PROGRAM

The following 8 steps are recommended in order to set up an effective energy management program[2]:

1. Establish Energy Management Goals
2. Establish Organizational Commitment
3. Establish Energy Use Baseline
4. Identify Feasible Energy Conservation Measures
5. Prioritize Opportunities for Implementation
6. Develop an Implementation Plan
7. Provide for Progress Tracking and Reporting
8. Maintain Energy Management Goals

Most new programs fail due to embedded human nature to fear and resist change. The main objective of this step by step approach is therefore to lay a solid foundation for energy management programs that incorporates

- A diverse project team
- Good information
- Understanding of "trade-offs",

thus reducing the likelihood of resistance to positive change[3].

3.3 SETTING UP AN ENERGY MANAGEMENT PROGRAM

3.3.1 Step 1: Establish Energy Management Goals

Before embarking on any energy management program, it is important to understand and establish the goals that the program is required to fulfil and how they fit in with the Municipality's mission, goals, strategic direction and other best management practices. Often wastewater treatment energy management goals overlap with other aspects of water management practices (e.g. operations and/or maintenance policies, procurement policies etc.).

Some of the goals that are important to Municipalities include

- Reduce total energy consumption and cost while complying with the DWS final effluent regulations
- Control peak energy demand
- Manage energy cost volatility by combining conservation with generation of energy from biosolids and use of other alternative fuels, leading towards energy sufficient WWTPs and independence from outside energy sources.
- Improve energy reliability
- Contribute to the alleviation of the electricity shortages in the country in line with Eskom's "every little bit helps" campaign
- Demonstrate leadership in sustainability and/or energy conservation initiatives
- Contribute to GHG emission reduction and help South Africa achieve its climate change mitigation target
- Raise the Municipality's public image

[2] EPA (2008)
[3] New York State Energy Research and Development Authority (2010)

Keys Points to Consider

- Align energy management goals with other wastewater management improvement programs and Municipality's best management practices e.g.
    - Incorporate energy conservation criteria in the design standards for both wastewater collection and treatment plants
    - Reflect the importance of energy conservation in supply chain management, procurement and operations policies and budgets
    - Include energy efficiency in employee KPIs and incentives
- Identify and understand secondary benefits of energy management and consider them in evaluating goals and energy conservation opportunities e.g.
    - Improved final effluent compliance, process understanding and operator knowledge
    - Reduction in other operating costs

3.3.2 Step 2: Establish Organization Commitment

Wastewater treatment and its energy use cuts across many departments within a municipality whose actions and decisions will be impacted through the implementation of an EMP. It is therefore important to create a diverse energy management team to bridge the gap between decision makers in these departments and the wide variety of issues and needs associated with energy use. A diverse, cross functional, strong energy management team that helps to resolve many of the organizational barriers to improving energy use needs to be put in place in order to secure commitment from the whole organization.

The size of the energy management team should mirror the complexity and size of the Municipality and be nimble and efficient i.e. it should be large enough to represent different perspectives on energy use, but should not be too large to hinder fast decision making.

The main responsibilities of the energy management team should include:

1. Secure and maintain employee buy-in
2. Develop a strategic energy management plan
3. Establish performance goals, metrics, and incentives.
4. Define resource needs.
5. Provide energy management information, coordination and communication

Figure 3-1 shows an example of an Energy Management Team organizational chart that could be applied by Municipalities.

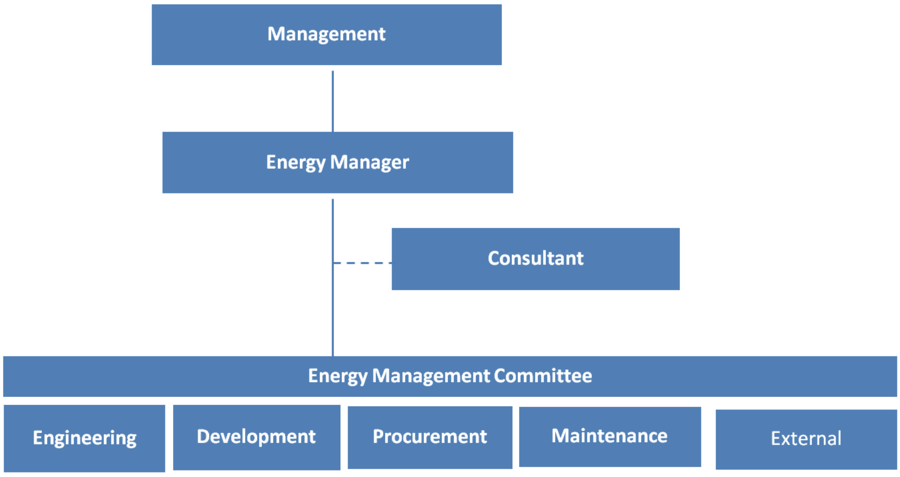

Figure 3-1: Typical Energy Management Team Organizational Chart

The key components to forming an energy management team IS establishing organizational commitment are discussed below:

Secure and Maintain Top management Commitment

Securing top management commitment and support is the most important step in planning energy efficiency programs. Experience has shown that attempting to implement energy management programs without management support is unsuccessful[4]. Maintaining management commitment, involvement and visibility ensures that employees apply their best efforts to the energy management program. Internal management members should also include very highly ranked senior officials e.g. mayor, city manager, finance manager, chief operations officer, board members, councillors.

The main role of top management is to:

- Demonstrate real commitment to energy management,
- Provide resources (both financial and human)
- Provide appropriate responsibility and authority designations within the EMP structures
- Provide incentives and ensure that all staff particularly on the ground Operations Staff are recognized for their efforts and contributions
- Showcase the Municipality`s commitment to energy management to external stakeholders

Top management can also include representatives from external organizations with vested interest in energy management and final effluent compliance such as DWS, Eskom, the Department of Energy or the Department of Environment.

[4] EPA (2008)

Key Points to Consider[5]

- Train top managers to increase their awareness and understanding of energy management.
- Highlight the benefits that other local and international Municipalities have realised from implementing EMPs
- Address managers' concerns. Find out what really motivates decision makers and incorporate these into the EMP goals so that top management remains committed and visible.
- Frequently communicate with management so that they stay up to date, interested and involved

Appoint an Energy Program Manager

In order to have a single point of responsibility and accountability, it is essential to appoint an Energy Manager whose primary duty is to provide effective leadership and guide energy management efforts. To ensure the success of an EMP, the appointed person must have a good track record of leading multi-disciplinary teams, project management and communication skills, be designated authority from top management and also have management authority within the municipality to effectively lead the EMP. For large metropolitan municipalities that have a lot of wastewater treatment plant Energy Co-ordinators reporting directly to the Energy Manager should also be appointed to implement EMPs for large plants or a group of plants.

Responsibilities for the Energy Manager include:

- Build and lead the Energy Management Team
- Develop energy management project plans and implement schedules
- Communicate with top management team
- Manage allocated resources, delegate responsibilities and stipulate deadlines
- Stimulate and maintain organizational interest in the implementation of EMPs.
- Initiate and assist in the development of energy use standards.
- Reviewing plans for WWTP expansions, process modifications, and equipment purchases to ensure compliance with set energy efficiency standards
- Direct the activities of outside consultants
- Prepare periodic energy efficiency reports so that management is continuously updated on improvements, energy savings, and cost reductions.

[5] Focusing on local case studies increases buy-in from top management e.g. case studies under this study (Sections 3 and 4) as well as those identified in Swartz et.al (2013) that show the benefits of aeration energy management programs

Key Points to Consider

- Choose an Energy Manager from the pool of managers and senior staff who are already familiar and understand the Municipality`s wastewater operations and energy use and have experience leading teams and programs e.g. Area catchment managers
- Key personality traits for a successful Manager include
  - Trusted and respected by staff as well as external service providers
  - Committed and enthusiastic
  - Good communicator
  - Ability to link across organisational ranks and to listen to others and consider diverse perspectives and ideas
- If a suitable person is not available internally consider appointment of a Specialist Consultant to assist the Energy Manager launch and implement new EMPs.

Establish an Energy Management Committee

In order to ensure buy in from all sectors of the organisation, it is necessary to create of an energy management committee that is diverse and cross functional. The co-operation of the operations and maintenance staff has been found to be vital to the success of any energy efficiency programs. However global experience shows that in most municipalities and water utilities, operators are never involved in evaluating any energy management decisions; be it design or procurement. Most of them do not know the energy use of their treatment plants or let alone see energy invoices, yet their day to day activities have the most direct impact on energy use. Therefore the energy management committee should consist of representatives from all departments.

It is also recommended that union and labour representative members be included on the energy management team to alleviate misplaced fears of job losses that is often associated with wastewater treatment energy efficiency programs because of the resultant increased automation.

Secure and Maintain Employee Buy-in

Once the Energy Management Team is selected, it is necessary, just like for top management, to secure employee buy in. Securing employee buy in will instil a culture within the municipality that energy conservation, efficiency and generation are an integral part of wastewater treatment. Key employees should get involved early and there should be continuous and open communication throughout the EMP.

The following is important:

- Early involvement and continuous communication from planning to implementation
- Employee input and opinions should be sought and valued
- Goals of EMPs should be communicated to employees and made sure that they are understood
- Clarification of individual and team roles and responsibilities
- Communication of energy related key performance indicators (KPIs) and incentives

Key points to consider

- Hold an inclusive EMP launch meeting
- Include Union leaders in dialogue
- Spend time talking to operators and treatment plant staff to get their input and understand their concerns and what improvements they would like to see from energy conservation programs
- Publicise energy issues to all staff to increase awareness e.g. staff meetings, notices in public areas and news bulletin
- Publicise EMP “early wins” to keep everyone aware, motivated and interested
- Continuously communicate
- Create an atmosphere that promotes and accepts new initiatives
- Give formal training sessions to improve energy management understanding

3.3.3 Step 3: Establish Energy Use Baseline

Before feasible energy conservation measures can be identified, it is important to understand the current energy consumption status at a treatment plant as well as regulations that impact on the proposed EMPs. Some studies have shown that just the process of investigating energy use, and improving awareness among staff, can provide measurable energy efficiency gains of about 3-5%[6]. Successfully establishing an understanding of energy use can demonstrate early some value of the energy efficiency before committing significant resources.

The main objectives of this step are to:

- Understand the amount of energy that is used by each treatment unit and the associated costs
- Understand energy bills and the rate structure that is used to set energy costs
- Create a baseline of energy use and the benchmarks to be used for comparison and evaluation purposes
- Assess final effluent compliance with the DWS regulations
- Identify operational and control parameters that can be easily changed to improve energy use and final effluent compliance.

In order to meet these objectives, the following should be undertaken:

Select Baseline Period

Establishing a “normalized” baseline enables accurate measurement of how a treatment plant`s energy use varies over time. At a minimum a baseline period of one year should be selected in order to identify any seasonal patterns. Three or more years is ideal so that any trends or anomalies in energy use can be identified.

Collect Existing Data

The first step is to collate existing data that is readily available. Data sources include site measured data, O&M records, ESKOM and municipal electricity billing records, supervisory control and data acquisition

[6] NYSERDA (2010)

(SCADA) system records, equipment/motor lists, design reports/manuals, regulatory documents and final effluent discharge licenses.

Basic data to be collected and analysed include:

- Wastewater flows and constituent parameters concentrations and loads
- Plant design information as well as process operation and control parameters
- Final effluent quality
- Inventory of energy using equipment showing motor sizes and load information
- Electricity data i.e. overall electricity consumption and peak demand
- Equipment run times including downtimes for repairs and maintenance
- Equipment design specifications
- Instrumentation and plant control
- Electricity consumption rates and costs for major equipment

Part of data collection should include a site walk through survey to fill in the gaps in the data that is available in records and document. The survey should include:

- Verification of equipment data and operating status
- Physical measurement of energy use and efficiency of large equipment e.g. r large pumps and aeration equipment (blowers and surface aerators)
- Interview Operations staff to:
    - obtain data that is recorded on site and not necessarily passed onto head office
    - Understand O&M practices and priorities
    - Understand any limitations (regulatory, engineering, personnel) to implementing ECMs
    - Collect suggestions for energy conservation opportunities
    - Identify any "Operator Initiative" energy conservation measures that are in place
    - Identify where additional metering is required in order to obtain more information on energy use.
    - Identify sampling points for collection of additional wastewater data
    - Verify PFDs and P&IDS

Analyse Data and Determine Baseline Plant Performance

The above data should be analysed to establish the influent flows, loads as well as baseline plant performance in terms of compliance with final effluent regulations. Theoretical baseline aeration energy requirements should also be determined using process models.

The following analysis is recommended using data from site measurements:

- Calculate Influent loads including seasonal and diurnal trends and variations as well as process control parameters
- Analyse aeration and control strategies
- Compare final effluent quality with final effluent discharge standards
- Apply mathematical modelling and simulation to determine aeration energy requirements, optimal process and aeration control parameters as well as model predicted final effluent parameters

- Split actual energy use into treatment units/functional areas. The split should ensure that large energy users (e.g. aeration, influent/effluent pumping, and sludge treatment) are accurately quantified and represented as stand-alone items.

Evaluate Energy Bills and Understand the Energy Tariff Structure

Many energy management strategies are directly linked to the pricing of energy, and it is critical to understand how the 'energy tariff structure' impacts energy costs. ESKOM provides electricity and bills Municipalities. Municipalities internally bill wastewater treatment plants and some of the municipal internal tariffs are not similar to the tariff that ESKOM would apply if the plant were directly billed by ESKOM[7]. Some of these internal tariffs which are not time of use can end up more expensive for a treatment plant than ESKOM's time of use tariffs which have cheaper off peak rates. Energy conservation measures save more money on time of use tariffs if energy consumption is shifted from peak to off peak charge periods. In order to implement effective energy conservation measures, it is recommended that details of the applicable ESKOM tariff for a specific treatment plant be obtained and investigations of the feasibility of migrating to a time of use tariff be carried out.

The following actions are recommended:

1. Analyse and interpret tariff structure and understand the rate structure as this will impact on the strategies adopted to reduce aeration energy. The main things to understand are
    - Number of meters and meter types.
    - Meter readings and any applicable multipliers
    - Consumption, demand and power factors
    - The various charges, their variations and linkages i.e. unit charge, time of use, seasonal, fixed and service charges etc.
2. Determine energy use profile

    The energy profile needs to be determined for the whole plant as well as for treatment units/functional areas. Representing the information in graphical form assists in determining any trends and anomalies.
    - Annual and monthly electricity consumption (kWh) and cost – total and for each process unit/functional area
    - Annual and monthly electric demand (kW) and cost
    - Rolling average electricity consumption
    - Where data is available also plot average daily and hourly consumption

Collect Additional data

Most data collected at WWTPs is focussed on compliance monitoring and not energy use assessment. It is therefore necessary to collect additional data for energy auditing purposes. Some of the additional data that might need to be collected includes:

- Actual energy consumption and efficiencies of large equipment e.g. blowers, aerators, diffusers, pumps
- Seasonal diurnal flow and load patterns to determine peak influent flows and loads and process performance

[7] As an example refer to Sections 3 and 4 for the different tariffs for Zeekoegat (owned and operated by the City of Tshwane). The tariff for the plant is an ESKOM time of use tariff) and JP Marais (owned by Ekurhuleni Municipality and operated by ERWAT). The tariff for the plant is not time of use and structured as an ESKOM tariff.

- Wastewater characteristics for application in advanced process modelling to evaluate aeration energy conservation strategies

Benchmark and Compare Energy Use

The objective of this step is to use the data from the above steps to convert energy use into useful benchmarks that can be used to compare with similar treatment plants and identify energy saving opportunities. The following is required:

- Identify useful performance measures and calculate energy use intensity[8].
- Calculate total and aeration energy intensities
- Calculate GHG emissions (carbon equivalent) to generate baseline electricity used
- Compare total and aeration energy use intensities with both local and international values for similar wastewater treatment plants
- Identify potential for aeration energy conservation
- Prepare simple energy models that can be used to predict future energy costs and consumption based on current baseline energy use and theoretically predicted energy use
- Review legal and other requirements. It is necessary to review legal and other requirements that wastewater treatment operations have to comply with and how they affect the nature and scope of the EMP. Legal requirements to review include:
    i. Final effluent discharge standards. The impact of the current and anticipated future changes need to be taken into account e.g. impact of stricter N and P limits
    ii. Worker Health and Safety
    iii. Environmental monitoring and reporting
    iv. Sludge utilization and disposal standards
    v. Reliability of treatment processes

    Internal municipal requirements also need to be reviewed e.g.
    i. Limiting increase in operating costs
    ii. Reducing peak loads and consequently peak power demand
    iii. Reducing GHG emissions

Key Points to Consider

Benchmarking is an important business tool that gives organizations a way to compare their operations with others and evaluate how they stack up against "best in class". It gives an opportunity for municipalities to evaluate how efficient and cost effective their wastewater treatment energy management programs are. The advantages of benchmarking include (Spellman 2010, EPA 2008)

- It's an objective setting process
- Forces an external view to ensure objective setting is correct
- Forces internal alignment to achieve goals
- Fosters teamwork by directing efforts to actions and practices necessary to remain competitive

Since South Africa does not have any wastewater treatment plant energy use benchmarks the sector would highly benefit from a nationwide benchmarking exercise which will assist municipalities formulate their energy management objectives.

[8] Robust performance measures should be selected for benchmarking to suit the purpose e.g. load related measures are more useful for benchmarking activated sludge aeration energy use (e.g. kWh/kg COD removed, kWh/pe/yr) rather than kWh/per volume of flow treated which is more useful for other systems like pumps

Communicate Early Findings

The key to success of EMPs is open communication. Once the baseline energy use assessment is complete, the findings should be communicated to the energy management team and other key stakeholders within the municipality. It is recommended that the findings be communicated via:

- Short, succinct report highlighting the key findings. The report should consist of summary tables and graphs with uniform information that is easy to grasp.
- Presentation to top management and other key decision makers.
- A workshop presentation to a wider audience consisting of members of energy management team and members of other departments that are impacted by the EMP.

3.3.4 Step 4: Identify and Evaluate Energy Conservation Opportunities

Although there are a number of examples of energy conservation measures that have been successfully implemented by other utilities, each wastewater treatment plant is different and there are no standard ECMs and energy saving targets that suit every WWTP. It is therefore essential to identify ECMs as well as targets and objectives that are:

- Specific to the Municipality and treatment plant
- Based on current performance
- What the municipality wants to achieve in a certain time frame
- Realistic, achievable and significant enough to motivate change

At this stage the energy management team should identify a broad array of aeration energy conservation measures, with the understanding that the next step of the process will select the most feasible options for implementation based on the evaluation criteria set in step 4.

The following actions are recommended.

- Research ECMs used at similar treatment plants both locally and internationally and establish success of implementation
- Discuss and brainstorm ECMs both internally as well as with external bodies e.g. other municipalities, ESKOM, DWS or consultants
- Apply advanced process modelling and simulation to evaluate feasible ECMs. If expertise is not available internally, then a specialist consultant needs to be appointed

Identify ECMs

The identified ECMs should be categorized into a manageable format that is easy to understand and communicate to the rest of the organization. One way of grouping ECMs is implementation approach in descending order of ease of implementation and capital investment requirements (i.e. the easiest and least cost first) e.g.

- Low Hanging Fruit
  - Process operation and control changes
  - Aeration operational and control changes
  - Business policy changes

- Low to Medium Capital Investment
  - Maintenance improvements

    - Automation/aeration control improvements
- High Capital Investment
    - Equipment replacement
    - Process redesign and improvements
    - Business measures

Set Energy Conservation Targets

Investigating into energy use improvements often yields many opportunities that are aligned with the Municipality`s overall mission and strategy on energy management. It is however impossible to implement all the improvements at the same time. Thus it is necessary to set specific targets in order to focus on the ones that the Municipality can successfully implement, track, and verify results in a reasonable timeframe.

Recommended Actions

- Set aeration energy conservation goals and targets. Some of the facts to consider in setting targets:
    - Current performance
    - Existing equipment
    - Planned upgrading and expansions
    - Skills availability – both internal and external

Key Points to Consider

- Energy conservation goals and targets should be based on addressing some of these questions:
    - Electricity consumption/ cost to be achieved and over what period?
    - Peak demand reduction?
    - Level of improvement of final effluent compliance?
    - Degree of automation and simplification of operations

3.3.5 Step 5: Prioritise Opportunities for Implementation

The objective of this step is to create a short list of energy efficiency opportunities that have been selected and carefully evaluated out of the list of opportunities generated in the previous step. This short list should

- meet the stated energy management goals of the team
- be economically viable
- implementable without creating a high level of risks or conflicts and ensuring compliance with final effluent discharge regulations.
-

The following actions are required:

Define Evaluation Criteria

The main difficulty of prioritizing energy efficiency opportunities is evaluating the importance of different goals and risks, using one objective system. While there is no set number of criteria to use for evaluating ECMs, it is recommended that a simple system which yields results in a short time be adopted. The criteria should also reflect the overall energy management goals for the Municipality.

Some of the criteria to consider include:

- Monetary value (payback period, ROI, life cycle costs)
- Availability of funding
- Existing need for process and equipment upgrades
- Regulatory requirements
- Ease of operation
- Achieving energy efficiency through coupling with energy regeneration
- Improvement in operator safety, skills and morale
- Support of other management goals (O&M, asset management, supply chain).

Key points to Consider

- Simple evaluation criteria are better. They yield results faster and with less friction among team members
- Work with Energy Management Team to select about four to five criteria best suited for your Municipality

Decide How to Apply the Criteria

Assigning a monetary value to soft benefits such as reducing the risk of final effluent non-compliance, or improving operator safety and morale poses a big challenge when evaluating energy efficiency opportunities. It is therefore necessary to develop more specialized evaluation criteria in order to include the non-monetary benefits. A simple quantitative ranking method has been found to be sufficient[9]. Because quantitative ranking is subjective it is important to document the process applied to determine the ranking criteria. This will ensure that

i. the procedure is understood by decision makers thus ensuring support in terms of resources
ii. the same process can be applied throughout the Municipality for other EMPs.

Key Points to Consider

- Select a monetary value analysis method that gives the most insight into both current and future costs e.g. while payback is easy to apply, life cycle analysis gives better understanding of the impact of initial capital investment as well as future costs and energy savings
- Apply a simple quantitative ranking method
- Document process applied to determine criteria

[9] EPA (2008)

Rank and Prioritise ECMs

Actions required in this step include the following:

- Determine monetary value of ECMs by applying selected monetary value analysis method
- Combine non-monetary and monetary items and rank energy efficiency opportunities.
- Tabulate all feasible ECMs (in a matrix table) and selected evaluation criteria including monetary value determined above
- Provide a score for each criteria and add up the total score for each ECM
- Establish a threshold score based on the Municipality`s requirements taking into account business, technical, legal, operational and stakeholder concerns
- Prioritize the ECMs based on the total score taking into account the threshold
- Test the sensitivity of results to determine the impact of important assumptions

Key Points to Consider

- Convert all energy efficiency items to monetary terms whenever possible. Monetary evaluations are easy to compare and communicate.
- Evaluate all energy management goals, including ancillary benefits whenever possible.
- Select a threshold score that ensures that the final results make sense in terms of the utility's overall capabilities

Define Performance Indicators

Quantitative performance indicators should be defined in order to measure progress from current baseline towards energy conservation targets set above. Examples of performance indicators to use can be:

- Electricity consumption (kWh)
- Peak electricity demand (kW)
- Energy use intensity (kWh/kg COD removed or kWh/pe/yr)

3.3.6 Step 6: Implement and Support Aeration Energy Management Program

This step focuses on how to put into reality the chosen ECMs identified in the previous two steps as well as build management systems to support the process e.g. training, communication plans, procedures, records and documentation. It also communicates to stakeholders how the project is going to be executed, the resources required and the outcomes of the project.

The following actions are recommended.

Develop Implementation Plan

- List the ECMs selected for implementation from Step 5. Describe the goals and objectives of each
- Describe the resources required, including a budget and financing plan

- Develop any specifications needed, including design criteria and procurement related documents
- Provide any changes in standard operating procedures, and/or process and aeration control strategies
- Set the schedule for implementation, including milestones and gaining the necessary regulatory approvals (if applicable)
- Set realistic expectations for the project in terms of resources required, schedule, procurement time frame, and expected results
- Make sure that the final results make sense in terms of the Municipality's overall capabilities
- Obtain Top Management approval. Top management needs to approve the implementation plan in order to approve resource allocation to the EMP.
  Important items to highlight include:
  - How the prioritized aeration ECMs align with other organizational goals and strategies
  - Cost; both financial and human resources
  - Human resources required
  - Timeframes and how it impacts normal operational duties
- Communicate details of EMP

  It is important to communicate the details of the EMP to employees as well as external stakeholders including suppliers and contractors. This will increase buy in and awareness of the organisation`s energy management programs.

Develop Management System Controls to Support EMP

To successfully implement and support the prioritized ECMs it is necessary to have robust operating controls in place. These controls include:

- Training for employees particularly operations staff who have to implement changes and ensure success operation of new equipment
- Communication
- Document control and record management
- Work instructions, energy conservation O&M manuals, and standard operating procedures.

In this step, review existing controls, identify additional controls required and implement them to support each ECM.

3.3.7 Step 7: Provide for Progress Tracking and Reporting

In order to create a sustainable energy management program, it is critical to measure the success of the project as it is being implemented. Measurements should provide:

- Performance metrics
- Progress
- Impacts on operations and maintenance, process performance, and staff.

Performance monitoring reports should be prepared and communicated to the main stakeholders i.e. anyone involved in the planning process, O&M staff responsible for implementation and senior management responsible for evaluating the project's success.

Progress tracking and reporting is important because it:

- Enables adjustments to be made to the existing program thus improving chances of success
- Provides guidance for future decision making and can help to refine planning assumptions
- Provides valuable feedback for planning and implementation staff, keeping them motivated and interested in the improvement process

Actions required in this step include the following:

- Assign the responsibility for tracking the progress of a project and reporting on that progress. The staff responsible for progress reporting should also be allocated the resources necessary to fulfil their responsibilities.
- Review what is currently being measured and monitored
- Determine additional monitoring and measurements required on the prioritized ECMs
- Develop an O&M plan to maintain efficiency of aeration equipment e.g. diffuser cleaning, sensor cleaning and calibration, motor servicing etc.
- Regularly review progress of energy targets and monitor compliance
- Implement corrective actions to stay on target
- Regularly communicate with staff and all stakeholders
- Set the performance metrics that will be used.
- Create a communication plan. The plan should identify who needs to be included in progress reports (e.g. elected officials, public, etc.), when reports should be made, and any actions that need to occur in response to reports.

Key points to Consider

- Performance metrics need to be focused so that only those benefits that can be directly attributed to a project are measured.
- Reporting should generate some follow-up activities to demonstrate a commitment to the project.

3.3.8 Step 8: Maintain and Expand EMPs within the whole Organization

The previous steps have shown how to implement, in a systematic way an EMP to minimize aeration energy use at activated sludge plants for a typical municipality. For municipalities with a number of plants, the program would initially be applied to a few plants before expanding to others. It is therefore important to maintain the success of the initial EMP and then expand it to other plants and other areas of water and wastewater management.

Recommended Actions:

- Continue to align energy goals with business and operational goals and strategies
    - Revise energy goals to match changes in business policies and/ or regulatory requirements
- Apply lessons learnt to improve execution of new EMPs

- Expand involvement of management and staff and other areas of business
- Communicate success and share with the South African wastewater sector
    - Attend and present findings at conferences and workshops e.g. WISA, SALGA conferences
    - Internal news bulletins, newsletters, notice boards, staff meetings

4. Case Study 1 – Zeekoegat WasteWater Treatment Plant

4.1 PLANT OVERVIEW

Zeekoegat WWTP is located upstream of Roodeplaat Dam on the Pienaars River. The plant treats mainly domestic wastewater with a small industrial contribution from Moreletaspruit and Hartebeestspruit. The remainder of wastewater from these areas is treated at Rooiwal WWTP. Screened and degritted raw wastewater is split between two modules which consist of primary settling tanks (PSTs), a balancing tank, an enhanced biological phosphorus removal (EBPR) activated sludge bioreactor, secondary settling tanks (SSTs) and final effluent disinfection.

Module 1 was commissioned in 1991 with an original design capacity of 30 Ml/d average dry weather flow (ADWF). The module was upgraded in 2013 and now has a rated capacity of 45 Ml/d ADWF. A second module with a rated capacity of 40 Ml/d ADWF was commissioned in June 2013. A new sludge handling and treatment facility consisting of a fermenter, anaerobic digesters, sludge dewatering and sludge liquor treatment facilities was commissioned in 2015.

Final effluent from the plant is discharged to Roodeplaat Dam.

4.2 TREATMENT PROCESS DESCRIPTION

Figure 4-1 shows an aerial photo of Zeekoegat WWTP. A brief description of the main process units is given below.

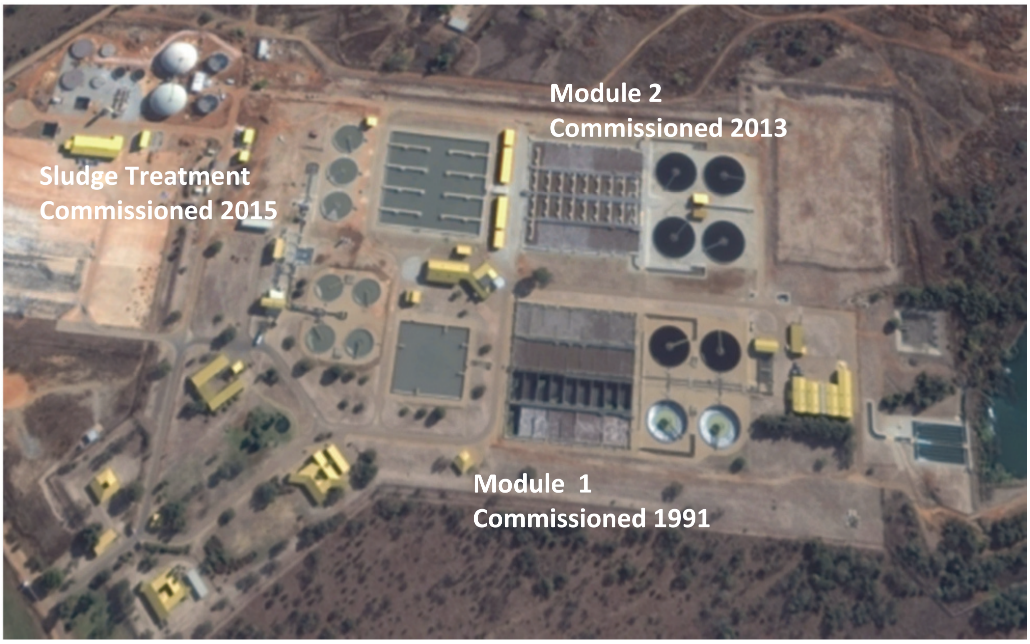

Figure 4-1: Zeekoegat WWTP Aerial Photo *(Courtesy Google Earth)*

4.2.1 Inlet Works

Raw wastewater flows into the inlet works which consists of a series of coarse and fine screens, vortex degritters and flow measurement. Screenings are washed and compacted in a screenings press prior to discharge into containers which are carried away for disposal. Grit is separated in a grit classifier and deposited in bins which are also carried away for disposal.

The degritted wastewater flows into a channel where the combined flow is measured by an ultrasonic flow meter and then flows into the main division box which splits the flow to Module 1 and 2 PSTs.

4.2.2 Primary Treatment

Degritted wastewater to Module 1 gravitates into the PST splitter box where it is spilt between 4x22m diameter PSTs. Module 2 degritted wastewater is split between 3x 24m diameter PSTs.

Prior to commissioning of the new sludge treatment facility in October 2015, the PSTs were operated on a rotating four day sludge storage/discharge cycle. For three days a PST accumulates primary sludge. On the fourth day the fermented sludge is pumped to the balancing tank. The fermented sludge can also be pumped directly to the activated sludge bioreactors. This mode of operation stimulates the formation of volatile fatty acids (VFAs) which supplement organic carbon required for optimal nutrient removal in the downstream BNR activated sludge process.

With the commissioning of the new sludge treatment facility, primary sludge is now pumped to 2 fermenters where it is fermented and generates VFA rich elutriant which is returned to the activated sludge process. Fermented sludge is pumped to the 2 anaerobic digesters for co-digestion with waste activated sludge (WAS).

The PST overflow gravitates to the Balancing Tanks.

4.2.3 Balancing Tanks

Each module has its own balancing tank fitted with submersible mixers to keep any remaining solids in suspension. The volumes for Module 1 and 2 Balancing tanks are 11,150 and 10,000 m^3 respectively.
The outflow from the Balancing Tanks is controlled to a pre-set flow. A magnetic flow meter measures the flow and controls a motorised pinch valve on the Balancing Tank outflow. The tanks are fitted with an emergency release, which discharges via a storm flow bypass pipeline to the emergency settling tank. The contents of the emergency settling tank can be returned to the head of works or can overflow to the maturation dam, downstream of the main treatment plant.

4.2.4 Secondary Treatment

Activated Sludge Process

Settled wastewater from each module's balancing tank flows to an activated sludge bioreactor which consists of two parallel streams; reactors 1&2 for Module 1 and reactors 3 & 4 for Module 2. The configuration for Module 1 was modified to be similar to Module 2 during the construction of Module 1. A schematic layout of the Module 1 bioreactor is shown in Figure.

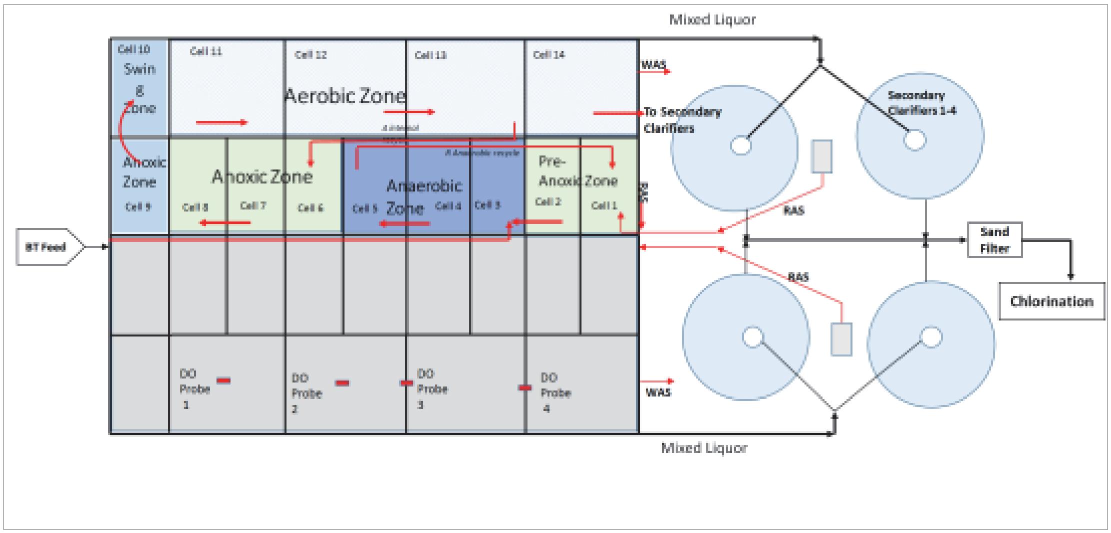

Figure 4-2: Zeekoegat WWTP Bioreactor Module Layout ***(Adapted from Golder & Associates, 2007)***

Each reactor consists of fourteen cells. The first eight cells are unaerated and mixed. Cells 9 and 10 can either be aerated or unaerated (swing cells). The last four cells are always aerated. The aeration system is discussed in more detail in Section 4.2.5.

In order to allow maximum operational flexibility and be able to meet low N and P limits the bioreactors were designed to be operated in any of five process configurations

- 3-stage Phoredox (A2O)
- Johannesburg
- Modified Johannesburg
- UCT (VIP)
- Modified UCT

The process configurations are changed by manipulating where the influent, return activated sludge (RAS) as well as the internal mixed liquor recycles are discharged. In 2014 when this study was conducted, the bioreactors were operated as a 3-stage Phoredox process.

Each Module bioreactor lane has two SSTs. Mixed liquor from each bioreactor is split equally between these two SSTs for final clarification. The underflow (RAS) from a pair of SSTs is pumped back to Cell 1 (or Cell 3) depending on the process configuration of a Module reactor. Thus, the sludge in each Module Reactor is maintained completely separate. WAS is wasted directly from each reactor and gravitates to the dissolved air flotation (DAF) units for further thickening.

The sizes of the ASP units are summarised in Table 4-1.

Table 4-1: Sizes of ASP Units

Treatment Unit	Units	Module 1	Module 2
Bioreactor			
Total volume	m^3	39,150	38,548
Water depth	m		
Cell Volume (each per Reactor)			
Cell 1-Cell 9	m^3	1,137	895
Cell 10	m^3	1,038	1,009
Cell 11-Cell 12	m^3	2,076	1,789
Cell 13-Cell 14	m^3	2,076	1,816
Internal mixed liquor "a" recycle			
Maximum a-recycle wrt ADWF	No.	1:6	1:6
Maximum r-recycle wrt ADWF	No.	1:1	1:1
Secondary Settling Tanks			
No. of secondary clarifiers	No.	4	4
Diameter	m	33	33
Side wall depth	m	3.5	3.5
Maximum RAS rate wrt. ADWF		1:1.5	1:1.5

4.2.5 Activated Sludge Aeration System

Module 1

The aerobic compartments are aerated by a fine-bubble diffused aeration system. During the construction of Module 2, the Module 1 aerobic cells were reconfigured to the same layout as Module 2 and the old diffusers were replaced with new EPDM membrane disc diffusers. Air is supplied by three Howden single stage centrifugal blowers (390 kW, each), two duty and one standby.

A summary of the blower and aeration control is given below. More details are given in the plant O&M manuals.

Figure 4-3: Module 1 Single Speed Centrifugal Blowers *(Photo Courtesy City of Tshwane)*

The blowers deliver air to a common manifold equipped with an airflow meter and pressure transmitter. The air flow splits to each reactor where it feeds the swing cells (9 & 10) and aerobic cells (11-14). There are four DO sensors located in each aerobic cell (11-14).

The chief Operator modified the original blower control and traditional fixed DO control algorithm and developed a new aeration control algorithm that takes into account manually observed final effluent ammonia concentrations. The modified control strategy is summarised as follows:

(i) Operator sets a blower manifold pressure set point
(ii) Based on experience, Operator uses observed final effluent ammonia measurements to set maximum DO setpoints and percentage valve opening dead bands in Cells 13 & 14.
(iii) The number of operational blowers and blower speeds are modulated to achieve the set point pressure and maintain DO and valve openings below the maximum setpoint and within the dead band respectively.
(iv) Minimum valve opening positions are set to ensure minimum blower and diffuser airflows are maintained

Although the ammonia concentrations are manually observed (from both the routine site measurements and online auto-analyzer) and not automatically linked to the aeration control system, the chief Operator's extensive experience on process performance under varying influent quality and operating parameters has resulted in a very efficient aeration control system.[10]

During the 2014 study, a single blower was mostly in operation during the winter months, with a second blower coming online during the summer months.

Module 2

Air to Module 2 is supplied by six HST9500 280NX Turbo blowers, supplied by ABS. Each reactor is supplied by three blowers (duty, assist, standby). The three blowers discharge into a common manifold equipped with two pressure transmitters (the average value from the two is used for control purposes). Details of the blower and aeration control philosophy are given in the ABS Blower and aeration control function design specification manual. The simplified basic design aeration control philosophy is as follows:

(i) Operator sets a target pressure for the air manifold
(ii) The blower speed and number of duty blowers are modulated to achieve the Operator set manifold pressure
(iii) Operator sets DO setpoint for each aerobic cell and associated cell airflow control valve modulates to achieve setpoint DO. Each aerobic cell has a dedicated airflow control value with actuator and feedback, an airflow meter and DO sensor
(iv) To prevent blower tripping, the Operator sets minimum valve opening positions that ensure minimum airflow. Also cell airflow measurements are used to override DO controlled valve open position to ensure diffuser minimum and maximum airflows are maintained

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[10] The modified aeration control system setup can be viewed to be similar to a feedback cascade ammonia DO control system without automatic measurement of the effluent ammonia

The basic aeration control philosophy is therefore fixed DO setpoint. Because of the better efficiency of the control algorithm used for Module 1, the chief operator mentioned that they are planning to modify the design control philosophy to the one applied for Module 1.

Figure 4-4: Module 2 Turbo Blowers *(Photo Courtesy efTEC)*

4.2.6 Tertiary Treatment

In order to ensure final effluent compliance with Ortho P limits at all times, standby ferric chloride dosing facilities were installed to supplement biological P removal when required. Dosing can be either into the mixed liquor effluent channel from the bioreactors prior to secondary clarification or effluent from the SSTs prior to the rapid sand filtration.

Effluent from the SSTs for each module flows to a set of rapid sand filters. After filtration effluent from the two sets of filters is collected in a common sump and then equally distributed to two chlorine contact tanks for disinfection prior to discharge to the maturation dam. Final effluent from the maturation dam overflows to the Roodeplaat dam.

4.2.7 Sludge Handling and Treatment

Commissioning of the new sludge handling and treatment facility started in January 2015. The facility consists of:

- Two primary sludge fermenters for VFA generation. The elutriant is returned to the balancing tanks
- Two fermented sludge thickeners for thickening fermented primary sludge. The thickeners also receive thickened overflow from the DAF units that thicken WAS. Supernatant from the thickeners flows to the liquor treatment tank
- Two anaerobic digesters that digest thickened primary sludge and WAS
- Five belt presses that dewater digested sludge. Dewatering liquor from the belt presses is pumped to the sludge liquor treatment tank
- Sludge liquor treatment that consists of a precipitation tank and two thickeners. Lime is dosed to precipitate excess phosphorus from the liquors. Effluent from the precipitation tank is

- thickened in the sludge liquor thickeners with the supernatant pumped to the balancing tanks and the underflow to the digested sludge holding tank that feeds the belt presses.
- Solar drying for drying digested sludge cake. The dried sludge is made available to external contractors who will compost it to produce a final product that can be used for soil conditioning

Some of the biogas is currently used to heat the boilers that provide heat for heating the digesters. Excess biogas s flared. There are plans to install a CHP engine that will utilise the biogas to generate electricity that can be used at the plant

4.2.8 Overall Plant Control System

The plant has various localised PLCs and a centralised Supervisory Control and Data Acquisition (SCADA) system. Major plant processes are monitored and controlled by local PLCs providing full automation to some of the processes.

In addition an online auto-analyser that automatically measures Ortho P, Nitrate, Nitrite and Ammonia and specific absorbance coefficient (SAC) was installed. According to 2014 records the auto-analyser measures values from the following streams:

- Reactors 1, 3 and 4 effluent
- Combined final effluent

4.3 FINAL EFFLUENT DISCHARGE PERMIT REQUIREMENTS

Final effluent is discharged to Roodeplaat Dam and is required to comply with the DWS's licence No. 27/2/2/2/A223/101/8. A summary of the limits for the main parameters is given in Table 4-2.

Table 4-2: Final Effluent Discharge Parameter Limits for Zeekoegat WWTP (DWS Licence – 27/2/2/2/A223/101/8)

Parameter	Unit	Limit
COD	mg/ℓ	50
Free and Saline Ammonia	mgN/ℓ	1
Nitrate/Nitrite	mgN/ℓ	6
Ortho-P (2009-2011)	mgP/ℓ	0.9
Ortho-P (2012-2015)	mgP/ℓ	0.5
Ortho-P (2012-2018)	mgP/ℓ	0.1
Total Suspended Solids	mg/ℓ	10
pH		$6.5 \leq pH \leq 8.5$
Electrical Conductivity	mS/m	80
Faecal Coliform	CFU/100 mℓ	0

The City of Tshwane indicated that the final effluent Ortho P limit might be reduced further in future and a figure as low as 0.035 mgP/l has been indicated in discussions between the City of Tshwane and the DWS.

4.4 PLANT CAPACITY AND PERFORMANCE

4.4.1 Baseline (2014) Influent Flows and Loads

The measured raw influent flows and loads from 1st January to 31st December 2014 were used as the baseline for the activated sludge aeration energy evaluation. Data from routine site measurements was used to calculate the average raw influent flows and loads given in Table 4-3. Also included in Table 4-3 are the design values applied during the 2009 upgrades.

Table 4-3: Zeekoegat WWTP 2014 Average Raw Influent Flows and Loads (Including design values)

Parameter	Units	2014	Design
Flows			
AAF	Ml/d	67.6	
ADWF	Ml/d	57.4	85
Loads			
TCOD	kg/d	28,251	53,890
TKN	kgNd	2,638	5,865
FSA	kgN/d	1,553	3,111
Total P	kgP/d	296	927
Ortho P	kgP/d	131	482
TSS	kg/d	15,080	23,630
Concentrations			
TCOD	mg/l	418	634
TKN	mgN/l	39	69
FSA	mgN/l	23	37
Total P	mgP/l	4	11
Ortho P	mgP/l	2	6
TSS	mg/l	223	278
Alkalinity	mg/l as $CaCO_3$	244	290

The plant loading is still below its design capacity receiving about 52%, 45% and 32% of the design TCOD, TKN and Total P loads respectively. The TSS load is slightly higher at 63% of the design load.

Additional data was also collected through a special sampling program during the 2014 winter (June to August) and 2015 summer (January to February) to determine the seasonal diurnal flow and load patterns as well as wastewater characteristics to be applied for mathematical modelling. A summary of wastewater characteristics is given in Table 3.4.

Graphical variations of the flows and loads in 2014 are given in Appendix A.

Table 4-4: Zeekoegat WWTP – Average Wastewater Characteristics (based on data collected during the 2014 and 2015 special sampling programs)

Parameter	Symbol	Value	
		Raw	Settled
Organics/COD			
BO (SB)/ Total ($S_{t)}$	fSbi	0.81	0.84
BPO (Sbp)/Total (St)	fSbpi	0.60	0.49
FBSO ($S`_{bs}$)/Total (S_t)	fSbsi	0.21	0.35
VFA (Sa/Total (St)	fSai	0.03	0.07
USO (S_{us})/Total (S_t)	fSusi	0.06	0.08
UPO (S_{up})/Total (S_t)	fSupi	0.13	0.08
Nitrogen Fractions			
FSA/TKN	fnai	0.67	0.77
Phosphorus Fractions			
Ortho P/ Total	fpai	0.49	0.66
Other Fractions			
TKN/COD		0.09	0.12
Total P/COD		0.011	0.12
FSA/TKN		0.65	0.77
Ortho P/ Total P		0.57	0.6
VSS/TSS		0.93	0.94

The wastewater characteristics and fractions fall within the generally expected ranges for South African Municipal wastewater. It should be noted that the average values in Table 4-4 were deduced from a rigorous data reconciliation process combining both statistical analysis of measured data and steady state activated sludge modelling.

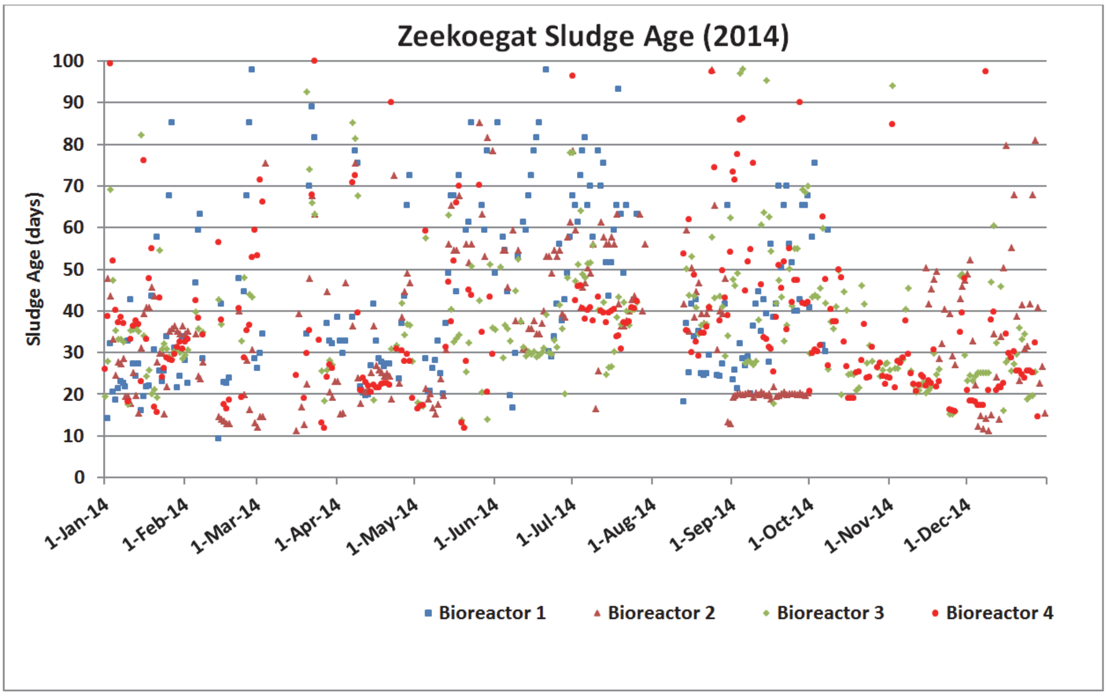
4.4.2 Baseline Plant Operation and Performance

Operating Parameters

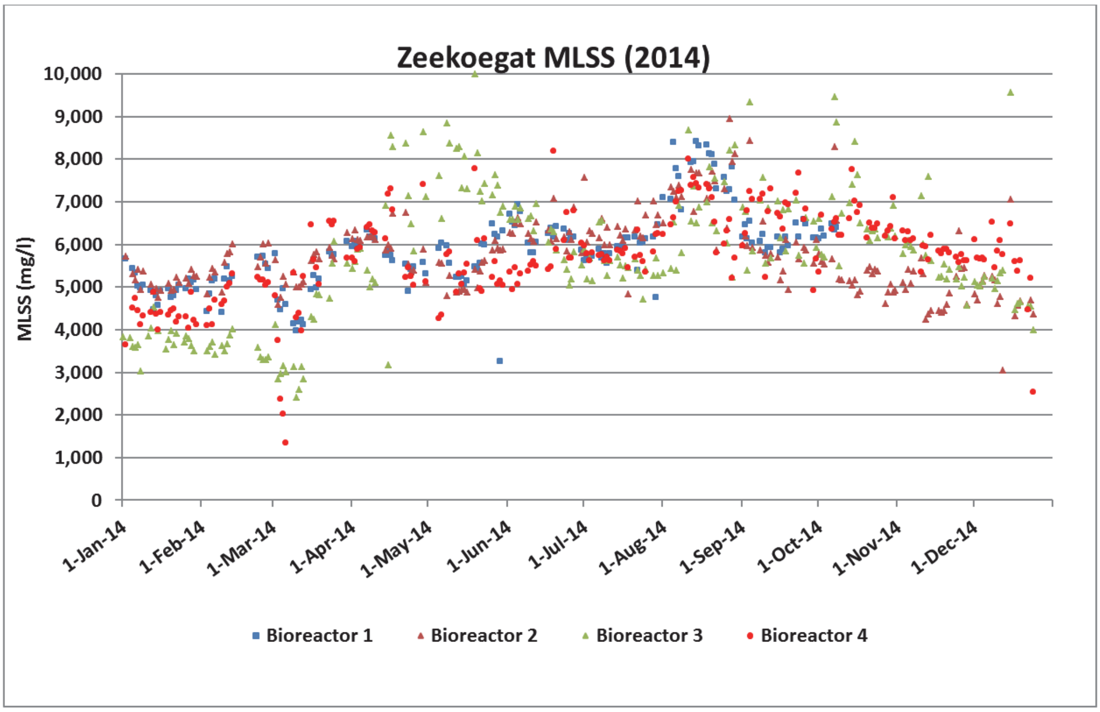
Prior to commissioning the new sludge treatment facility in 2015, the plant was in essence treating raw wastewater since primary sludge was discharged to the bioreactors. The existing DAF units, which were designed to thicken WAS generated from treating settled wastewater at the recommended design sludge age range of 20-25 days, do not have sufficient capacity to treat the additional WAS generated from treating raw wastewater. Thus to reduce the quantity of WAS, in 2014 the plant was operated at very long sludge ages averaging 25-35 days in summer and 40-60 days in winter. The MLSS concentrations were consequently high ranging from 4,000-7,000 mg/l. Figure 4-5 shows the variation of MLSS and sludge age for the four reactors in 2014.

The a-recycle was abstracted from the outlet of the third aerobic cell for all the reactors where only two out of the six installed pumps are accessible for each reactor. This limited the a-recycle to a maximum of about 2xADWF.

The s-recycle averaged about 1xADWF and could be increased to the design maximum of 2xADWF.



(a)



(b)

Figure 4-5: Zeekoegat 2014 (a) Sludge Age and (b) Bioreactors MLSS Concentration

Final Effluent Quality

The process performance was assessed by evaluating the final effluent parameter concentrations measured on site and comparing the values with the permit limits. Final effluent is regularly monitored hence there is plenty of data to assess process performance. Samples collected on a daily basis by the insitu composite auto-sampler are analysed for FSA, Ortho P, Nitrate, Nitrite, TSS and TCOD. In addition, parameter concentrations are also measured and recorded by the auto-analyzer. In line with permit requirements, the data collected by the auto-sampler was evaluated to assess final effluent compliance.

Average final effluent parameter concentrations from site measured data for 2014 are summarised in Table 4-5. Graphical variations are given in Figure 4-6.

Table 4-5: Zeekoegat WWTP 2014 Average Final Effluent Requirements (also included are the License Limits)

Parameter	Units	Average Measured Value	Licence Limits
FSA	mgN/l	0.7	1
Nitrate/nitrite[1]	mgN/l	6.4	6
Ortho P	mgP/l	0.3	0.5
Total Suspended Solids	mg/l	6.8	10
TCOD	mg/l	39	50

Note: The licence limit is for nitrate and nitrite. However site collected composite final effluent samples are only analysed for nitrate. The average measured nitrate concentration was 6.1 mgN/l. In order to be able to compare with the licence limit the average nitrite value of 0.2 mgN/l recorded by the online auto-analyser was added to the average nitrate value from the composite sampler data.

The following is noted from Table 4-5 and Figure 4-6

- Average TCOD, TSS, Ortho P and FSA concentrations were below the licence limits. However out of the 355 daily measured values for each parameter, the following percentages exceeded the licence limits
    - TCOD – 9%
    - TSS – 15%
    - FSA – 10%
    - Ortho P – 13%
- The average nitrate/nitrite concentration of 6.4 mgN/l exceeded the licence limit of 6 mgN/l. The measured data also exceeded the permit limit 53% of the time during the year
- Apart from nitrate/nitrite, the plant is complying with the licence limits

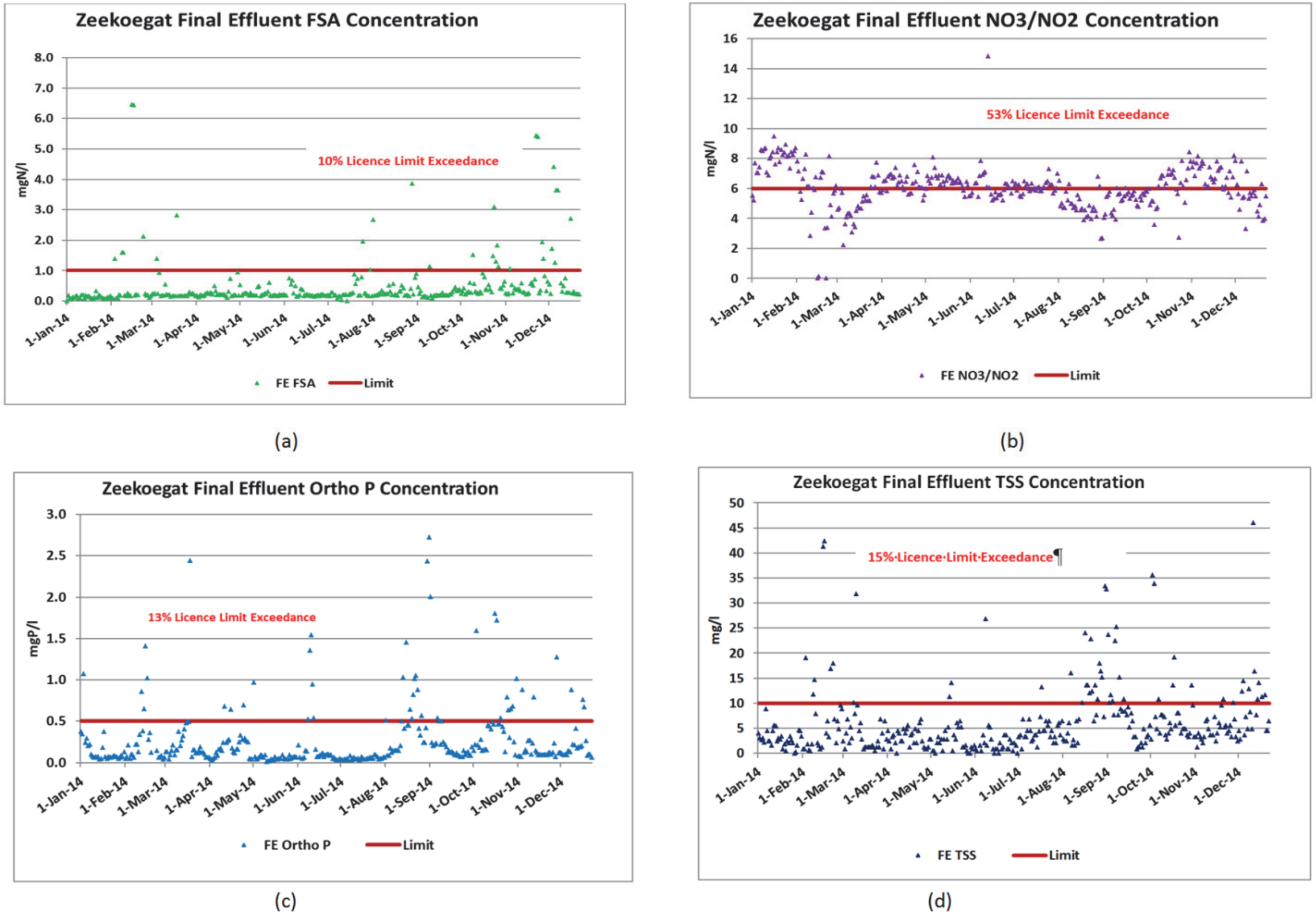
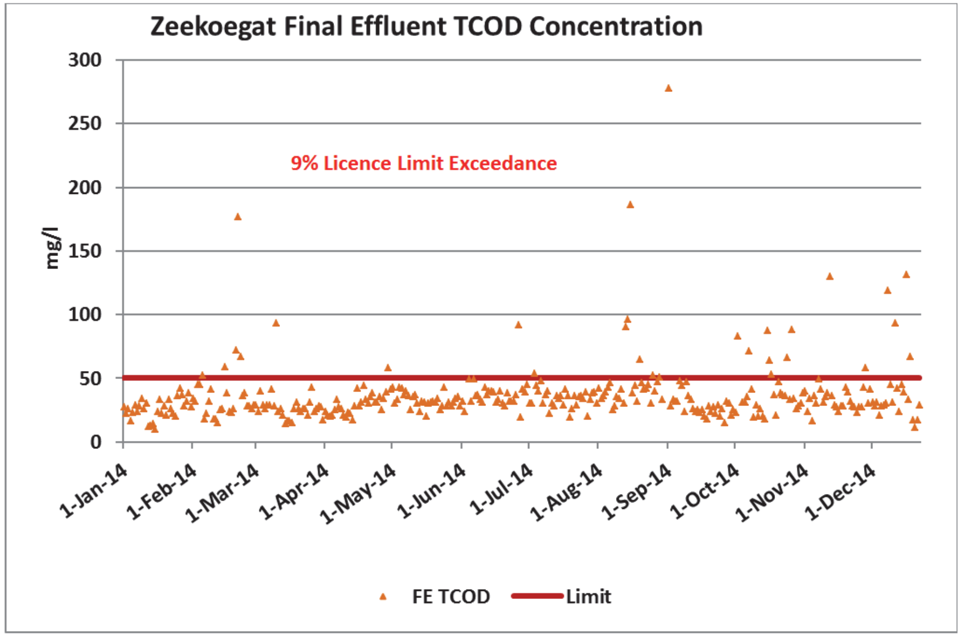


Figure 4 6: Zeekoegat WWTP 2014 Final Effluent Quality



(e)

Figure 4-6: Zeekoegat WWTP 2014 Final Effluent Quality (continued)

4.5 ENERGY PROFILE

4.5.1 Energy Sources

The main source of energy at Zeekoegat WWTP is electricity which is used in the treatment process as well as for lighting. All the electricity used at the plant is supplied by Eskom. In addition to the incoming power, there is a diesel standby generator that is used during power outages to maintain critical process units functional.

4.5.2 Energy Tariff

While electricity is supplied by ESKOM, the plant is billed monthly by the City of Tshwane. The plant is billed under Eskom's Megaflex 11 kV Time of Use (ToU) tariff with the following main components:

- Three ToU periods – peak, standard, off peak
- High demand season: June-August
- Low demand season: September-May
- Active energy (consumption) charges (c/kWh); seasonal and ToU
- Demand charge (kVA) – peak and standard
- Fixed charge

A summary of the active energy (consumption) charges applicable in 2014 is given in Table 4-6.

Table 4-6: Zeekoegat WWTP 2014 Summary of ESKOM Tariff Charges

	Low Demand Season	High Demand Season		Low Demand Season
	Jan-May	June	Jul-Aug	Sep-Dec
Active Energy Charge (c/kWh)				
Peak	74.75	266.68	332.8	93.30
Standard	45.90	69.70	87.00	57.30
Off Peak	32.15	37.3	46.60	40.20
Demand Charge (R/kVA)				
Peak	124	124	119.50	119.50
Standard	124	124	119.50	119.50
Fixed Charge (R/month)	1,380	1,380	1,485	1,485

4.5.3 Greenhouse Gas Emissions and Cost

South Africa does not yet have legislation that limits greenhouse gas (GHG) emissions hence there is no economic benefit in carbon reductions. It is however still important to quantify the reduction in emissions (on electricity generated by ESKOM) as a result of implementing the ECMs identified in this study. An emission factor of 0.99 grams of carbon per kWh of electricity has therefore been applied. This value typically represents the emission factor for electricity generated in South Africa[11].

[11] Typical values in the USA and Europe can be as low as 0.55 kg CO_2/kWh. Also refer to Chetty and Pillay (2015)

4.5.4 Baseline Energy Use and Cost

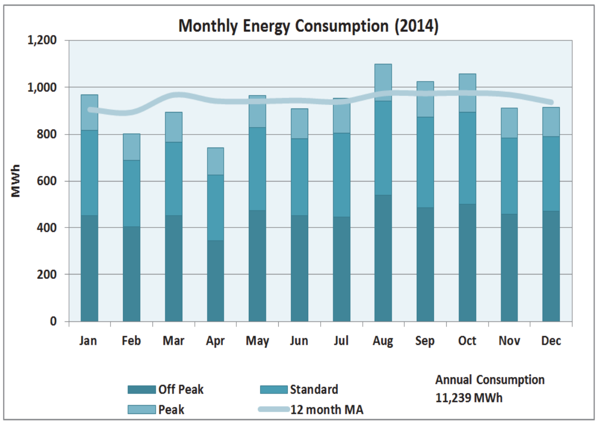
Energy Use

Electricity bills for 2013 and 2014 were analysed. A summary of the monthly consumption and demand is given in Table 4-7.

Graphical representations of the values are given in Figure 4-7. The 2013 data was used in calculating the 12-month moving average values shown in the graphs.

Table 4-7: Zeekoegat WWTP 2014 Electricity Consumption and Demand

Month	Consumption (kWh)				Demand (kVA)
	Peak	Off Peak	Standard	Total	
Jan	150,652	449,493	367,130	967,275	1,388
Feb	113,074	402,967	286,639	802,680	1,861
Mar	125,322	450,435	316,964	892,721	1,608
Apr	115,153	344,079	283,569	742,801	1,599
May	136,679	473,560	355,857	966,096	1,688
Jun	129,391	450,608	330,040	910,040	1,708
Jul	147,032	445,856	360,016	952,904	1,740
Aug	155,952	539,366	402,010	1,097,328	2,036
Sep	151,366	487,471	385,523	1,024,360	1,860
Oct	162,999	502,367	390,546	1,055,912	1,844
Nov	129,200	456,152	327,344	912,696	1,620
Dec	124,576	471,376	318,152	914,104	1,696
Total	**1,641,397**	**5,473,729**	**4,123,791**	**11,238,917**	



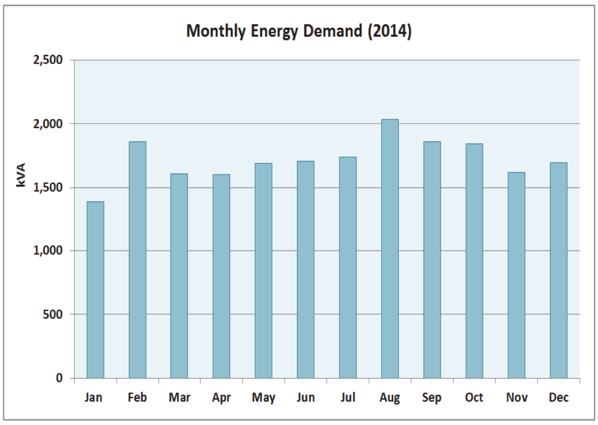


Figure 4-7: Zeekoegat WWTP 2014 Monthly Energy Consumption and Demand

The following is noted form the energy use profiles:

- The average monthly and daily consumption were 937,579 kWh/month and 30,800 kWh/d respectively. The annual total was and 11,239 MWh/yr.

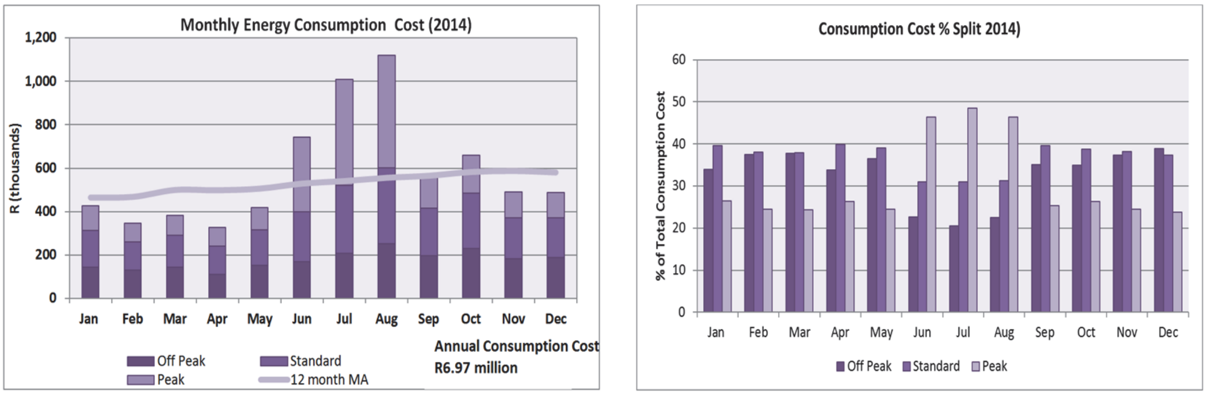
- The consumption profile suggests a higher than average consumption from July to October with slight peaks in January and May. During the remaining months the consumption drops to below average with April recording the lowest consumption.
- Average monthly demand was 1,721 kVA

4.5.5 Energy Cost

Table 4-8 and Figure 4-8 give the breakdown of the monthly electricity costs for Zeekoegat WWTP. In 2014, the plant was billed about R9.8 million for electricity usage. The consumption accounted for about R7 million (approximately 71%) with the balance being demand and fixed charges. On average about R583,000 and R231,000 was billed for consumption and demand charges respectively.

Table 4-8: Zeekoegat WWTP 2014 Electricity Cost

Month	Consumption Charge (R)				Demand Charge (R)	Fixed Charge (R)	Total Charge (R)
	Peak	Off Peak	Standard	Total			
Jan	112,612	144,512	168,513	425,637	227,771	1,380	654,788
Feb	84,523	129,554	131,568	345,644	232,915	1,380	579,940
Mar	93,678	144,815	145,486	383,980	204,528	1,380	589,888
Apr	86,077	110,622	130,156	326,855	221,342	1,380	549,577
May	102,168	152,249	163,338	417,756	238,616	1,380	657,751
Jun	345,061	168,077	230,038	743,176	241,443	1,380	985,999
Jul	489,322	207,769	313,214	1,010,305	236,048	1,380	1,247,733
Aug	519,008	251,345	349,749	1,120,102	215,826	1,485	1,337,413
Sep	141,225	195,963	220,905	558,093	252,328	1,485	811,905
Oct	173,369	230,225	255,112	658,706	250,157	1,485	910,348
Nov	120,544	183,373	187,568	491,485	219,761	1,485	712,731
Dec	116,229	189,493	182,301	488,024	230,079	1,485	719,588
Total	**2,383,816**	**2,107,996**	**2,477,949**	**6,969,761**	**2,770,815**	**17,085**	**9,757,662**



(a) (b)

Figure 4-8: Zeekoegat WWTP 2014 Consumption Cost Breakdown (a) Monthly Consumption Cost (b) % Cost Contribution for each ToU period

The consumption cost for the high demand season (June-August) is 41% of the total consumption cost. Peak period charges also contributed the highest percentage of the cost at 46-48%. During the low demand season, standard and off peak charges were higher.

4.5.6 Energy Split

The total electricity consumption and billed cost distribution by treatment unit/functional area for the plant is shown in Table 4-9. There were no records of power usage by the main units at the plant. Aeration power use was theoretically calculated using modelling and the power consumption for the other units was allocated based on duty motor sizes. It was recommended to the City of Tshwane that they keep records of run times as well as power and current drawn by the main units as part of the operation and control of the plant.

A graphical representation of the electricity consumption split is shown in Figure 4-9.

Table 4-9: Zeekoegat WWTP Electricity Consumption and Cost Split by Treatment Unit/Functional Area (January-December 2014)

Process Unit	Distribution (%)	Consumption (kWh)	Consumption Cost (R/yr)
Screens	2.3	261,037	161,881
Degritters	0.3	32,324	20,045
PSTs	1.2	135,955	84,312
Balancing Tanks	4.1	464,284	287,924
Aeration	42.2	4,742,823	2,941,239
Bioreactor Mixers	10.3	1,154,181	715,760
Mixed Liquor Recycle Pumps	11.0	1,235,153	765,974
SSTs	0.6	69,349	43,006
RAS Pumps	3.8	430,981	267,271
DAF	6.2	691,464	428,808
Aerobic Digestion	3.5	391,801	242,974
Effluent Pumping	5.3	597,823	370,737
Chlorination	0.6	63,668	39,483
Sludge Irrigation	4.5	502,811	311,816
Buildings and Lighting	4.1	465,264	288,531
Total	**100**	**11,238,917**	**6,969,761**

Aeration blowers accounted for about 42% of the total electricity consumption and cost at 4,742,823kWh/yr and R2, 9 million respectively.

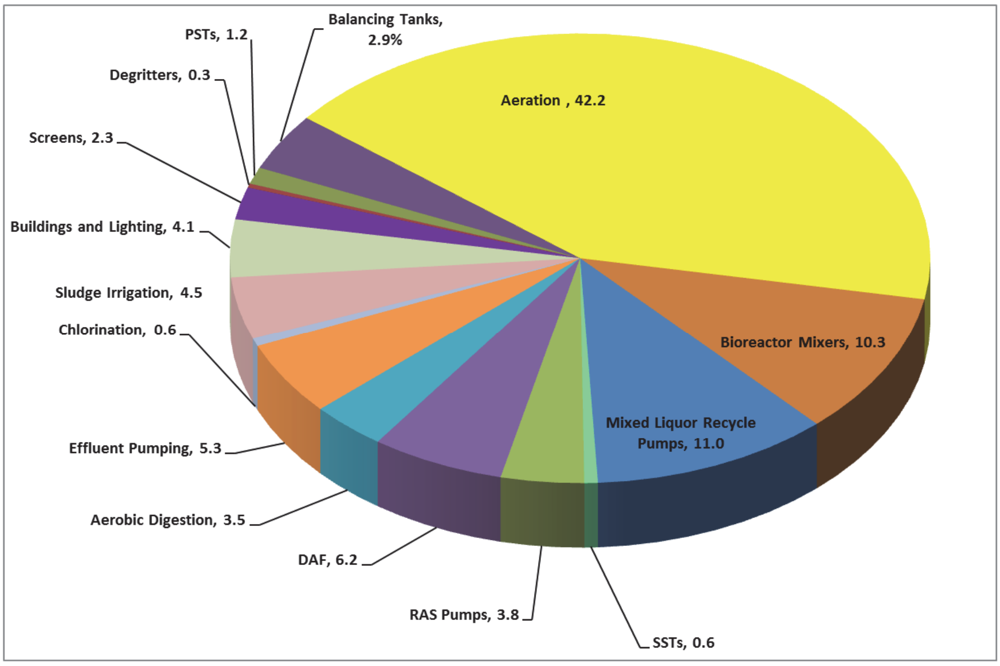


Figure 4-9: Zeekoegat WWTP 2014 Total Billed Electricity Consumption Split

4.5.7 Benchmarking Energy Use

As discussed in Section 2, benchmarking is critical to the success of any energy management initiative. By benchmarking energy use, Municipalities can compare themselves with the rest of the industry then set realistic energy use reduction goals and targets that can bring them in line with the best in the industry.

Consumption energy use per kgCOD treated and kWh/pe/yr have been selected as the most robust benchmark criteria for energy consumption rather than per unit flow. The pe is based on 100 gCOD/hd/d which is the typical value for South Africa. The benchmark energy use intensity for Zeekoegat WWTP is summarised in Table 4-10.

Table 4-10: Zeekoegat WWTP Energy Use Intensity Based on 2014 Consumption Values

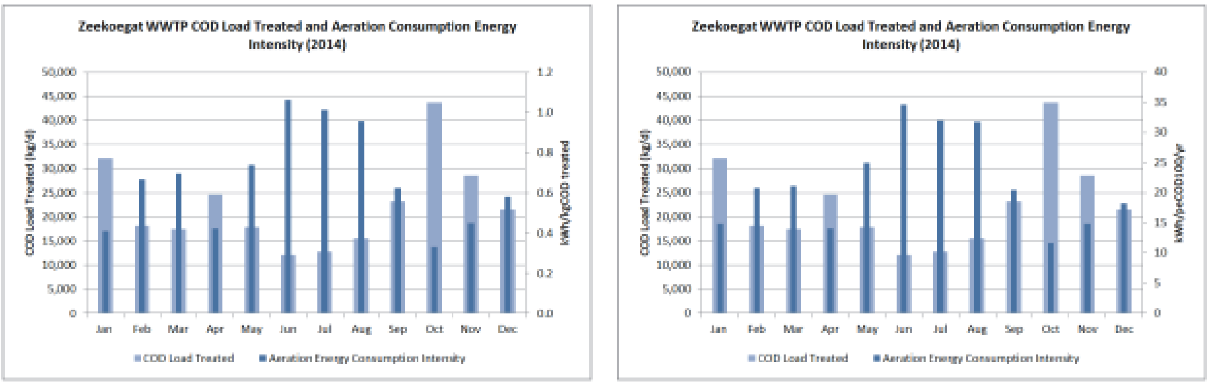
	Total Consumption	Aeration Consumption
kWh/kgCOD $_{treated}$	1.6	0.7
kWh/pe COD_{100}/yr	51	22
R/kgCOD $_{treated}$	1.4	0.6
R/pe COD_{100}/yr	47	20

No benchmark energy use intensity figures are available for South African plants to serve as a comparison. Most of the international energy studies give energy use intensity per unit of flow. While this is useful for hydraulic equipment such as pumps, it is not a very accurate measure for aeration energy where the energy used is directly proportional to the load being treated. Benchmarks based on COD load were obtained from studies conducted in Austria, Sweden, Germany and the USA and are summarised below:

- Total Consumption
  - Austria & Germany – 21 kWh/yr/pe COD_{100}
  - Sweden – 38 kWh/yr/pe COD_{100}
  - USA surveys on medium sized plants ~ 0.7-2.25 kWh/kg COD treated
- Aeration Consumption
  - Austria & Germany – 14.5 kWh/yr/pe COD_{100}
  - Sweden – 17 kWh/yr/pe COD_{100}

Both the total and aeration consumption energy intensities are higher than the values observed in Austria, Germany and Sweden, but within the range observed at some USA plants. Aeration consumption energy intensity is 52% higher than the values observed in Austria and Germany and 29% higher than the Swedish values.

Annual variation in energy use intensity is shown in Figure 4-10.



(a) (b)

Figure 4-10: Zeekoegat WWTP Monthly Variation in Aeration Energy Use Intensity and COD Load Treated (a) kWh/kgCOD treated (b) kWh/peCOD_{100}/yr

The aeration energy use intensity is highest during the tariff's high demand season (June-August).

4.6 EVALUATION OF FEASIBLE AERATION CONSERVATION MEASURES

The analysis in Section 4.5.6 has shown that aeration consumes the highest energy accounting for approximately 42% of total energy used at Zeekoegat WWTP. The primary objective of this study is to identify and evaluate energy conservation opportunities for the aeration system at the wastewater treatment plant. The opportunities can range from simple low cost measures that involve changing process and aeration control parameters using existing equipment to more costly complex measures that involve changing aeration control systems and/or equipment. The potential aeration ECMs that can be implemented at Zeekoegat and the rationale for selecting them are discussed below. The evaluation is based on the performance of the plant in 2014 which has been adopted as the baseline period.

4.6.1 Optimized Process Control with Current Aeration Control Strategy

As discussed in Section 4.2.5, the operators have implemented an aeration control strategy that is aimed at minimising aeration energy wastage. By modifying the design blower and fixed DO aeration control strategies, the DO concentration in both modules' aerobic zones was below the maximum design stipulated value of 2 mg/l.

Despite these efforts to optimize aeration control, the process operating parameters were not optimized to minimize process oxygen demand to treat to just the level to meet final effluent standards Because of the limited capacity of the DAF units, the process was run at very high sludge ages of 25-40 days in summer and 40-60 days in winter. During certain periods, there was no sludge wastage from the process. The optimal sludge age range to meet the final effluent ammonia limit of 1 mgN/l is 25-30 days in winter and 15-20 days in summer. Running the process at such high sludge ages consumes more energy without any additional treatment benefit either in final effluent or sludge quality since the active fraction of the sludge is already sufficiently low for dewatering on sludge drying beds at sludge ages of about 30 days. Not only was energy wasted in the bioreactor, additional energy was wasted by digesting the already relatively inert WAS in the downstream aerobic digesters.

In addition to operating at high sludge ages the plant was not operating at optimum a-recycle ratios in order to maximise denitrification (and recover more oxygen used in nitrification). For each reactor, the a-recycle was drawn from the end of the 3rd aerobic cell (Cell 13), where only two a-recycle pumps can be utilized limiting the a-recycle to about 60.5 Ml/d which was approximately 2xADWF. The 3-stage Phoredox process configuration was operated with an anoxic mass fraction of 29%. At the high sludge ages that the process was operated at, model predictions indicate theoretical optimal a-recycle ratios ranging from 2.6 to 10xADWF for the observed mixed liquor temperature range of 18-25^{o}C. The operating a-recycle was therefore too low to fully utilize the denitrification potential of the anoxic zone. Consequently, the plant failed to comply with the final effluent nitrate/nitrite licence limit. By moving the a-recycle withdrawal point to the end of the last aerobic cell (Cell 14) all the six installed a-recycle pumps are available and can be utilized thus allowing the a-recycle to be varied to a maximum of 121Ml/d (1:12 w.r.t 2014 ADWF and 1:6 w.r.t design ADWF) which is within the optimal range to fully utilize the denitrification potential of the anoxic zone.

This evaluation shows that there is potential to reduce aeration energy requirements from the current baseline values by optimizing the operating sludge age and a-recycle ratios while utilizing the existing aeration control strategy. The optimization will also improve denitrification and result in final effluent compliance with the nitrate/nitrite final effluent limit which is currently not being met.

4.6.2 Advanced Process Control

Global wastewater industry experience has shown that implementing advanced process control (APC)[12], a combination of optimal process control and advanced aeration control strategies rather than traditional feedback oxygen based real time control can save up to 25% in aeration energy. Literature reviews show that industry definitions of APC when applied to wastewater energy use reduction can differ from place to place. For the purposes of this report, APC is concurrent implementation of optimal process control (as outlined in 4.6.1) and advanced aeration control strategies other than traditional feedback DO based control.

Some of the aeration control strategies that have been tested internationally and can be implemented at Zeekoegat WWTP include:

1. Ammonia Based Control
   - Feedback (FB) cascaded ammonia/DO control
   - Feedforward feedback (FF-FB) ammonia on DO control
2. Proprietary Control Systems
   - Model predictive control (e.g. systems offered by companies like Perceptive Engineering and Siemens etc.)
   - Symbio™ – monitors NADH and control aeration to promote simultaneous nitrification and denitrification (Eimco Water Technologies)
   - Bioprocess intelligent optimization system (BIOS™) – feedforward control algorithm online process optimization program (Biochem technology)
3. Emerging technologies using other control parameters
   - Respirometry and critical oxygen point control (Strathkelvin Instruments – Scotland)
   - Off gas analysis – feedforward off gas monitoring and control

It should be noted that aeration equipment supply companies also offer "black box" type of APC packages that can be used as traditional DO control, feedback ammonia/ DO control to move complex packages that include additional monitoring instruments as well as blower and process control packages (e.g. Xylem's OSCAR system).

Evaluation of proprietary systems is beyond the scope of this study and these options have not been considered.

Of the above, ammonia based control would be most suitable for implementing at Zeekoegat because it has been proven through both modelling and full scale installations to reduce aeration energy use as well as improve biological P and N removal and final effluent compliance. Also it will be easy to implement as control algorithms can be developed and incorporated into the existing blower, aeration and process control systems with minimal modifications.

[12] Currently, the generally applied definition of APC in wastewater treatment energy efficiency is the application of sophisticated control engineering methods that incorporates both aeration and process controls resulting in optimal process performance and energy use. APC differs from real time control which is what most of the basic aeration control systems that are currently in use are (e.g. traditional feedback DO control using PID loops) as it involves both measurement and control of the measured parameter. APC generally relies on a model of some sort e.g. ASIM model, model predictive multivariable algorithms

4.6.3 Replacing Existing Blowers with More Efficient Ones

Module 1 has old Howden single stage centrifugal blowers with reported efficiency ranges of 65-80%. Recent advances in aeration technology have resulted in blowers that are more efficient than the single stage centrifugal blowers. The latest high speed turbo (such as the ABS turbo blowers installed for Module 2) and rotary lobe "Hybrid type" blowers (e.g. Aerzen's Delta Hybrid) are reported to have higher wire to air efficiencies in the range of 70-85%. These new blowers when coupled with good design to select the most optimal units to match process airflow requirements as well as optimal aeration system design and control strategies, have been reported to have much lower life cycle costs than the traditional conventional blower technologies i.e. positive displacement, single and multi-stage centrifugal.

In view of this replacing the existing Module 1 conventional single stage centrifugal blowers with the latest blowers with higher efficiency and lower life cycle costs has been considered as an option. For continuity it has been assumed in this study that the Module 1 blowers will be replaced with the same type ABS turbo blowers installed for Module 2.

4.6.4 Process Modelling and Simulation

Advanced dynamic process modelling and simulation was applied to evaluate the identified aeration ECMs outlined above. Simulations were carried out using the BIOWIN™ simulation package. The advantages of applying advanced process modelling and simulation to evaluate aeration ECMs have already been discussed in Section 1.2.3. Baseline 2014 data as well as data collected during the special sampling programs in June-August 2014 and January-February 2015 were used to validate and calibrate the model as well as evaluate the various ECMs. The evaluation was carried out on the 3-stage Phoredox process configuration that the plant was operated as in 2014.

It should be noted that modelling of NO_2 emission from the activated sludge process was not included in this evaluation although BIOWIN has the ability to simulate NO_2 emissions. Studies have also shown the layout of the activated sludge process does not affect its carbon emission significantly and is much less than the carbon emissions generated at the fossil fuel power station to provide energy to treat the wastewater[13].

The results of the detailed evaluation of selected feasible aeration ECMs are discussed in the next section.

4.7 FEASIBLE AERATION ENERGY CONSERVATION MEASURES – ANALYSIS RESULTS

Based on the analysis in Section 4.6, aeration ECMs that were considered feasible for implementation at Zeekoegat were selected and further analysed using advanced dynamic process modelling and simulation. The ECMS were classified by ease of implementation without major interference with the existing process as well as capital investment requirements as follows:

1. Simple Low Capital Investment
    - Optimised process control by operating at optimal sludge age and maximising denitrification
2. Low to Medium Capital Investment
    - Ammonia based advanced process control strategies

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[13] For more information on carbon emissions in activated sludge plants a number of publications are available e.g. Using Bioprocess Stoichiometry to Build a Plant-Wide Mass Balance Based Steady-State WWTP (Ekama, 2009)

3. Complex High Capital Investment
    - Replacing Module 1 single stage centrifugal blowers with the same high speed turbo blowers installed in Module 2 and implementing advanced process control.

The following methodology and assumptions were applied in calculating the aeration energy consumption and cost savings for each ECM:

- The 2014 aeration energy consumption and cost of 4,742,823kWh/yr and R2.94 million was used as the baseline.
- Electricity rates given in ESKOM's Megaflex 11 kV tariff in Section 4.5.2
- An emission factor of 0.99 $kgCO_2e/kWh$ of electricity was applied to estimate carbon reduction.
- Equipment cost estimates were obtained from local suppliers. Engineering and construction costs were estimated based on the Module 2 construction costs

4.7.1 Simple Measures – Optimised Process and Aeration Control

This measure involves adjusting the process operating and aeration control parameters to model predicted optimal values as detailed in Section 4.6.1. The model predicted optimal operating parameters based on the 2014 flow, load and wastewater characteristics data are:

- Winter (June-September) sludge age approximately 25-30 days
- Summer (October-May) sludge age approximately 15-20 days
- a-recycle to be drawn from last aerobic cell and increased to an average of 4xADWF in order to meet the nitrate/nitrite final effluent limit. Depending on the final effluent nitrate/nitrite concentration, the a-recycle should be varied from a minimum of 2xADWF at lowest winter temperature of 15^{o}C to a maximum of 6xADWF at summer mixed liquid temperatures above 23^{o}C.
- Blower and airflow control to be adjusted using the existing algorithm to maintain on average DO setpoints in Cells 11, 12, 13 and 14 at 1, 1,0.5 0.5 mg/l respectively.

The model predicted aeration energy consumption and cost savings as well as final effluent quality are given in Table 4-11. Also included are the 2014 baseline values for comparison.

Table 4-11: Zeekoegat WWTP Model Predicted Parameters for Implementing Optimised Process Control

	Units	Baseline (2014)	Optimised Process Control
Aeration Energy Parameter			
Consumption	MWh/yr	4,678	4,265
Consumption Saving	MWh/yr		413
% Consumption Saving	%		9
Consumption Cost	R/yr	2,901,169	2,604,182
Consumption Cost Saving	R/yr		296,987
% Consumption Cost Saving	%		10
Demand Saving	kW		47
Final Effluent Quality*			
FSA	mgN/l	0.40	0.30
Ortho P	mgP/l	0.30	0.05
Nitrate/Nitrite	mgN/l	6.00	3.00

From the results in Table 4-11 implementing optimised process and aeration control with the existing aeration equipment and control systems results in:

- Potentially 9% and 10% savings in power consumption and power consumption costs respectively. A demand saving of 47 kW is also realised as a result of savings in consumption
- Average final effluent nitrate/nitrite concentration of 3 mgN/l which is 50% below the average baseline value and permit limit of 6 mgN/l. 2014 baseline performance showed that 53% of the composite samples collected over 355 days exceeded the permit limit. Model diurnal simulations showed that peak nitrate/nitrite concentrations were below the permit limit of 6 mgN/l ensuring final effluent compliance all the time. Lower nitrate/nitrite values are due to improved denitrification as a result of increasing the a-recycle to optimal values.
- Average Ortho P concentration of 0.05 mgP/l which is 6 times less than the baseline measured average value of 0.3 mgP/l. The improved biological P removal is due to improved denitrification and reduced DO concentrations in the last aerobic cell resulting in less nitrate and DO being returned to the anaerobic zone via RAS flow.

4.7.2 Low to Medium Investment Measures – Advanced Process Control

Ammonia based aeration control strategy was selected as the most feasible measure to implement at low to medium capital investment and minimal modifications to the existing process and aeration control protocols. Both FB cascaded ammonia/DO and FF-FB ammonia on DO control were evaluated.

Implementing these control strategies will require at least the following preliminary modifications

- For FB cascaded ammonia/DO control
    - Installation of ammonia sensors in the outlets to the last aerobic cells to measure effluent ammonia.
    - Cascaded control systems that link the measured ammonia with measured DO in the 3rd aerobic cell and the blower control system. Fallback control systems in case of failure also need to be incorporated
    - Modifications to the SCADA system to incorporate all the control changes

- For FF-FB ammonia on DO control
    - Installation of ammonia sensors on the outlet of the aerobic cells as above as well as on the influent to measure influent ammonia
    - A cascaded control system that links the measured influent ammonia, the model that predicts oxygen demand based on the measured influent ammonia, the measured cell 4 effluent ammonia with DO in the 3rd aerobic cell and the blower control system
    - Modifications to the SCADA system

For practical implementation additional evaluation of the above will be required. For example, an engineer with experience in wastewater treatment process and control systems engineering will have to be appointed to carry out further modelling and simulation as well as design the control algorithms. The engineer will also recommend any modifications required to the existing blowers control system and/or the current operation of the bioreactor lanes to determine how best to incorporate the changes with minimum number of additional sensors and control systems to maintain ease of operation and control. In addition, a detailed sensor and instrumentation evaluation will need to be conducted in order to install practically functional instruments and control system.

Table 4-12 shows model predicted aeration energy consumption and cost savings as well as final effluent quality when these measures are implemented. Also included are the 2014 baseline values for comparison.

Table 4-12: Zeekoegat WWTP Model Predicted Parameters for Implementing Advanced Process Control (with ammonia based aeration control)

	Units	Baseline	Advanced Process Control	
			FB Cascade NH_4^+/DO	FF-FB NH_4^+/DO
Aeration Energy Parameter				
Consumption	MWh/yr	4,678	3,957	3,930
Consumption Saving	MWh/yr		721	748
% Consumption Saving	%		15	16
Consumption Cost	R/yr	2,901,169	2,416,000	2,400,000
Consumption Cost Saving	R/yr		485,169	501,169
% Consumption Cost Saving	%		17	17
Demand Saving	kW		82	85
Final Effluent Quality*				
FSA	mgN/l	0.40	0.8	0.8
Ortho P	mgP/l	0.30	0.03	0.01
Nitrate/Nitrite	mgN/l	6.00	1.50	1.0

Model predicted values in Table 4-12 indicate that implementing advanced process control (with ammonia based aeration control) utilizing the existing aeration equipment results in:

- Potentially 15-17% savings in power consumption and costs. Demand savings of 82-85 kW is also realised as a results of savings in consumption
- Average final effluent nitrate/nitrite concentrate of 1-1.5 mgN/l; 75-83% below the average baseline value and permit limit of 6 mgN/l.
- Average Ortho P concentration of 0.01-0.03 mgP/l; achieving near complete Ortho P removal.
- Model predicted final effluent Ortho P and nitrate/nitrite concentrations are much lower than the current measured values as well as those predicted with optimised process control in Section 4.7.1.
- Model predictions show that there is no significant difference in the energy savings as well as final effluent quality between the two modes of ammonia based control. In practice FF-FB ammonia on DO control is more accurate as it uses a model (ASIM type) to predict the oxygen demand based on the influent ammonia concentration and therefore yields higher energy savings. However FF-FB ammonia on DO control requires more sensors and control algorithms and is therefore more complex to maintain and operate.

4.7.3 Complex High Capital Investment Measures – Replace Old Module 1 Blowers

Module 1 single stage centrifugal blowers are replaced with turbo blowers similar to the ones for Module 2. Table 4-13 summarises the model predicted energy and cost savings that can be achieved with the same control strategies discussed in Sections 4.7.2 and 4.7.3.

Table 4-13: Comparison of Model Predicted Energy and Cost Savings for Replacing Module 1 Blowers

	Units	Baseline	Replace Old Module Blowers		
			Optimised Process Control	Advanced Process Control	
				FB Cascade NH_4^+/ DO	FF-FB NH_4^+/DO
Aeration Energy Parameter					
Consumption	MWh/yr	4,678	3,963	3,674	3,647
Consumption Saving	MWh/yr		715	1,005	1,031
% Consumption Saving	%		15	21	22
Consumption Cost	R/yr	2,901,169	2,420,040	2,243,040	2,226,975
Consumption Cost Saving	R/yr		481,129	658,129	674,194
% Consumption Cost Saving	%		17	23	23
Demand Saving	kW		82	115	118
Final Effluent Quality*					
FSA	mgN/l	0.40	0.30	0.8	0.8
Ortho P	mgP/l	0.30	0.05	0.03	0.01
Nitrate/Nitrite	mgN/l	6.00	3.00	1.50	1.0

The following is noted:

- Consumption energy and cost savings increase further as follows:
  - From 9-16% and 10-17% respectively with simple optimised process control
  - From 15-21% and 17-23% respectively with advanced process control

4.7.4 Comparison of Feasible ECMs

A summary of the financial analysis for implementing the feasible aeration ECMs discussed is presented in Table 4-14. Simple payback was adopted for the purposes of this project because it's a simple quick way of assessing how long funding is committed to a project. However, simple payback when compared with other superior economic performance evaluation techniques has the following main disadvantages:

- it focuses on how quickly the initial investment can be recovered and does not take into account all costs and savings after the payback period
- it does not take into account the time value of money when comparing future savings with initial capital investment

Simple payback is therefore not a true indicator of long-term economic performance.

For practical implementation of ECMs international best practice recommends that a more superior economic evaluation technique such as life cycle cost analysis (LCCA) be adopted. LCCA is particularly suited for evaluating energy conservation projects because of the following:

- it takes into account all costs incurred over the service life of a project (i.e. construction, maintenance & operation, recapitalization, and disposal)

- incorporates financial performance evaluation techniques that reflect the time value of money. The most commonly applied are net savings, investment to savings ratio, adjusted internal rate of return
- by applying the above, options can be compared and the most cost-effective option identified for implementation

Table 4-14: Financial Comparison of Feasible Aeration Energy Conservation Measures

		Using Existing Blowers			Replace Old Module Blowers		
	Units	Simple	Advanced Process Control		Simple	Advanced Process Control	
		Optimal Process Control	FB Cascade NH_4^+/DO	FF-FB NH_4^+/DO	Optimal Process Control	FB Cascade NH_4^+/DO	FF-FB NH_4^+/DO
Estimated Project Costs							
Capital Costs	R		645,535	991,595	2,104,221	2,749,756	3,095,816
Engineering Costs*	R		161,384	247,899	526,055	687,439	773,954
Total Project Costs	**R**		**806,919**	**1,239,494**	**2,630,276**	**3,437,195**	**3,869,770**
Annual Electricity Use Reduction							
Consumption	MWh/yr	413	721	748	715	1,005	1,031
Demand **	kW	47	82	85	82	115	118
Carbon Reduction **	t/yr	409	714	741	708	995	1,021
Annual Savings							
Consumption	R	296,987	484,803	501,585	481,129	658,129	674,194
Demand	R						
Total Annual Savings	**R**	**296,987**	**484,803**	**501,585**	**481,129**	**658,129**	**674,194**
Estimated Simple Payback	**years**	**0.0**	**1.7**	**2.5**	**5.5**	**5.2**	**5.7**

* Engineering costs assumed at 25% of capital costs. Engineering costs do not include advanced process modelling costs

** Demand reduction cost savings were not evaluated

*** Carbon reduction based on 0.99 kg CO_2 /kWh generated. Carbon reduction costs savings were not included

The following is noted from Table 4-14:

- Optimised control of the plant does not require any capital investment and will yield immediate annual aeration energy consumption cost savings of about R297,000
- The payback period for upgrading to advance process control is about 2 years while upgrading the Module 1 blowers results in measures with payback periods of 5.5-5.7 years
- Although replacing Module 1 blowers has longer payback periods, it yields the highest savings which will be realised after the payback period.

4.7.5 Other Benefits and Impacts of Implementing Aeration Energy Conservation Measures

Detailed process auditing and optimization through desktop application of mathematical modelling & simulation (taking into account diurnal and seasonal variations of flows and loads) has been applied in evaluating aeration ECMs in this project. This approach, which does not just focus on changing aeration and control equipment but also thoroughly examines the operation and control of the treatment plant results in other non-energy benefits for the treatment process as presented below.

Optimal Process Operation & Control Parameters

The process is well designed with flexibility to be operated in five modes to achieve final effluent compliance and fairly automated with DO sensors in every aerobic cell and a multi parameter online auto analyser. The operators have also taken significant measures to improve aeration energy efficiency through the use of automated aeration control and final effluent monitoring. Despite these efforts, some of the key process operating parameters were non-optimal and based on design values resulting in both aeration energy wastage and final effluent non-compliance for nitrate/nitrite. Actual practical optimal operating parameters cannot be easily determined through trial and error on site. Advanced process modelling applied in evaluating feasible aeration energy conservation measures enabled easy identification of the following critical process operating parameters for the 3-stage Phoredox configuration that the plant is currently being operated.

Sludge Age

Modelling identified the optimal sludge age ranges for winter and summer operations. Operating the plant at optimal sludge ages will not only result in energy use reduction but will also improve process performance as nitrification, denitrification and enhanced biological P removal efficiency rely on the process operating at optimal sludge ages. In 2014 the plant was operated at abnormally high sludge ages (> 35 days) due to the limited capacity of the sludge handling and treatment facilities. However with the commissioning of the new sludge handling and treatment plant, there is now sufficient capacity to process both primary and WAS and enable the plant to be run at optimal sludge ages with the associated benefits identified in this study.

Internal Mixed Liquor "a" Recycle Rate

One of the main issues at Zeekoegat has been failure to comply with the final effluent nitrate/nitrite license limit of 6 mgN/l. This is because drawing the a-recycle, from the outlet of the 3rd aerobic cell of each reactor where only two of the six pumps could be utilised limited the a-recycle rate to up to 2x ADWF which is too low and does not fully utilise the denitrification potential of the anoxic zone. Modelling and simulation identified the optimal a-recycle that is required to meet the final effluent nitrate/nitrite limit[14]. Improved denitrification has the following benefits:

- increase in recovery of energy used in nitrification and hence decrease in overall process energy requirements
- reduction in nitrate recycled to the anaerobic zone and hence improved biological P removal.

Return Activated Sludge "s" Recycle Rate

Currently the RAS rates are selected based on Operator experience and SST performance and varied between 0.9 to 2xADWF in 2014. The modelling identified that s-recycle rates can be reduced to as low as 0.5-0.9 x ADWF. The lower optimal s-recycle rates have the following benefits:

- minimum oxygen is returned to the anaerobic zone improving enhanced biological phosphorus removal
- Reduction in RAS pumps energy use

[14] In September 2015, the chief Operator changed the a-recycle abstraction point from the end of the 3rd aerobic cell to the last aerobic cell and utilised the available six pumps to increase the a-recycle to the recommended rate. It was reported afterwards that denitrification has improved and final effluent is complying with the required license limit of 6 mgN/l.

At these lower rates sufficient sludge is still returned to the bioreactor for optimal biological activity and there is minimum denitrification in the SSTs (denitrification in the SSTs is also minimised due to optimal denitrification as a result of changes to the a-recycle rate). Reduced RAS rates have been reported in practice (and verified through CFD modelling) to improve the thickening and clarification functions of SSTs thus improving final effluent compliance with TSS licence limits.

Improved Final Effluent Quality and Compliance with Final Effluent Discharge Licence Limits

Implementing advanced process control i.e. a combination of optimal process as well as aeration control strategies (Section 4.6) results in overall improved final effluent compliance. Through a combination of these, aeration is limited to achieve DO levels that meet nitrification requirements to final effluent ammonia limits. This together with optimal a-recycle control improves denitrification and reduces nitrate levels. Lower nitrate levels and DO returned to the anaerobic zone improve enhanced biological P removal. Model predictions for Zeekoegat show that, depending on the control strategy adopted:

- Nitrate/nitrite can be reduced to less than 2 mgN/l, greater than 67% below the final effluent limit of 6mgN/l
- Ortho P can be reduced to less than 0.1 mgP/l. This complies with the future final effluent Ortho P limit of 0.1 mgP/l that is proposed to come into effect in 2018. In practice a combination of optimal biological process control and ferric dosing should be able to meet even the ultra-low ortho P limit of 0.035 mgP/l that can possibly be put into effect by the DWS.

Assessment of Existing Plant Capacity

The detailed process modelling enables the real capacity of the process to be assessed and enable prediction of when the capacity will likely be fully utilised, thus assisting in planning for future capacity needs. With the commissioning of the new sludge handling and treatment facility, the City of Tshwane could benefit from reassessing the capacity of the plant using advanced process modelling taking into account the impact of primary sludge not being discharged to the balancing tanks.

Ease of Plant Operation

Implementing aeration ECMs through this approach results in simplified plant operation for operations staff who because of the data intensive nature of this approach, had to be closely involved with the project and responsible for data collection and physical process audits. This together with access to the knowledge dissemination workshop enhanced the staff`s knowledge about the plant. In addition implementing advanced process control strategies increases automation which further simplifies the overall operation and control of the plant.

4.7.6 Summary

Zeekoegat WWTP is a sophisticated EBPR activated sludge plant. The bioreactor has been optimally designed with flexible process configurations to enable compliance with the strict final effluent N and P license limits under varying influent flows, loads, influent quality and operating conditions. The plant has also been designed to minimise aeration energy use with a highly efficient fine bubble diffused aeration system consisting of latest model membrane diffusers in both modules, single speed centrifugal blowers for Module 1 and the latest high speed turbo blowers for Module 2. Influent flow is also balanced after primary clarification and constant flow is drawn from the balancing tanks to the bioreactor, effectively eliminating large diurnal load variations and minimising peak energy demand. To minimise aeration energy use further, the chief Operator developed a special aeration control algorithm which is more efficient than the contractor installed traditional fixed DO control strategy.

In terms of compliance with the DWS final effluent discharge license requirements, the plant has generally been performing well complying with all the other parameter limits except for nitrate/nitrite.

In 2014, the total annual power consumption at the plant was 11,239 MWh at a cost of R9, 8 million. As is typical of activated sludge processes, aeration consumes the most energy at the plant accounting for approximately 42% of the total energy usage 4,743 MWh/ and a cost of R2.9 million. This aeration percentage use is lower than the values generally observed at activated sludge plants where aeration consumes upwards of 50% of the total energy. The lower consumption is due to an optimal design with flow balancing and flexibility in the process configuration, installation of an efficient fine bubble diffused aeration system as well as implementation of an efficient aeration control strategy. The baseline total and aeration energy use intensities, which serve as a benchmark for the plant, were 1.6 kWh/kgCOD treated (51 kWh/peCOD$_{100}$/yr) and 0.7 kWh/kgCOD treated (22 kWh/peCOD$_{100}$/yr) respectively.

The analysis carried out in this project showed that while the plant is generally energy efficient, there are still significant opportunities to reduce the aeration energy consumption further to bring it to levels of some internationally observed benchmarks which are as low as 14.5-20 kWh/pe COD$_{100}$/yr. The recommended aeration ECMs to achieve this reduction discussed in detail in Section 4.7, are summarized in Table 4-15.

The following conclusions were drawn for Zeekoegat WWTP from this study:

1. Feasible measures to reduce aeration energy consumption can be divided into 3 broad categories

(i) Simple "Low Hanging Fruit" measures utilizing existing aeration and control equipment:
This does not require any capital investment but identifying optimal process operating parameters that minimise aeration energy consumption while producing final effluent that complies with the discharge license requirement i.e. operating the plant at optimal sludge age, anoxic mass fraction, internal mixed liquor and RAS recycle ratios while utilising the existing aeration control strategy. Aeration energy consumption cost saving of about 9% can potentially be achieved through simply optimizing process operation and control

(ii) *Low to medium capital investment measures utilising the existing aeration equipment*:
These measures involve implementing advanced process control that combines optimal process control with upgrading the current aeration control strategy from traditional DO based control. While there are other aeration control strategies that can be considered, the simplest and most practically feasible to implement evaluated in this project is feedback ammonia with cascade DO control. Investment in additional sensors as well as upgrading of the whole aeration control system will be required. Potentially 17% of aeration energy consumption cost can be saved by implementing this measure. Preliminary financial analysis indicates a payback period of 1.7 years.

(iii) High capital investment by replacing Module 1 blowers:
This measure requires replacing the existing Module 1 single stage centrifugal blowers with newer more efficient models. With the new blowers further savings can be achieved by either implementing simple process optimization as in (i) and increasing aeration energy cost savings

from 9 to 17% or implementing advanced process control as in (ii) and increasing aeration energy cost savings to 23%. Preliminary financial analysis shows payback periods of 5.5 and 5.2 years respectively. Although this measure requires higher capital investment, it yields higher energy savings which will be realised after the payback period

2. Modelling results show that implementing the identified aeration ECMs improves process performance resulting in final effluent nitrate/nitrite and Ortho P concentrations that are much lower than the current performance of the plant as well as the final effluent discharge license limits; The concentrations are also lower than the ultralow 0.1 mgP/l Ortho P limit that is proposed to come into effect in 2018
3. It should be noted that the model predicted savings for medium and high capital investment measures might not be realised in practice due to the universally acknowledged challenges of implementing control systems in wastewater treatment. The following is therefore recommended before practically implementing any measures in order to increase the chances of success:

    - A more detailed investigation of market available options for process and aeration control as well as blower technologies and the feasibility of incorporating them into the existing plant. The quality and costs of equipment including maintenance requirements are of critical importance to the success of the aeration ECMs
    - Application of a superior economic evaluation technique such as life cycle cost analysis, which takes into account all the costs incurred during the project life, so that the most cost effective measures can be selected for implementation
    - Further process evaluation and modelling to determine inter alia (i) capacity and efficiency of the existing blowers and diffusers (including minimum turn downs and maintenance requirements (ii) impact of new sludge handling and treatment facilities on process capacity and energy requirements (iii) process configuration and control optimisation to incorporate the above
    - Keeping records of power usage by blowers and other main equipment to accurately assess the power usage and improve the cost analysis for aeration ECMs

Table 4-15: Summary of Model Predicted Feasible Aeration ECMs

	Units	Baseline	Existing Blowers			Replace Module 1 Blowers		
			Simple	Advanced Process Control		Simple	Advanced Process Control	
			Optimised Process Control	FB Cascade NH_4^+/DO	FF/FB NH_4^+/DO	Optimised Process Control	FB Cascade NH_4^+/DO	FF/FB NH_4^+/DO
Aeration Energy Consumption								
Average Annual Consumption	MWh/yr	4,678	4,265	3,957	3,930	3,963	3,674	3,647
Average Annual Consumption	R'000/yr	2,901	2,604	2,416	2,400	2,420	2,243,	2,227
Energy Intensity per COD treated	kWh/kgCOD	0.71	0.64	0.60	0.59	0.60	0.55	0.55
Energy Intensity per pe (COD_{100})	(kWh/pe/yr)	25.8	23.5	21.8	21.7	21.8	20.2	20.1
% Consumption Cost Reduction			9	17	17	17	23	23
Average Final Effluent Quality								
FSA	mgN/l	0.40	0.30	0.8	0.8	0.30	0.8	0.8
Ortho P	mgP/l	0.30	0.05	0.03	0.01	0.05	0.03	0.01
Nitrate/Nitrite	mgN/l	6.00	3.00	1.50	1.0	3.00	1.50	1.0
Financial Evaluation								
Estimated Project Costs								
Capital Costs	R'000		646	992	2,104	2,750	3,096	
Engineering Costs*	R'000		161	248	526	687	774	
Total Project Costs	R		807	1,240	2,630	3,437	3,870	
Annual Electricity Use Reduction								
Consumption	MWh		413	721	748	715	1,005	1,031
Demand **	kW		47	82	85	82	115	118
Carbon Reduction **	t		409	714	741	708	995	1,021
Annual Savings								
Consumption	R'000		297	485	502	481	658	674
Demand	R'000							
Total Annual Savings	R'000		297	485	502	481	658	674
Estimated Simple Payback	years		0.0	1.7	2.5	5.5	5.2	5.7

5. Case Study 2 – JP Marais WWTP

5.1 PLANT OVERVIEW

ERWAT's JP Marais WWTP is located south east of Daveyton off the intersection of the N12 and R51 and treats mainly domestic wastewater from Benoni, part of Daveyton and Modderbee Prison. The plant was commissioned in 1990 with a design capacity of 15 Ml/d ADWF, 60 Ml/d PWWF and COD load of 15,000 kg/d. The treatment consists of inlet works, primary sedimentation, a BAR activated sludge bioreactor, secondary clarification and final effluent disinfection. Final effluent is discharged to the Blesbok Spruit. Occasionally, some of the effluent is pumped to Modderbee Prison where it is used for irrigation.

5.2 TREATMENT PROCESS DESCRIPTION

A photographic layout for JP Marais WWTP is shown in Figure 5-1. A brief description of the main process units is given below.

Figure 5-1: JP Marais WWTP Aerial Photo

5.2.1 Inlet Works

Wastewater flows via two gravity mains to the treatment plant raw influent lift pump station sump. Three (currently 1 duty, 2 standby) 45 kW Flender screw pumps pump wastewater to the inlet works.

Two coarse and 2 fine screens (one duty, one stand-by for each channel) installed in two channels in series provide screening for the influent raw wastewater. The screens which normally operate in automatic mode are equipped with a screenings press. Grit removal is via two vortex degritters in parallel. Dewatered screenings and grit are taken offsite for disposal at landfills.

An ultrasonic meter in a Venturi flume just after the degritters measures raw influent flow.

5.2.2 Primary Treatment

Degritted wastewater flows into a 24 m diameter active PST with a volume of 1,855 m^3. The sludge withdrawal pipe is connected to a pair of 4 kW Gorman Rupp (1 duty, 1 standby) sludge pumps which are operated through the manipulation of a 3 way valve and sluice gates, in the following manner:

- recirculation of sludge by pumping pre-screened settled primary sludge back into the PST. This promotes the formation of VFAs that are essential for biological excess phosphorus removal in the bioreactor. The VFAs are washed out with settled sewage and flow to the bioreactor. This is the normal mode of operation
- pumping primary sludge to the bioreactor. This is done at least once a day as there are no primary sludge handling and treatment facilities
- if the sludge screen is blocked and/or out of service, primary sludge can be redirected either back to the PST or the bioreactor at the plant. There is provision to redirect sludge to separate sludge treatment facilities if installed in future.

5.2.3 Secondary Treatment

Sewage flows through an underground pipe from the PST and is combined with RAS prior to discharge, via a bottom duct, to the activated sludge bioreactor. The ASP consists of a single bioreactor lane, two secondary clarifiers and a single tertiary treatment clarifier. The bioreactor is configured as a 3 stage Phoredox process. The process was designed to be operated at a maximum sludge age of 15 days and MLSS concentration of 4,000 mg/l.

The anaerobic zone is divided into 3 compartments to give plug flow conditions. Each zone is mixed by a 1 kW submersible mixer.

The anoxic zone is mixed by two submersible 2 kW mixers. There is no dividing wall between the anoxic and aerobic zone. The volume of the anoxic zone can be increased if required, by turning off the first set of aerators in the aerobic zone. Ten 45 kW surface aerators arranged in rows of two provide aeration in the aerobic zone. A submersible 4 kW mixer installed at the end of the aerobic zone is used as the a-recycle pump and pumps mixed liquor from the aerobic zone to the anoxic zone for denitrification.

Mixed liquor from the bioreactor flows to the secondary clarifier splitter box where the flow is split between two SSTs. Clarified effluent is disinfected via chlorination and discharged into a storm water channel which flows to the Blesbok Spruit. Final effluent can also be pumped (2x 11kW pumps; one duty one standby) to Modderbee prison for irrigation as required. Each SST has a pair of manually controlled 7.5 kW pumps (1 duty, 1 standby) that pump RAS back to the bioreactor inlet.

Sludge is wasted from the last cell of the aerobic zone. Two x 30 kW Gorman Rupp WAS pumps have been provided and they pump WAS (as well as scum and chemical sludge) to Welgedacht WWTP for further treatment and disposal.

A standby ferric dosing unit has been installed for use when the final effluent P limit of 1 mgP/l cannot be met by biological treatment. The tertiary treatment clarifier is also brought into operation when ferric dosing is required. Two x 5.5 kW (1 duty, 1 standby) mono pumps remove sludge from the bottom of the tertiary clarifier and pump it to either (i) WAS pump station sump or (ii) the bioreactor inlet with RAS.

A summary of the sizes of the ASP units is given in Table 5-1.

Table 5-1: Summary of Secondary Treatment Process Unit sizes for JP Marais WWTP

Treatment Unit	Units	Details
Bioreactor		
Total volume	m^3	10,875
Water depth	m	4.5
Anaerobic zone	m^3	1,380
Anoxic zone	m^3	895
Aerobic total	m^3	8,600
Size of surface aerators	kW	55
No. of aerators	No.	10
Secondary and Tertiary Clarifiers		
No. of secondary clarifiers	No.	2
No. of tertiary clarifiers	No.	1
Diameter	m	30
Area (each)	m^2	707
Volume (each)	m^3	
Maximum RAS rate (per clarifier)	l/s	100
Maximum RAS rate wrt. ADWF		~1:1

The anaerobic and anoxic mass fractions are 0.13 and 0.08 respectively. The anoxic mass fraction can be increased by turning off upstream aerators. If the first two aerators are turned off, the anoxic volume increases to 2,615 m^3 giving an anoxic mass fraction of 0.24. Turning off the first four aerators increases the anoxic volume and mass fraction to 4,335 m^3 and 0.40 respectively.

5.2.4 Activated Sludge Aeration System

The aeration system consists of 10 x 55 kW low single speed surface aerators arranged in rows of 2 along the aerobic zone. The design did not allow for a tapered aeration configuration to cater for reduced oxygen demand in the downstream aerobic cells. Two DO meters were installed. Both are located in the last aerobic cell; one approximately in the centre and the other near the bioreactor outlet. The DO meters were out of service for the whole duration of the project in 2014. A portable DO meter was used to monitor DO concentrations.

The plant was designed to operate using a fixed DO aeration control strategy hence the aeration system is controlled to primarily maintain a set DO in the aerobic zone stipulated in the design to be maintained between 1 and 2 mgO/l.

Aeration control was designed to be achieved as follows:

- a fixed DO setpoint is selected by the operator.
- immersion depth of the surface aerators is varied using an adjustable weir at the bioreactor outlet. A PLC, using the signal from the DO meters (average of the two meters) is used to automatically control the height of the overflow weir.
- aerators can be automatically controlled by timers (to switch them ON or OFF) in case of malfunction of the DO meters, weir control mechanism and/or the PLC.

Figure 5-2: JP Marais Surface Aerators

The weir control mechanism was also out of service during the study period in 2014. When the DO sensors were out of service, operators used the final effluent ammonia and nitrate concentrations as well as DO concentrations measured with portable DO meters to determine which and when to switch off some of the aerators.

In 2015, ERWAT installed a number of new sensors (COD, ammonia, TSS, and Ortho-P) in the bioreactor, final effluent and raw influent (after the degritters). The old DO sensors were replaced by new ones located in the same position. Although the new instruments were installed primarily for monitoring they provide options for future modification to incorporate automated control of the plant.

5.2.5 Sludge Handling and Treatment

There are no sludge handling and treatment facilities at the plant. The PST is operated as an active primary tank for VFA generation and primary sludge is partly recirculated and partly discharged to the anaerobic zone of the bioreactor as described in Section 5.2.2. WAS is pumped to the nearby Welgedacht WWTP where it combines with raw sewage at the inlet works and discharged into the activated sludge process.

5.2.6 Overall Plant Control System

Plant control is through a combination of manual control and localised PLCs. There is no SCADA system.

5.2.7 Disinfection of Final Effluent

A chlorination system is used to disinfect final effluent which is discharged to Blesbok Spruit. Part of the effluent is pumped to Modderbee Prison where it is reused for irrigation.

5.3 FINAL EFFLUENT DISCHARGE REQUIREMENTS

The plant operates under a DWS final effluent discharge Exemption Permit No. 2059B. The limits for the main parameters under this permit are given in Table 5-2.

Table 5-2: Final Effluent Discharge Parameter Limits for JP Marais WWTP (DWS Permit No. 2059B)

Parameter	Unit	limit
COD	mg/ℓ	55
Free and Saline Ammonia	mgN/ℓ	4
Nitrate/Nitrite	mgN/ℓ	6
Ortho-P (2009-2011)	mgP/ℓ	0.6
Total Suspended Solids	mg/ℓ	15
pH		6.5 < pH < 8.5
Electrical Conductivity	mS/m	80
E Coli	CFU/100 mℓ	0

5.4 PLANT CAPACITY AND PERFORMANCE

5.4.1 Baseline (2014) Influent Flows and Loads

The measured influent flows and loads from 1st January to 31 December 2014 were used as the baseline for the activated sludge aeration energy evaluation. From January 2013 to August 2014, due to construction work at Welgedacht WWTP, part of the influent flow was diverted to JP Marais. This increased both the average daily flow and loads to JP Marais during this period.

Data from routine site measurements was used to calculate the influent flows and loads given in Table 5-3. Despite the flow increase due to the diversion from Welgedacht WWTP, the average raw influent COD load was still 40% below the design value of 15,000 kg/d. When the flow diversion discontinued in August 2014, the average daily flow decreased by 48% while the average COD, TKN and Total P loads decreased by 17%, 34% and 38% respectively.

Graphical variations of the influent flow and TCOD load are given in Figure 5-3.

Additional data was also collected through a special sampling program during the 2014 winter (June to August) and 2015 summer (January to February) to determine the seasonal diurnal flow and load patterns as well as robust wastewater characteristics for mathematical modelling. A summary of wastewater characteristics obtained from this data is given in
Table 5-4

Table 5-3: JP Marais WWTP 2014 Raw Influent Flows and Loads (including design values)

Parameter	Units	Jan-Aug	Sep-Dec	Annual	Design
Flows					
ADWF	m^3/d	19,243	11,201	19,243	15,000
ADF	m^3/d	21,447	13,661	18,693	
Loads					
TCOD	kg/d	9,125	7,568	8,621	15,000
TKN	kgN/d	754	500	665	
FSA	kgN/d	490	325	432	
Total P	kgP/d	96	60	84	
Ortho P	kgP/d	55	34	48	
TSS	kg/d	3,328	2,210	2,933	
Concentrations					
TCOD	mg/l	429	554	461	1,000
TKN	mgN/l	35	37	36	
FSA	mgN/l	23	24	23	
Total P	mgP/l	4.5	4.4	4.5	
Ortho P	mgP/l	2.6	2.5	2.5	
TSS	mg/l	155	162	157	
PST Removal Rates					
COD	%	39			
TKN	%	9.4			
Total P	%	-5			
TSS	%	62			

Table 5-4: Average Wastewater Characteristics (based on data collected during the 2014 and 2015 special sampling programs)

Parameter	Symbol	Raw	Settled
Wastewater Characteristic Fractions			
BO (SB)/Total (St)	FSbi	0.79	0.82
BPO (Sbp)/Total (St)	FSbpi	0.53	0.44
BSO (Sbs)/Total (St)	FSbsi	0.26	0.38
VFA (Sa/Total (St)	FSai	0.03	0.07*
USO (Sus)/Total (St)	FSusi	0.08	0.11
UPO (Sup)/Total (St)	FSupi	0.13	0.07*
Nitrogen Fractions			
FSA/TKN	Fnai	0.65	0.01
Phosphorus Fractions			
Ortho P/Total P		0.57	0.60
Other Fractions			
TKN/COD		0.09	0.71
Total P/COD		0.12	0.12
VSS/TSS		0.10	

The wastewater characteristics and fractions fall within the generally expected ranges for South African municipal wastewater. It should be noted that the average values in Table 5-4 were deduced from a rigorous data reconciliation process combining both statistical analysis of measured data and steady state activated sludge modelling.

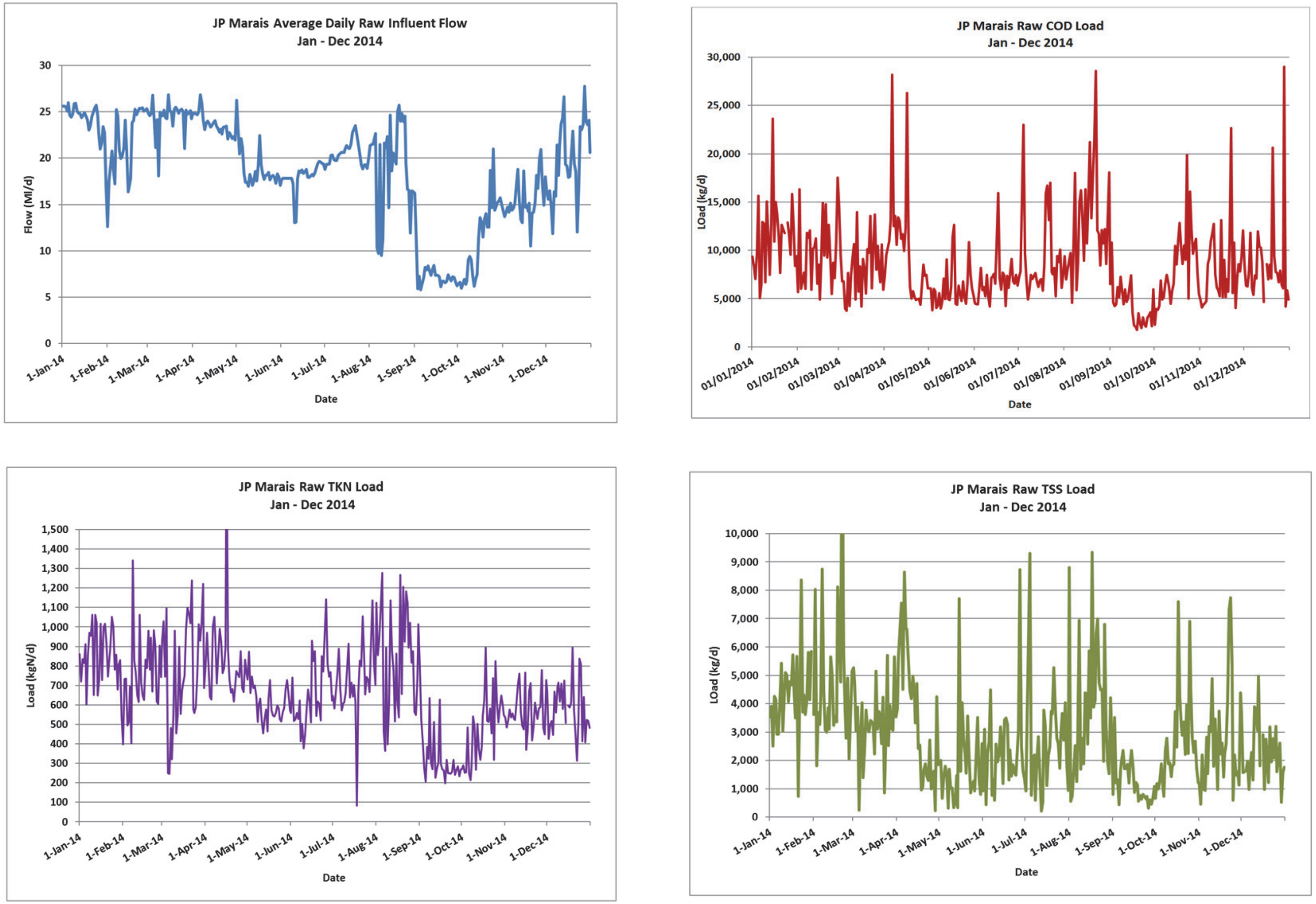

Figure 5-3: JP Marais WWTP 2014 Influent Flow and Loads

5.4.2 Baseline Plant Operation and Performance

Operating Parameters

Waste activated sludge is extracted from the last cell of the bioreactor by two pumps. It was reported that from April to May 2014, one WAS pump was out of service. Although there is a flow meter to record WAS wastage, there was very few recorded data to give an accurate indication of the process operating sludge age. The average MLSS concentration from January to August, with the Welgedacht flow, was 3,500 mg/l which indicates an average sludge age of about 13 days. From September to December, the average MLSS concentration increased to 5,000 mg/l which indicates an operating sludge age of about 25 days.

Similarly, although the RAS pumps are equipped with flow meters, very little data on RAS rates was available. The few available recorded data showed that the average s-recycle was about 1.7xADWF.

There were no records of the a-recycle rate. The a-recycle pump has a maximum capacity of 30.2 Ml/d which is 2 times the design ADWF of 15 Ml/d.

Effluent Quality

The process performance was assessed by evaluating site measured final effluent parameter values. There is an in-situ final effluent composite auto-sampler. Samples were sporadically analysed from January to September; once a month and sometimes on a daily basis. However from October to December, samples were analysed almost on a daily basis. Samples were analysed for FSA, Ortho P, Nitrate, TSS and TCOD.

Average final effluent parameter concentrations for 2014 are summarised in Table 5-5. The averages have been calculated for the two periods January to August, with the Welgedacht flow and September to December, without the flow diversion. Graphical variations are given in Figure 5-4.

Table 5-5: JP Marais WWTP 2014 Average Final Effluent Requirements. Also included are the License Limits

Parameter	Units	Average Measured Value		Permit Limits
		Jan-Aug	Sep-Dec	
FSA	mgN/l	10	2.3	4
Nitrate[1]	mgN/l	1.8	0.9	6
Ortho P	mgP/l	0.3	0.4	0.6
Total Suspended Solids	mg/l	23	12	15
TCOD	mg/l		35	55

1 The permit limit is for nitrate/nitrite. Site measured values are for nitrate

The following is noted from Table 5-5 and Figure 5-4:

- From January to August (with Welgedacht flow)
    - The average FSA concentration was 10 mgN/l; 2.5 times higher than the permit limit of 4 mgN/l. Of the 74 measurements recorded, 85% were above the permit limit
    - The average nitrate concentration of 1.8 mgN/l is about 3 times lower than the permit limit. Only 4% of the recorded values exceeded the limit

  - The average Ortho P limit of 0.3 mgP/l is 50% lower than the permit limit of 6 mgP/l
  - Average TSS concentration of 23 mg/l was 1.5 times higher than the permit limit of 15 mg/l. 55% of the recorded values also exceeded the limit

- From September to December (without Welgedacht flow) all the average concentrations were below the permit limits. The daily samples % exceedance of the permit limit was also lower during this period. Of the 84 recorded measurements the following percentages exceeded the permit limits:
  - FSA – 15%
  - Nitrate/nitrite – 0%
  - Ortho P – 12%
  - COD – 2%
  - TSS – 3%

- The plant failed to comply with FSA and TSS limits with the additional load from Welgedacht. During this time model based results indicate that the plant was being operated at a low sludge age which resulted in poor nitrification especially during the winter months. In addition low DO concentrations (average 0.3 mg/l) were measured in cells 2 to 4 of the aerobic zone during the special sampling program in June and July 2014.
- Although the site measured nitrate values are very low, model predictions indicate that with the low design anoxic mass fraction of 0.08, the final effluent nitrate concentration should be much higher averaging about 12 mgN/l. The possibility of analytical error is unlikely since 123 values were recorded and out of these only 2 exceeded the limit of 6 mgN/l. Therefore the low nitrate concentrations is highly likely due to substantial denitrification occurring in the unaerated pockets in the aerobic zone created by the non-uniform aeration pattern of the surface aerators as well as operators occasionally turning off some of the aerators.

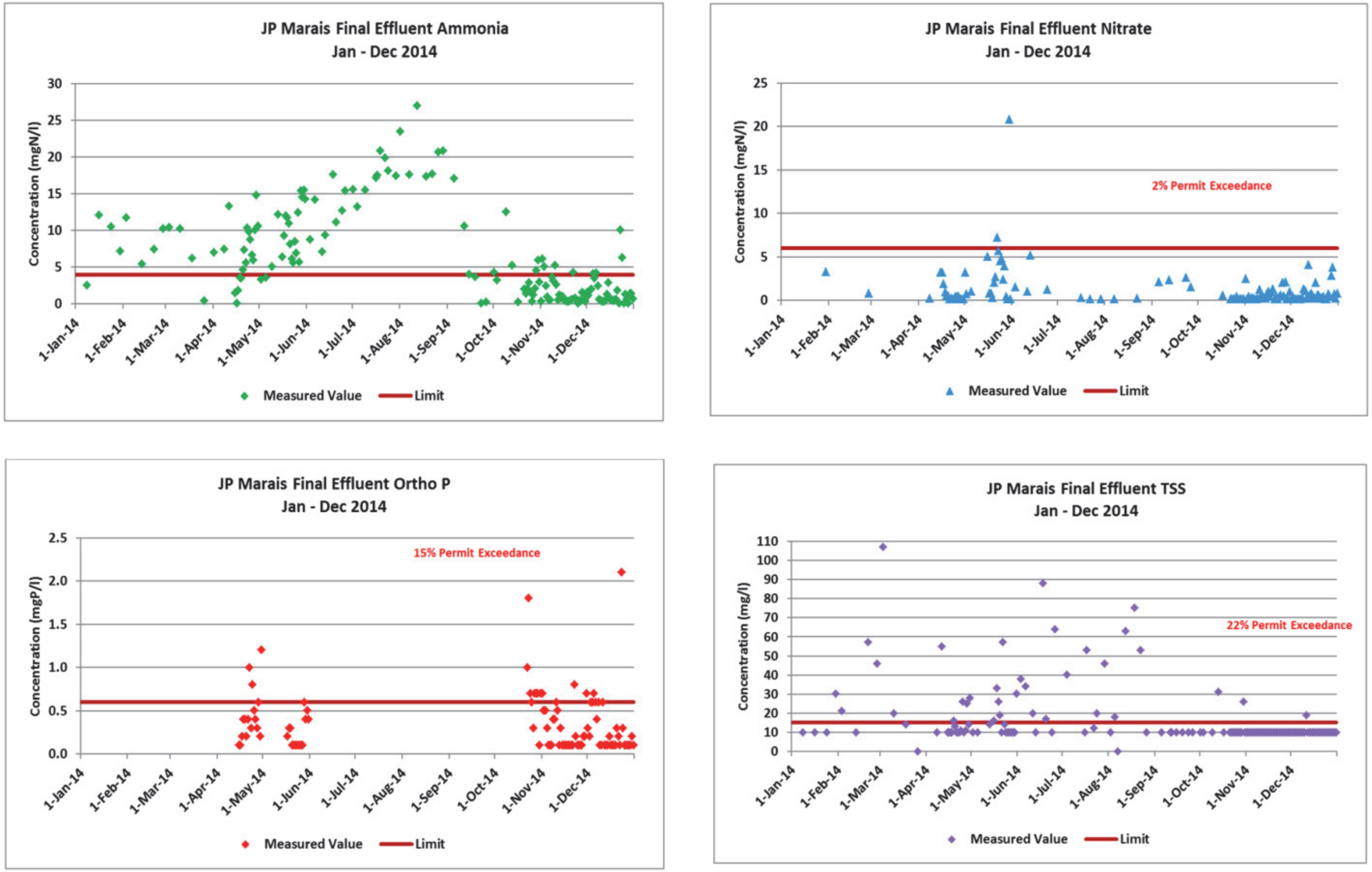

Figure 5-4: JP Marais WWTP 2014 Final Effluent Quality

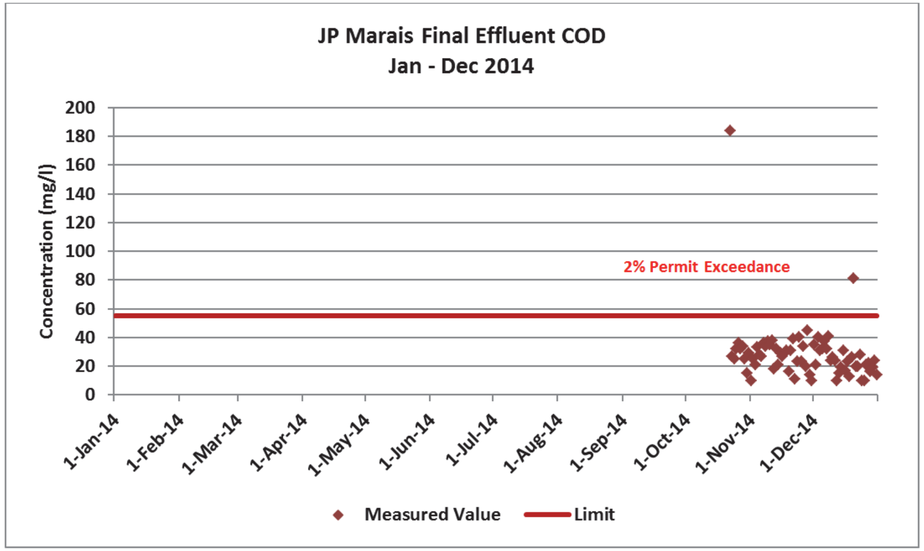

Figure 5-4: JP Marais WWTP 2014 Final Effluent Quality (continued)

5.5 ENERGY PROFILE

5.5.1 Energy Sources and Tariff

The main source of energy at JP Marais WWTP is electricity which is used in the treatment process as well as for lighting. In addition to the incoming power, there is a diesel standby generator for use during power outages.

Electricity is supplied and billed to the plant by Ekurhuleni Municipality. ERWAT were not able to provide a detailed breakdown of the tariff charge structure and rates. Only the average consumption charges from Ekurhuleni were provided as follows:

- January to May – 88c/kw
- June to September – 157c/kw
- October to December – 88c/kw

It appears that the tariff from Ekurhuleni is not a time of use tariff which would be applicable if the plant were billed on the basis of the Eskom tariff structures. Based on Eskom's 2014 tariff structures, the applicable tariff would be likely the Miniflex Local Authority[15]. The main components of this tariff are as follows:

- Three ToU periods – peak, standard, off peak
- High demand season: June-August
- Low demand season: September-May
- Active energy (consumption) charges (c/kWh) seasonal and ToU
- Demand charge (k/VA)
- Service charge
- Network access charge

As discussed in Section 3.3.3 it might be worthwhile for ERWAT to investigate the cost effectiveness of the various tariff structures if they pursue energy efficiency initiatives.

5.5.2 Baseline Energy Use and Cost

Energy Use

Electricity bills for 2013 and 2014 were analysed. Bills for only seven months (June to December) were available for 2013. A summary of the monthly consumption and demand is given in Table 5-6. Graphical representations of the values are given in Figure 5-5. The 2013 data was applied in calculating 6-month moving average values shown in the graphs.

[15] Neither ERWAT nor Ekurhuleni Municipality could supply details of the ESKOM tariff and it was assumed based on the size of the plant

Table 5-6: JP Marais WWTP 2014 Electricity Consumption and Demand

Month	Consumption (kWh)	Demand (Peak) kVa
Jan	297,974	644
Feb	291,801	656
Mar	274,180	652
Apr	260,528	592
May	289,874	642
Jun	305,946	663
Jul	301,941	656
Aug	286,166	624
Sep	274,947	628
Oct	246,810	554
Nov	250,377	576
Dec	259,597	617
Total	**3,340,141**	

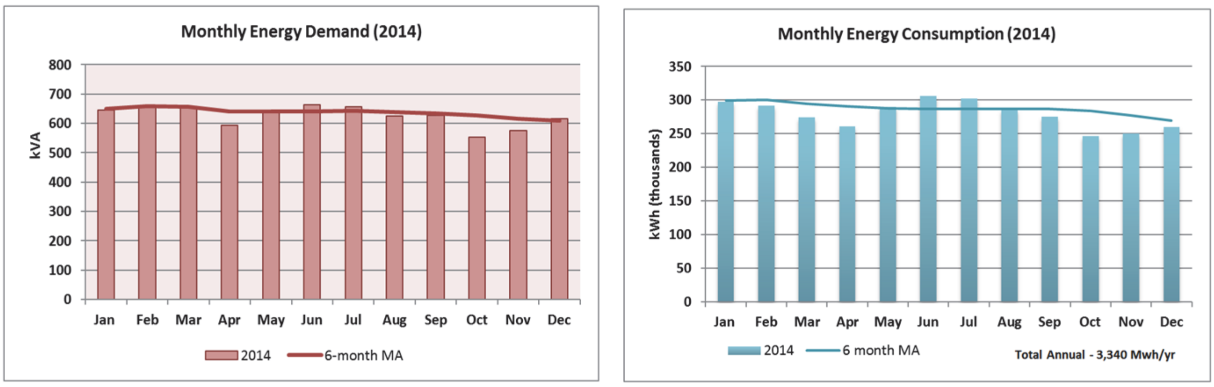

Figure 5-5: JP Marais WWTP 2014 Energy Consumption and Demand Profiles

The following is noted from the energy use profile:

- The average monthly and daily consumption were 278,345 kWh/month and 9,151 kWh/d respectively. The annual total was 3,340 MWh/yr.
- The consumption profile suggests a higher than average consumption and from May to August with slight peaks from January to February. June had the highest consumption. During the remaining months the consumption drops to below average, with October recording the lowest consumption.
- The demand profile follows a similar pattern with average monthly demand of 625 kVA.

5.5.3 Energy Cost

Table 5-7 gives the breakdown of the monthly electricity costs for JP Marais. . Graphical representations are given in Figure 5-6.

In 2014, the plant was billed about R4 million for electricity usage; an average of R334, 000 per month. Consumption accounted for around R3.1 million (77%), demand R650, 400 (16%), network access R234, 400 (6%) and the balance 1% being service charges.

Table 5-7: JP Marais WWTP Electricity Cost

Month	Consumption Charge (R)	Demand Charge R	Service Charge R	Network Access Charge R	Total Charge R
Jan	228,814.40	51,567.47	1,908.13	19,061.25	301,351.25
Feb	224,073.91	52,467.82	1,908.13	19,061.25	297,511.11
Mar	210,542.59	52,190.64	1,908.13	19,061.25	283,702.61
Apr	200,059.30	47,408.57	1,908.13	19,061.25	268,437.25
May	222,594.50	51,408.09	1,908.13	19,061.25	294,971.97
Jun	234,935.80	53,063.00	1,908.13	19,061.25	308,968.18
Jul	386,666.06	63,041.46	2,049.33	19,061.25	470,818.10
Aug	393,592.70	64,375.76	2,049.33	20,470.66	480,488.45
Sep	378,162.20	64,785.92	2,049.33	20,470.66	465,468.11
Oct	203,543.89	47,584.96	2,049.33	20,470.66	273,648.84
Nov	206,486.27	49,491.13	2,049.33	19,772.93	277,799.66
Dec	214,089.47	53,000.36	2,049.33	19,772.93	288,912.09
Total	**3,103,561.09**	**650,385.18**	**23,744.76**	**234,386.59**	**4,012,077.62**

The consumption cost for the high demand season (June-August) is 33% of the total consumption cost.

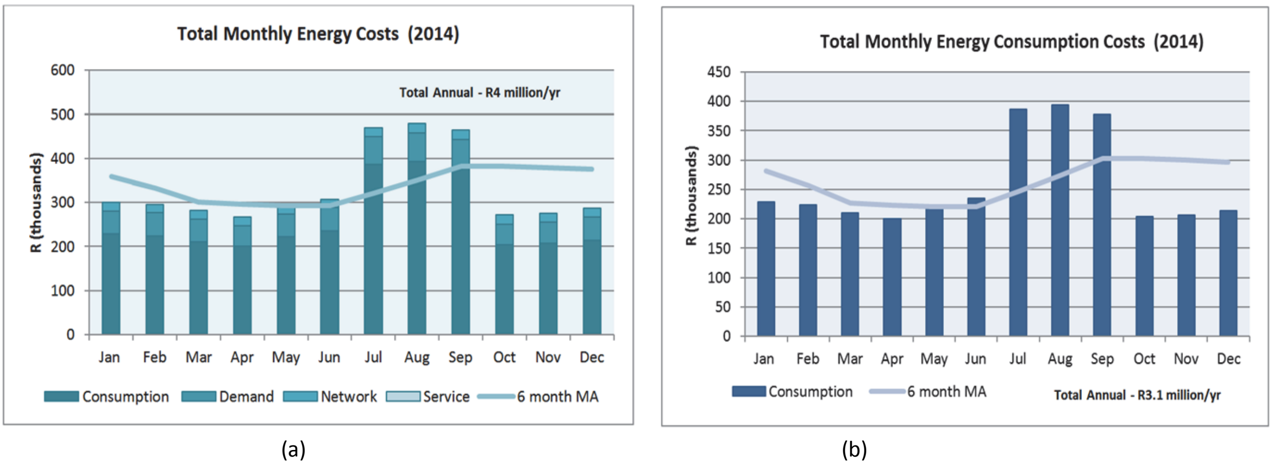

Figure 5-6: JP Marais WWTP 2014 Energy Cost Profiles (a) Total (b) Consumption

5.5.4 Energy Split

The total electricity consumption and billed cost split by treatment unit/functional area for the plant is shown in Table 5-8. Monthly records of run time and current drawn for all the large electrical equipment were available and were used to calculate the power usage distribution.

A graphical representation of the electricity consumption split is shown in Figure 5-7.

Table 5-8: JP Marais WWTP 2014 Electricity Consumption and Cost Split by Treatment Unit/Functional Area

Process Unit	Distribution (%)	Consumption (kWh)	Consumption Cost (R/yr)
Raw Influent Screw Pumps	7.2	241,015	223,944
Screens	0.2	8,009	7,441
Degritter	0.3	10,502	9,758
Sludge Recirculation Pumps	1.0	33,854	31,456
Aeration	74	2,465,226	2,290,616
Mixers	0.0	100	93
RAS Pumps	5.1	170,557	158,476
WAS Pumps	6.7	226,741	210,681
Clarifiers	0.3	11,097	10,311
Other Pumping (chemical, irrigation, effluent reuse)	2.1	70,260	65,284
Chlorination	0.3	8,819	8,195
Buildings and Lighting	2.8	93,961	87,306
Total	**100**	**3,340,141**	**3,103,561**

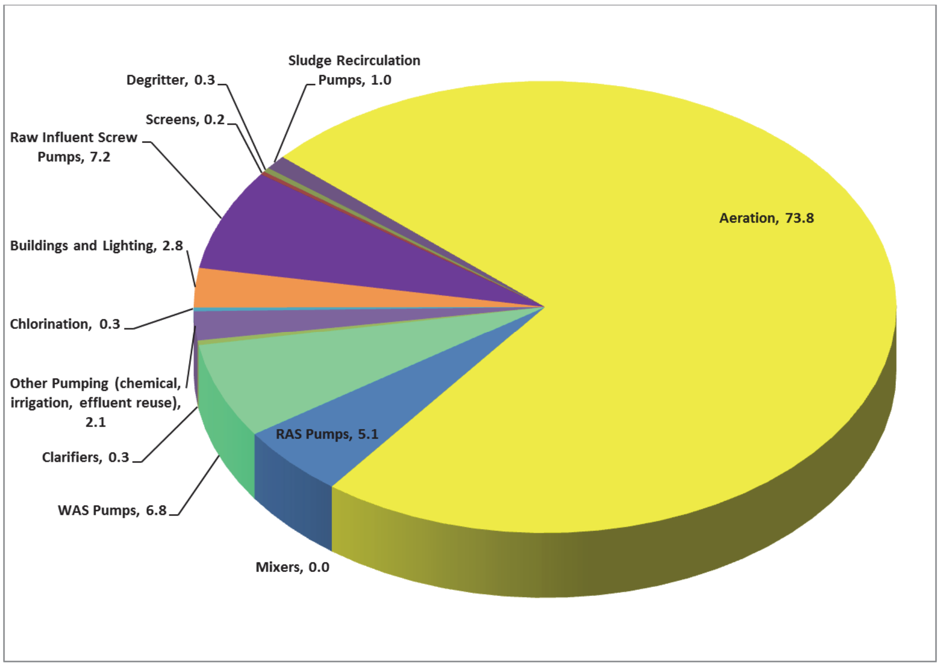

Figure 5-7: JP Marais WWTP 2014 Total Billed Electricity Consumption Split

Aeration accounted for about 74% of the total electricity consumption and cost at 2,465 MWh/yr and R2, 3 million respectively.

5.5.5 Benchmarking Energy Use

As discussed in Section 2, benchmarking is critical to the success of any energy management initiative. By benchmarking energy use, Municipalities can compare themselves with the rest of the industry then set realistic energy use reduction goals that can bring them in line with the best in the industry.

The benchmark energy use intensity for JP Marais is summarised in Table 5-9.

Table 5-9: JP Marais WWTP Energy Use Intensity Based on 2014 Consumption Values

	Total Consumption	Aeration Consumption		
		JP Marais	**Zeekoegat**	**International**
kWh/kgCOD $_{treated}$	1.2	0.9	0.7	0.7-2.25
kWh/pe COD_{100}/yr	44	31	22	14.5-17
R/kgCOD $_{treated}$	1.1	0.82	0.6	
R/pe COD_{100}/yr	41	32	20	

The aeration energy use intensity for JP Marais is 45% higher than values calculated for Zeekoegat, 120% higher than values observed in Austria and Germany and 88% higher than values observed in Sweden.

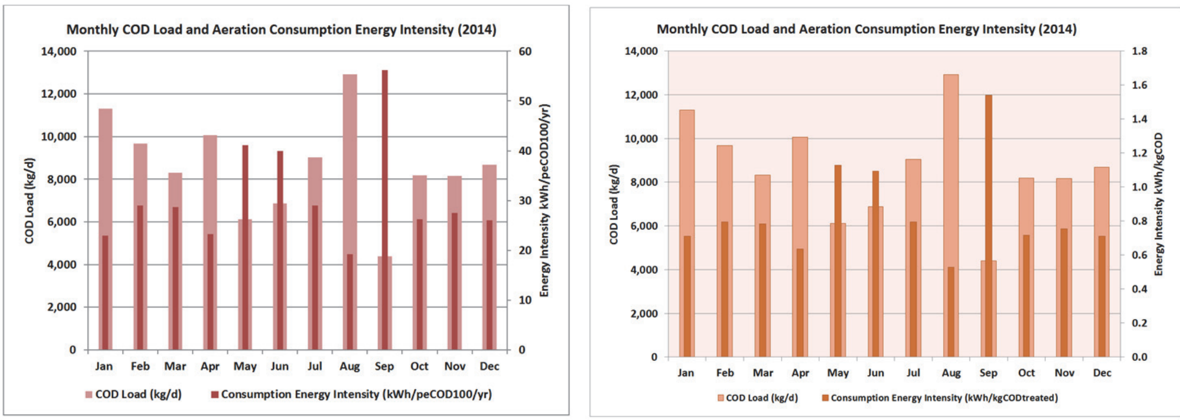

Figure 5-8: JP Marais WWTP 2014 Energy Use Intensity Profile

5.6 EVALUATION OF FEASIBLE AERATION CONSERVATION MEASURES

JP Marais is typical of most South African activated sludge plants that utilise surface aeration which has low oxygen transfer efficiencies. Aeration energy use intensity is therefore higher than for plants utilising more efficient aeration systems as reflected in the analysis in Section 0 and Section 5.5. JP Marais aeration energy use intensity of 31 kWh/peCOD$_{100}$/yr is 36% higher than for Zeekoegat WWTP which uses FBDA and almost double that observed in plants in Austria and Germany. There is therefore scope to reduce aeration energy use at JP Marais. Feasible aeration ECMs for the plant can be divided into the following broad categories:

- Utilising existing surface aerators
- Replacing existing surface aerators with more efficient systems
- Re-designing the plant configuration

Each of these categories is evaluated in more detail below. Terminology and technical details of ECMs given under Section 4.6 for Zeekoegat WWTP have not been repeated in this section.

5.6.1 Utilising Existing Surface Aerators

Optimized Process Control with Current Aeration Control Strategy

Being an older plant constructed in 1990, JP Marais is not highly automated and has localised PLCs and no SCADA system. Most of the process control and data collection is done manually. In 2014 data on critical control parameters such as sludge wastage, a-recycle and RAS rates as well as DO concentrations were not regularly monitored and recorded. Equipment breakdowns (WAS pumps, bioreactor adjustable weir, DO sensors) also posed challenges to keeping regular records and optimal process control.

Based on the few data that were available, the plant was run at low sludge ages averaging about 13 days when it was receiving flow diverted from Welgedacht WWTP and the plant failed to nitrify sufficiently to meet the permit limit. In addition, a few DO measurements taken in June and July indicated very low concentrations of less than 0.5 mg/l in the 2nd to the 4th cells of the aerobic reactor which could have contributed to the poor nitrification. The plant also failed to comply with the TSS limit. From October to December when the flow diversion was stopped, the sludge age was increased to about 25 days and the plant was nitrifying sufficiently to meet the final effluent limit. The summer sludge age was however too high thus wasting energy.

The 3-stage Phoredox process design anoxic mass fraction of 0.08 is too low to achieve denitrification to meet the nitrate/nitrite limit of 6 mgN/l. Site measurements indicate average final effluent values of around 2 mgN/l while model predictions indicate much higher values of about 10 mgN/l. The possibility of analytical error is unlikely since 123 values were recorded and out of these only 2 exceeded the limit of 6 mgN/l. The most feasible explanation is that significant denitrification occurs in unaerated pockets within the bioreactors due to uneven aeration pattern. Operators also report that they occasionally turn off some of the aerators if portable DO measurements indicate high concentrations thus creating a higher anoxic mass fraction. The a-recycle rate is not known since no data was collected from the a-recycle pump flow meter.

The two old DO sensors that were out of service in 2014 were replaced with new ones in 2015. Both sensors are located in the last aerobic cell; the same location as the old ones. Locating both sensors in the last cell is not optimal for DO monitoring and control and model predictions show that one of the sensors should be located at the end of the 2nd aerobic cell. Operators will get a better indication of the DO along the reactor and use this together with effluent quality to determine the depth of immersion for the aerators by raising or lowering the adjustable weir or when and which aerators to manually switch off as stipulated in the engineering design. The new nitrate, FSA, and TSS sensors in the last aerobic cell will greatly assist Operators with final effluent quality data and improve the manual aeration control.

The above analysis shows that there is potential to reduce aeration energy requirements from the current baseline values by optimizing the operating sludge age, anoxic mass fraction, a-recycle ratio and DO control with the existing surface aerators and the original design manual DO control system.

However, if the surface aerators are replaced with a system that provides uniform aeration, it is recommended that an optimal anoxic mass fraction be created by operating the upstream aerobic zones as swing zones that can increase the anoxic mass fraction from the current 8% to up to 39%.The a-recycle can be varied to maximise the denitrification potential of the anoxic zone.

Automated Aeration Control

Manual aeration control for a plant of JP Marais` size is not only onerous for Operators but is not efficient and thus wastes energy. Implementing automated aeration control will result in both energy savings as well as optimised process control. Since new sensors have already been installed, automation will only require installation of additional PLCs (and a SCADA system if cost effective), control algorithms, modifications to the existing aerators and utilisation of the adjustable weir as to adjust liquid level, and impeller submergence. The following control strategies are feasible:

1. Automate adjustable weir control using the feedback from DO sensors (traditional feedback DO control). The control system design will have to take into account the generally long response times in weir operated systems. Combining aerator on/off control with weir control is usually implemented to increase the efficiency of the control system
2. Install VFDs on existing aerators and use traditional feedback DO (or advanced feedback ammonia with cascade DO) control to adjust aerator speed. Combined VFD and adjustable weir control can also be used to maximize power reduction.

Automated process control has to be implemented together with optimised process control as discussed in Section 4.6 to maximise energy savings.

5.6.2 Replacing Existing Surface Aerators with More Efficient Systems

Higher aeration energy savings can be achieved by replacing the existing slow speed surface aerators with more efficient systems. Feasible options to consider are given below.

Fine Bubble Diffused Aeration

Fine bubble diffused aeration has up to three times higher oxygen transfer efficiencies than the existing slow speed surface aerators. Some equipment manufacturers report overall efficiencies as high as 6 to 7 times more with new blower and membrane diffuser technologies. Major modifications to the existing plant will be required to install fine bubble diffusers at the bottom of the bioreactor, air pipes and blowers. The costs of the modifications as wells as the logistics will need to be carefully considered since there is only one bioreactor lane at the plant.

Hybrid Aerator/Mixer with Diffused Air

The latest hybrid aerator technologies that are a combined aerator/mixer utilise diffused air provided by a high efficiency blower. The aerator resorts to mixing mode when the blower is turned off and this dual functionality provides more flexibility than surface aeration or fine bubble diffused aeration alone. One of the proprietary aerators supplied by Aeration Industries International is reported to have higher oxygen transfer efficiencies than fine bubble diffused aeration due to the unique design that forces air down through the shaft and exits in a high velocity stream of fine bubbles that are evenly dispersed throughout the entire aerobic tank.

Hybrid aerators of the type supplied by Aeration Industries International have simple designs and are easier to retrofit at a plant like JP Marais which was designed for surface aeration than FBDA and would thus be the more feasible practical option.

Dual Impeller Surface Aeration

The dual impeller aerator incorporates a specialized lower impeller which is attached to the same shaft as the surface impeller. The lower impeller which is located near the floor of the tank directs mixing energy along the floor, thus improving mixing at the bottom of the tank. Conventional single impeller aerators are limited in their turndown due to the need to maintain mixing at the bottom of the tank. The additional mixing by the bottom impeller for the dual impeller aerators allows operation at lower power intensities and higher power turndown capability. Turndowns of greater than 80 percent have been quoted by some suppliers ((EIMO/OVIVO). The combined use of two-speed or VFD-driven motors and variable-height weirs (with either simple feedback DO control or advanced process control) can be used to maximize power reduction.

Replacing the existing single impeller surface aerators with dual impeller ones will require minor modifications to the bioreactor and is also a better practical option than FBDA

5.6.3 Redesigning the Plant Configuration

The following two design modifications can reduce aeration energy use.

Influent Flow Balancing

Implementing raw influent flow balancing as for Zeekoegat WWTP will reduce peak flows and loads to the plant resulting in energy savings. In South Africa where rainfall is generally for short durations, flow balancing is an effective way of reducing peak dry weather flows and loads influent to the treatment process. Balancing tanks result in aeration energy savings because they

- Reduce peak energy consumption which result in savings on peak demand charges
- Simplify aeration control and improve the efficiency of aeration control systems thus reducing aeration power consumption

Model simulation results and experience at plants that have implemented both flow balancing and advanced process control strategies indicate that energy savings greater than 20% can be achieved.

Flow balancing has other additional benefits to the plant such as:

- Improved process performance due to the reduction of peak flows and loads which improves final effluent quality
- Increased capacity due to reduction in peak dry weather flow to average values
- Improvement in chemical treatment processes (e.g. chemical P removal, chlorination) as reduction in peak loads improves chemical feed control

Redesign of Aeration System

The existing aeration system is not tapered to take into account the reduction in oxygen demand along the length of the bioreactor. Redesigning the aeration system will result in an optimal aerator layout that will reduce energy use. Simulations for this project to evaluate alternative aeration equipment have been carried out with a tapered aeration design.

5.7 FEASIBLE AERATION ENERGY CONSERVATION MEASURES-ANALYSIS RESULTS

The following feasible ECMs from Section 4.6 were selected for further analysis using advanced process modelling and simulation. The ECMS were classified by ease of implementation without major interference with the existing process as well as capital investment requirements as follows:

4. Simple Low Capital Investment
    - Optimised process control by operating at optimal sludge age and maximising denitrification
5. Low to Medium Capital Investment
    - Automated aeration control
6. Complex High Capital Investment
    - Replace surface aerators with more efficient aeration systems including redesign of aeration system
    - Implement influent flow balancing

5.7.1 Simple Measures – Optimised Process and Aeration Control

This measure requires the following modifications to current process operation and control:

- Optimal operating sludge age
    - Winter (June-September) sludge age approximately 20-25 days
    - Summer (October-May) sludge age approximately 12-15 days
- Optimal control of a-recycle rate to vary to the maximum design rate of 2xADWF
- Anoxic mass fraction to be increased from 0.08 to vary to a maximum of 0.39 by intermittently switching off the first 4 upstream aerators. It should be noted that because of the uneven aeration pattern of the surface aerators that creates unaerated pockets within the aerobic zone, it is difficult to know and effectively control the anoxic mass fraction
- The DO sensors at the end of the aerobic zone to be moved to the end of the 2^{nd} aerobic cell
- Adjustable weir to be refurbished and used to adjust aerator submergence

The model predicted aeration energy consumption and cost savings as well as final effluent quality when these measures are implemented are given in Table 5-10. Also included are the 2014 baseline values for comparison.

Table 5-10: JP Marais WWTP Model Predicted Parameters for Optimised Process Control

Aeration Energy Parameter	Units	Baseline (2014)	Optimised Process Control
Consumption	MWh/yr	2,465	2,109
Consumption Saving	MWh/yr		356
% Consumption Saving	%		14
Consumption Cost	R/yr	2,290,428	1,959,872
Consumption Cost Saving	R/yr		330,556
% Consumption Cost Saving	%		14
Demand Saving	kW		41
Final Effluent Quality*			
FSA	mgN/l	10	1
Ortho P	mgP/l	0.3	0.2
Nitrate/Nitrite	mgN/l	12	4

Note: *Model predicted. Average measured for 2014 was 1.2 mgN/l

From the results in Table 5-10 implementing optimised process and aeration control with the existing aeration equipment and control systems results in:

- Potentially 14% savings in power consumption and cost. A demand saving of 41 kW is also realised as a results of savings in consumption
- Average final effluent nitrate/nitrite concentration of 4 mgN/l which is 3 times less than the 2014 operation model predicted value and 66% less than the permit limit of 6 mgN/l. Diurnal simulations showed that peak nitrate/nitrite concentrations were always below the permit limit of 6 mgN/l ensuring final effluent compliance all the time. Lower nitrate/nitrite values are due to improved denitrification as a result of increasing the a-recycle to optimal values.
- Average Ortho P concentration of 0.2 mgP/l which is 33% less than the baseline measured average value of 0.3 mgN/l.

5.7.2 Low to Medium Investment Measures – Automated Aeration Control

This measure involves full automation of aeration control as outlined in Section 5.6.1. The analysis is for the following modifications:

- Optimal process operation as outlined in Section 5.6.1 above
- Installation of aerator VFDs
- Installation of PLCs and associated control systems to implement feedback cascade ammonia DO control utilising the already installed ammonia and DO sensors
- Aerators to be controlled by a combination of VFDs and weir level adjustment

The model predicted aeration energy consumption and cost savings as well as final effluent quality when these measures are implemented are given in Table 5-11. Also included are the 2014 baseline values for comparison.

Table 5-11: JP Marais WWTP Model Predicted Parameters for Implementing Automated Aeration Control (with ammonia based aeration control)

Aeration Energy Parameter	Units	Baseline	Automated Aeration Control
			FB Cascade NH_4^+/DO
Consumption	MWh/yr	2,465	1,953
Consumption Saving	MWh/yr		512
% Consumption Saving	%		21
Consumption Cost	R/yr	2,290,428	1,814,761
Consumption Cost Saving	R/yr		475,667
% Consumption Cost Saving	%		21
Demand Saving	kW		58
Final Effluent Quality			
FSA	mgN/l	10	3.5
Ortho P	mgP/l	0.3	0.1
Nitrate/Nitrite	mgN/l	12	3

Model predicted values in Table 5-11 indicate that implementing advanced process control (with ammonia based aeration control) utilizing the existing aeration equipment results in:

- Potentially 21% savings in power consumption and costs. Demand savings of 58 kW is also realised as a result of savings in consumption
- Average final effluent nitrate/nitrite concentration of 3mgN/l; 50% below permit limit of 6 mgN/l.
- Average Ortho P concentration of 0.1 mgP/l; 66% below the baseline measured value and 6 times less than the permit limit of 0.6 mgP/l
- Model predicted final effluent Ortho P and nitrate/nitrite concentrations are much lower than the current measured values as well as those predicted with optimised process control in Section 4.7.1.

5.7.3 Complex High Capital Investment Measures – Replace Existing Surface Aerators

The evaluation was carried out for replacing existing surface aerators with:

- FBDA with membrane diffusers and turbo blowers
- Hybrid aerator/mixer

Model simulations were carried out with both traditional feedback DO as well as advanced process control strategies.

Table 5-12 summarises the model predicted energy and cost savings that can be achieved with these two measures.

Table 5-12: JP Marais WWTP Model Predicted Energy and Cost Savings for Replacing Surface Aerators with More Efficient Systems

	Units	Baseline	FBDA			Hybrid Aerator/Mixer
			FB DO	FB Cascade NH_4^+/DO	FF/FB NH_4^+/DO	FB Cascade NH_4^+/DO
Consumption	MWh/yr	2,465,024	1,712,043	1,659,376	1,596,121	1,492,410
Consumption Saving	MWh/yr		752,981	805,648	868,903	972,614
% Consumption Saving	%		31	33	35	39
Consumption Cost	R/yr	2,290,428	1,590,780	1,541,844	1,483,069	1,386,704
Consumption Cost Saving	R/yr		699,648	748,585	807,359	903,724
% Consumption Cost Saving	%		31	33	35	39
Demand Saving	kW		86	92	99	111
Final Effluent Quality*						
FSA	mgN/l	10	1	3.5	3.5	3.5
Ortho P	mgP/l	0.3	0.2	0.05	0.05	0.05
Nitrate/Nitrite	mgN/l	12	4	3	3	3

With FBDA potential energy consumption and cost savings of 31-35% can be realised depending on the aeration control strategy adopted. The hybrid aerator/ mixer which has been assumed to have higher energy efficiency than FBDA can potentially save 39% of energy consumption and cost. Demand savings of 86-111 kW can also be potentially realised as a result of consumption savings.

5.7.4 Comparison of Feasible ECMs

A summary of the financial analysis for implementing the feasible aeration ECMs is presented in Table 5-13. The same methodology outlined in Section 4.7.4 for Zeekoegat WWTP was followed. Costs for fine bubble diffusers, blowers and control systems were obtained from local suppliers.

Table 5-13: Financial Comparison of Feasible Aeration Energy Conservation Measures

		Using Existing Surface Aerators		Replace Existing Surface Aerators			
				FBDA			Hybrid Aerator/Mixer
	Units	Optimized Process & Current Aeration Control	Automated Aeration Control – FB Cascade NH_4^+/DO[1]	FB DO	FB Cascade NH_4^+/DO	FF FB NH_4^+ on DO Control	FB Cascade NH_4^+/DO
Estimated Project Costs							
Capital Costs	R		385,990	3,563,870	3,660,367	3,756,865	NCA
Engineering Costs[2]	R		115,797	890,967	915,092	939,216	
Total Project Costs	**R**	0	501,787	4,454,837	4,575,459	4,696,081	0
Annual Electricity Use Reduction							
Consumption	MWh/yr	356	512	753	806	870	973
Demand [3]	kW	14	21	31	33	35	39
Carbon Reduction [4]	t/yr	352	507	745	798	860	963
Annual Savings							
Consumption	R/yr	330,556	475,667	699,648	748,585	807,359	903,724
Demand	R/yr						0
Total Annual Savings	R/yr	330,556	475,667	699,648	748,585	807,359	903,724
Estimated Simple Payback	**years**	0.0	1.1	6.4	6.1	5.8	NA

Notes
1. Costs of VFDs not included
2. Engineering costs assumed at 25% of capital costs. Engineering costs do not include advanced process modelling costs.
3. Demand reduction cost savings were not evaluated
4. Carbon reduction based on 0.99 kg CO_2/kWh generated. Carbon reduction costs savings were not included

The following is noted from Table 5-13:

- Optimised control of the plant does not require any capital investment and will potentially yield immediate annual aeration energy consumption cost savings of about R331,000
- The payback period for upgrading to automated control is about 1 year. It should be noted that the cost of installing VFDs on the aerators could not be assessed during the study and was therefore not included in the analysis
- Although replacing surface aerators has longer payback periods, it yields the highest savings which will be realised after the payback period ranging from 5.8 to 6.4years.

5.7.5 Other Benefits and Impacts of Implementing Aeration Energy Conservation Measures

The additional benefits of implementing aeration ECMs that have been evaluated through detailed process modelling have been detailed in Section 4.7.5 for Zeekoegat. The same benefits realised for Zeekoegat are also applicable to JP Marais:

- Optimal process parameters
- Improved final effluent quality
- Ease of plant operation
- Assessment of existing plant capacity

5.7.6 Summary

JP Marais is an old plant constructed in 1990. The design of the activated sludge process is typical of most activated sludge processes of this era that were not designed for energy efficiency. The plant uses traditional slow single speed surface aerators which have low energy transfer efficiency. In addition the aeration design is not tapered and the design automated aeration control system was not functional during 2014 because of the breakdown of both the adjustable weir and DO sensors. Thus JP Marais has an aeration energy use intensity that is 45% higher than Zeekoegat WWTP that was designed and is controlled for energy efficiency.

In terms of compliance with the DWS final effluent discharge permit requirements, the plant started performing well after the flow diversion from Welgedacht WWTP was discontinued. From September 2014, final effluent complied with all the permit parameter limits.

In 2014, the total annual power consumption at the plant was 3,340 MWh at a cost of R3.1 million. Aeration consumes the most energy at the plant accounting for approximately 74% of the total energy usage at 2,465 MWh/yr and a cost of R2.3 million. This is on the higher end of the values generally observed at activated sludge plants. The higher aeration percentage use is not only due to the inefficient surface aerators but also due to the absence of sludge handling and treatment facilities which would account for some of the consumption and reduce the percentage due to aeration. The baseline total consumption and aeration energy use intensities, which serve as a benchmark for the plant, were 1.2 kWh/kgCOD treated (44 kWh/peCOD_{100}/yr) and 0.9 kWh/kgCOD treated (31 kWh/pe COD_{100}/yr) respectively.

The analysis carried out in this project showed that the plant's aeration system is not energy efficient and there are significant opportunities to reduce the aeration energy consumption further to bring the intensity to at least the levels of Zeekoegat WWTP of 22 kWh/pe COD_{100}/yr. The recommended aeration ECMs to achieve this reduction discussed in detail in Section 5.7, are summarized in Table 5-14.

The following conclusions were drawn for JP Marais:

1. Feasible measures to reduce aeration energy consumption can be divided into 3 broad categories
   (i) *Simple " Low Hanging Fruit" measures utilizing existing aeration and control equipment:*
   This does not require any capital investment but identifying optimal process operating parameters that minimise aeration energy consumption while producing final effluent that complies with the discharge permit requirement i.e. operating the plant at optimal sludge age, anoxic mass fraction, internal mixed liquor and RAS recycle ratios and fixed DO setpoints. Aeration energy consumption cost saving of about 14% can potentially be achieved through simply optimizing process operation and control.

   (ii) *Low to medium capital investment measures utilising the existing aeration equipment:*
   The measure involves fully automating aeration control by installing PLCs, aerator VFDs and control systems that utilise the already installed adjustable weir and ammonia and DO sensors. The simplest and most practical feasible control strategies to implement are either traditional feedback DO control or feedback ammonia with cascade DO control. Potentially 21% of aeration energy consumption cost can be

saved by implementing this measure. Preliminary financial analysis indicates a payback period of 1.1 years.

Table 5-14: JP Marais WWTP-Summary of Model Predicted Feasible Aeration ECMs

	Units	Baseline	Using Existing Surface Aerators		Replace Existing Surface Aerators			
			Optimised Process Control	FB Cascade NH_4^+/DO	FBDA FB DO	FB Cascade NH_4^+/DO	FB DO	Hybrid Aerator/ Mixer FB Cascade NH_4^+/DO
Aeration Energy								
Consumption	(MWh/yr)	2,465	2,109	1,953	1,712	1,659	1,596	1,492
Consumption Cost	(R/yr)	2,290,428	1,959,872	1,814,761	1,590,780	1,541,844	1,483,069	1,959,872
Energy Intensity	(kWh/kgCOD treated)	0.89	0.76	0.70	0.62	0.60	0.57	0.54
Energy Intensity	(kWh/pe COD $_{100}$/yr)	32	28	26	22	22	21	20
Consumption Cost Saving	**%**		14	21	31	33	35	39
Average Final Effluent Quality								
FSA	mgN/l	10	1	3.5	3.5	3.5	3.5	3.5
Ortho P	mgP/l	0.3	0.2	0.1	0.1	0.1	0.1	0.1
Nitrate/Nitrite	mgN/l	12*	4	3	3	3	3	3
Financial Evaluation								
Estimated Project Costs								
Capital Costs	R			385,990	3,563,870	3,660,367	3,756,865	NCA
Engineering Costs*	R			115,797	890,967	915,092	939,216	
Total Project Costs	**R**		0	501,787	4,454,837	4,575,459	4,696,081	0
Annual Electricity Use Reduction								
Consumption	MWh/yr		356	512	753	806	869	973
Demand **	kW		41	58	86	92	99	111
Carbon Reduction **	t/yr		352	507	745	798	860	963
Annual Savings								
Consumption	R		470,119	604,896	812,928	858,380	912,969	1,002,472
Demand	R							0
Total Annual Savings	R		470,119	604,896	812,928	858,380	912,969	1,002,472
Estimated Simple Payback	**years**		0.0	0.8	5.5	5.3	5.1	NA

(iii) *High Capital Investment by Replacing Existing Surface Aerators:*
This measure requires a complete redesign of the aeration system and replacing the surface aerators with either FBDA or hybrid aerator/mixer or dual impeller surface aerators. Only FBDA and hybrid aerator/mixer were evaluated in this study. FBDA can potentially save 31-33% of aeration energy consumption costs while hybrid aerator/ mixer can increase savings to about 39%. Preliminary financial analysis shows payback periods ranging from 5.8 to 6.4 years. Although this measure requires higher capital

investment, it yields higher energy savings which will be realised after the payback period.

Installation of FBDA will require extensive modifications to the bioreactor which was designed for surface aeration. In addition installation of diffusers would require emptying of the bioreactor which would pose a treatment challenge since the pant ha only one lane. Thus it is more practically feasible to replace the surface aerators with either hybrid aerator/mixers or dual impeller aerators.

(iv) *High Capital Investment by Installing an Efficient Balancing Tank:*
Installing a balancing tank is a proven way of reducing peak energy demand with additional benefits of improving process and aeration control (which reduces energy consumption) as well as process performance and hence final effluent quality. A balancing tank combined with an efficient aeration system similar to Zeekoegat WWTP will yield maximum energy savings. Preliminary estimates in this study show that saving greater than 40% can be achieved with FDBA and advanced process control. A detailed engineering design to properly size the balancing tank and further evaluation of aeration ECMs is required if this option is considered.

2. Modelling results show that implementing the identified aeration ECMs improves process performance resulting in final effluent nitrate/nitrite and Ortho P concentrates that are much lower than the current performance of the plant as well as the final effluent discharge permit limits.
3. It should be noted that the model predicted savings for medium and high capital investment measures might not be realised in practice due to the challenges of implementing control systems in wastewater treatment. If the measures are to be implemented in practice the following is recommended:

   - A more detailed investigation of market available options for aeration technology as well as process and aeration control technologies that can replace the existing surface aerators and the feasibility of incorporating them into the existing plant. The quality and costs including maintenance requirements are of critical importance to the success of the aeration ECMs.
   - Application of a superior economic evaluation technique such as life cycle cost analysis, which takes into account all the costs incurred during the project life, so that the most cost effective measures can be selected for implementation
   - Detailed engineering design support for medium to high capital measures that require significant modifications to the existing plant as well as new treatment units and equipment
   - Further process evaluation and modelling to optimise the selected ECMs.

6. Case Studies – Conclusions and Recommendations

6.1 SUMMARY

Two biological nutrient removal activated sludge plants were selected as case studies for this project: (i) Zeekoegat wastewater treatment plant owned and operated by the City of Tshwane with a design capacity of 85 Ml/d average dry weather flow and utilising fine bubble diffused aeration and (ii) JP Marais wastewater treatment plant operated by the East Rand Water Care Company, with a design capacity of 15 Ml/d and utilising surface aeration.

The scope of work for both plants covered, collection and analysis of plant data, determination of 2014 baseline energy use and benchmarking, identification of feasible aeration energy conservation measures, application of advanced process modelling and simulation to determine optimal process and aeration control strategies and economic evaluation of feasible measures.
Feasible aeration conservation measures were classified into three categories:

- Simple measures that only require changes to process operation and control to optimal levels, with little to no additional capital investment apart from operator training
- Low to medium capital measures that involve upgrading aeration and control strategies requiring investment in new monitoring equipment and control systems
- Complex measures that involve (i) redesigning and replacing less efficient aeration systems with more efficient technologies (ii) introduction of influent flow balancing

Zeekoegat is a fairly new plant with the second module and aeration upgrades commissioned in 2013. The plant was designed to minimise aeration energy use with highly efficient fine bubble diffused aeration systems. Influent flow is balanced after primary clarification and the plant aeration control system is also optimised to minimise energy wastage. Final effluent complied with all parameter limits except for nitrate/nitrite. For the 2014 baseline year:

- Total annual power consumption was 11,240 MWh at a cost of R9, 8 million. Aeration accounted for approximately 42% of the total at 4,750 MWh and a cost of R2.9 million
- The baseline aeration energy use intensity, which serves as a benchmark for the plant was 22 kWh/peCOD$_{100}$/yr (0.7 kWh/kgCOD treated).

The following feasible aeration energy conservation measures were identified:

(iv) *Simple measures utilizing existing process and aeration equipment*
Optimal process and aeration control resulting in potential cost savings of 9%.

(v) *Low to medium capital investment*
Upgrading the current aeration control strategy from traditional dissolved oxygen based control to ammonia based control with potential cost saving of 17%. Preliminary financial analysis indicates a payback period of 1.7 years.

(vi) *Complex High capital investment*
Replacing the existing Module 1 single stage centrifugal blowers with more efficient turbo blowers similar to Module 2. Potential savings of 19-23% can be achieved with payback periods of 5.2-5.5 years.

JP Marais is an old plant constructed in 1990. The design of the activated sludge process is typical of most activated sludge processes of this era that were not designed for energy efficiency. The plant uses traditional slow, single-speed surface aerators which have low energy transfer efficiency. In addition the aeration design is not tapered and aeration control was designed to be semi-automated but was manually controlled in 2014 due to equipment breakdowns.

- Total annual power consumption at the plant was 3,340 MWh at a cost of R3.1 million. Aeration accounted for 74% of the total energy usage at 2,465 MWh/yr and a cost of R2.3 million.
- Aeration energy use intensity, which serves as a benchmark for the plant was 31 kWh/pe COD_{100}/yr (0.9 kWh/kgCOD treated). The value is 41% higher than that for Zeekoegat

Feasible aeration energy conservation measures were as follows:

(v) *Simple measures utilizing existing process and aeration equipment*
Optimal process and aeration resulting in potential cost savings of about 14%

(vi) *Low to medium capital investment measures utilising the existing aeration equipment*
Fully automating aeration control and implementing advanced process control with ammonia based aeration control. Potential cost savings of 21% and a payback period of 1.1 years.

(vii) *High capital investment – replacing existing surface aerators*
This measure requires a complete redesign of the aeration system and replacing the surface aerators with either fine bubble diffused aeration, hybrid aerator/mixers or dual impeller surface aerators. Potential cost savings of 31-39% can be achieved with payback periods ranging from 5.8 to 6.4 years.

(viii) *High capital investment – installing an influent balancing tank*
Installing a balancing tank combined with an efficient aeration system similar to the one at Zeekoegat plant will yield maximum energy savings greater than 40%. Flow balancing also results in simplified more efficient process and aeration control systems

For both plants implementing advanced process control strategies resulted in optimal process and aeration control which improved both denitrification and enhanced biological phosphorus removal. Model predicted final effluent nitrate/nitrite and Ortho Phosphate values were significantly lower than the baseline measured values as well as licence discharge limits.

While the models predict substantial savings in aeration energy and costs, cognisance has to be taken of the challenges of practically implementing energy conservation measures. Some of the challenges identified locally and globally included:

- Unreliable technology
- Poor designs
- Limited funding, technical expertise and top management commitment
- Restrictive/poor supply chain management practices
- Lack of or misleading incentives to stakeholders

6.2 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made based on the findings from the case studies:

1. The approach of applying advanced process modelling to evaluate aeration energy conservation measures yields other benefits, the most significant of which is ***to ensure that final effluent compliance with regulatory requirements is met satisfying the primary wastewater treatment objective of protecting the environment.***
2. Model predicted energy and cost savings might not be realised in practice due to both technological and human challenges that have been identified as hindering the implementation of efficient process and aeration control systems in practice.
3. Before practically implementing aeration energy conservation measures identified from desktop studies of this nature, the following is recommended:

    - A more detailed investigation of market available options for aeration technologies as well as process and aeration control technologies. The quality and costs including maintenance requirements are of critical importance to the success of the aeration energy conservation measures
    - Application of a superior economic evaluation technique such as life cycle cost analysis, which takes into account all the costs incurred during the project life, so that the most cost effective measures can be selected for implementation
    - Detailed engineering design support for medium to high capital measures that require significant modifications to existing infrastructure as well as new treatment units and equipment
4. The South African water sector should consider conducting a nation-wide aeration energy use benchmarking exercise for activated sludge plants to guide municipalities in planning for energy management initiatives.

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