Water and Wastewater Management in Local Government:

Skills Needs and Development

Final Report Part II

To

The Local Government Sector Education and Training (LGSETA)

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Executive summary

Conventional and advanced wastewater treatment methods

Wastewater treatment has experienced many challenges in the recent years. On the one hand this has been due to the stringent environmental laws governing discharge limits, and on the other hand it is due to the emerging contaminants that do not lend themselves to the conventional treatment methods. The response to these challenges has been an effort to develop more robust but low-cost treatment methods. To obtain an optimal balance between cost and robustness, a lot of scientific and engineering work needs to be done to exploit the competencies at the interface of the relevant disciplines. In this regard, there are several approaches that have been employed in recently, of which there are two main ones. The first one is the integration of conventional methods (biodegradation) with advanced ones (advanced oxidation processes). The other one is the process intensification. Previous research has shown that integrating biological process with heterogeneous photocatalysis improves the performance of anaerobic digesters (AD). Further, the performance of the integrated systems can be improved through reactor choice and process intensification, in which individual reactors are optimized. Fluidized bed reactors (FBR) are of special interest due to the fact that they have high performance for multiphase operations such as heterogeneous photocatalytic degradation of biorecalcitrant wastewater.

Photocatalysis has been considered as a rapid process for degrading recalcitrant organic contaminants in wastewater. Titanium dioxide has been widely applied as an appropriate photocatalyst due to its high activity. In many cases the TiO_2 has been used in slurry or suspension during photocatalysis. However, the problem of applying TiO_2 in slurry form has been the difficulty in separating it from the treated effluent since it does not settle but remains in suspension

Acid Mine drainage

Acid mine drainage is considered as one of the main pollutants of water in many countries that have historic or current mining activities. Although any mineral deposit contains sulphide is a potential source of AMD, certain types of mining are more prone than the others. There are records of acid mine drainage where coal, pyritic Sulphur, copper, zinc, silver and lead among others have been mined. Acid mine drainage is produced by the oxidative dissolution of sulphide minerals in the presence of oxygen and water. Treatment methods currently used in South Africa are reverse osmosis and neutralization method. Waste sludge and brine are produced, depending on level of treatment, requiring disposal.

Economic sustainability and technical feasibility become key drivers in determining the sustainability of any proposed method or system for any application. Recovery of sulphuric acid from acid mine drainage is thought to be economically sustainable process of reducing the environmental impact of acid mine drainage. The recovery of sulphuric acid process will be integrated with adsorption techniques for the removal of metals and heavy metals.

Water Energy Nexus

Whilst the concept of water-energy nexus is inherent in most systems, it has been ignored for many years, thereby leading to missed opportunities. In the past, energy and water systems have been developed and managed independently. Water plays a critical role in the generation of electricity and energy is required to treat and distribute water. This has been true for many decades, but the water and energy systems have investigated and developed independently. Recent trends have focused on looking at the connections that exist between water and energy in industries for sustainable operation. Global shortages of energy and water have rendered comprehensive approaches to water and energy optimization even more important than ever before, hence the work presented in this report.Process industries have recently committed and allocated resources to mitigating the detrimental impact on the environment due to their activities. They have made significant progress, in conserving resources, and reducing the intensity of energy usage. These efforts have gradually shifted from a unit-based approach to a systems-level paradigm. Process integration is a holistic approach to process design and operation which emphasizes the unity of the process. Process integration design tools have been developed over the past two decades to attain process improvement, productivity enhancement, conservation in mass and energy resources, and reductions in the operating and capital costs of chemical processes. This technique has been successfully applied in many industries world-wide and particularly in Europe and USA. In the case of USA processing industries, the amount of reuse and recycle of wastewater has been tremendous - gross water use to water intake ratios exceed 7.5 in petroleum refining and 3 in chemical production. The gross water is the amount of water that would have to be used if there was no reuse and recycle.

Recently, process integration techniques have been applied in a South African main power plant with the objective of reducing the water intake. This objective can be achieved by identifying water sources (providers) and sinks (users) in the water network, followed by matching appropriate sources and sinks as water quality allows. The water network, therefore, first has to be compiled and flow and quality data can subsequently be allocated to process units in the network. The process integration tool showed savings of between 4% and 13% of the water intake by changing the way water is currently utilized and reused at the station. Management of the cooling cycle, and especially blowdown water, together with related procedures have a significant impact on the amount of freshwater intake and are responsible for the bulk of the possible savings identified by the work since most of water used at the station is supplied to the cooling towers. Optimization of water utilization in the power station has a direct impact on the amount of waste produced, which translates into at least 50% (or more) reduction in wastewater management costs. This is mainly due to savings in freshwater consumption.

Skills Gap

AMD and recalcitrant pollutant: Skill are needed to implement cutting-edge technologies to address emerging contaminants including AMD, which pose problems to both water and wastewater treatment systems. In South Africa management of AMD, pharmaceutical wastes and other biorecalcitrant wastes need urgent attention. The skill requirements for the processes that manage such wastes include, the use of membranes, photocatalysis and adsorption techniques. There are a few Universities in South Africa including University of Stellenbosch, University of the Witwatersrand and the Vaal University of technology that have developed membrane techniques for AMD remediation and advanced oxidation processes. However, these skills have not been transferred to the people who need them most; local government and industries.

Process integration: To address the problem of emerging contaminants, there are two approaches that define the trajectory of the research path that adds value to life. The first one is the use of wastes or low-cost materials as feedstock for energy production. This approach is often described as waste beneficiation. In recent years, the efficiency of many processes has been enhanced by the use of nano-modified materials. The second approach involves the integration of the conventional energy production processes with advanced ones to improve production. The application of process integration in wastewater treatment is an area that has not been developed in many engineering curriculum in South Africa.

Sustainable Process Engineering: Water management is largely about striking balance between demand and supply. Sustainable Process Engineering (SPE) is one of the emerging technologies, which optimizes the use of water, still needs a lot of skill development. It is important to note that the National Research Foundation/Department of Science Technology Chair in SPE at the University of the Witwatersrand is the only research group that develops and applies process integration tools for wastewater minimization in process industries. The SPE technology is aimed at reducing water consumption and hence reduces water demand.

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Acronyms

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AD	Anaerobic Digestion
AOPs	Advanced Oxidation Processes
BOD	Biochemical Oxygen Demand
CBZ	Carbamazepine
COD:	Chemical Oxygen Demand
DBSA	Development Bank Of Southern Africa
DCF	Diclofenac
DON	Dissolved Organic Nitrogen
DRWH	Domestic Rainwater Harvesting
DWA	Department of Water Affairs
DWAF	Department of Water Affairs And Forest
EDCs	Endocrine Disrupting Compounds
FBB:	Fluidized Bed Bioreactor
GIS	Geographical Information System
HRT	Hydraulic Retention Time
ISBD	In Situ Biological Denitrification
ISRM	In Situ Redox Manipulation: ISRM
LCFAs	Low Carbon Fatty Acids
LPM	Litres Per Minute MB
	Methelyne Blue
MWW:	Molasses Wastewater
NGDB	National Groundwater Database
NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
NWP	North West Province
NWP-SOER	North West Province Environmental Outlook
PAC	Powdered Activated Carbon
PPCPs	Pharmaceutical and Personal Care Products

PRBs	Permeable Reactive Barriers
RWH	Rainwater Harvesting
SAWS	South African Weather Services
SEM	Scanning Electron Microscopy
LGSETA	Local Government Sector Education And Training Authority
SMX	Sulfamethoxazole
TiO_2	Titanium (IV) Oxide
TOC	Total Organic Carbon
UKZN	University of Kwazulu Natal
US	University of Stellenbosch
UV	Ultraviolet
VUT	Vaal University of Technology
WC	Water Conservation
WDM	Water Management Demand
WH	Water Harvesting
WRC	Water Research Commission
WSA	Water Service Authorities
WSLG	Water Sector Leadership Group
WSP	Water Services Providers
WWTPs	Wastewater Treatment Plants
CPU	Condensate Polishing Units
PA	Pinch Analysis
MEN	Mass Exchange Network
CMB	Central Monitoring Basin
HCSD	High Concentration Slurry Disposal
BMCR	Boiler Maximum Continuous Rating
ETP	Effluent Treatment Plant ,
GAMS	General Algebraic Modelling System
ZLED	Zero Liquid Effluent Discharge
OD	Oxygen Demand
AU	Animal Unit

CARA	Conservation of Agricultural Resource Act
POU	Point Of Use
SIPP	Silver-Impregnated Porous Pot Filter
CWF	Ceramic Water Filter
PLWH	People Living With The Human Immunodeficiency Virus
UF	Ultra Filtration
CBOs	Community-Based Organizations

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CHAPTER 1

1. Wastewater treatment

1.1 Introduction

Over the years technologies and industrial products have changed and hence the characteristics of the resulting wastewater. Consequently, design works must include systems that can treat non-traditional constituents. Public concerns over the presence of trace organic chemicals in water are accelerating the application of advanced treatment technologies to remove objectionable compounds from wastewater. Although there is reasonable certainty that the removal of trace organic compounds will be needed, the timing, the specific compounds or classes of compounds that will require removal, and the technologies that will be needed, are unknown. Going forward, planning strategies might include leaving space on the plant site and in the hydraulic profile based on the technologies that we now know can remove some trace organics, including advanced oxidation processes and biological nutrient removal.

It has been reported that more than R3 billion per annum is spent on treating wastewater in South Africa yet compliance by some parts of the sector is poor. This has a negative impact on the country's water resource quality (Lutchamma-Dudoo, 2010).

The treatment processes are predominantly influenced by the available infrastructure, characteristics of the wastewater and cost. The wastewater treatment plants are distributed throughout the country and the level of their operations is varied. Figure 3 shows the distribution of the wastewater plants in various parts of South Africa.

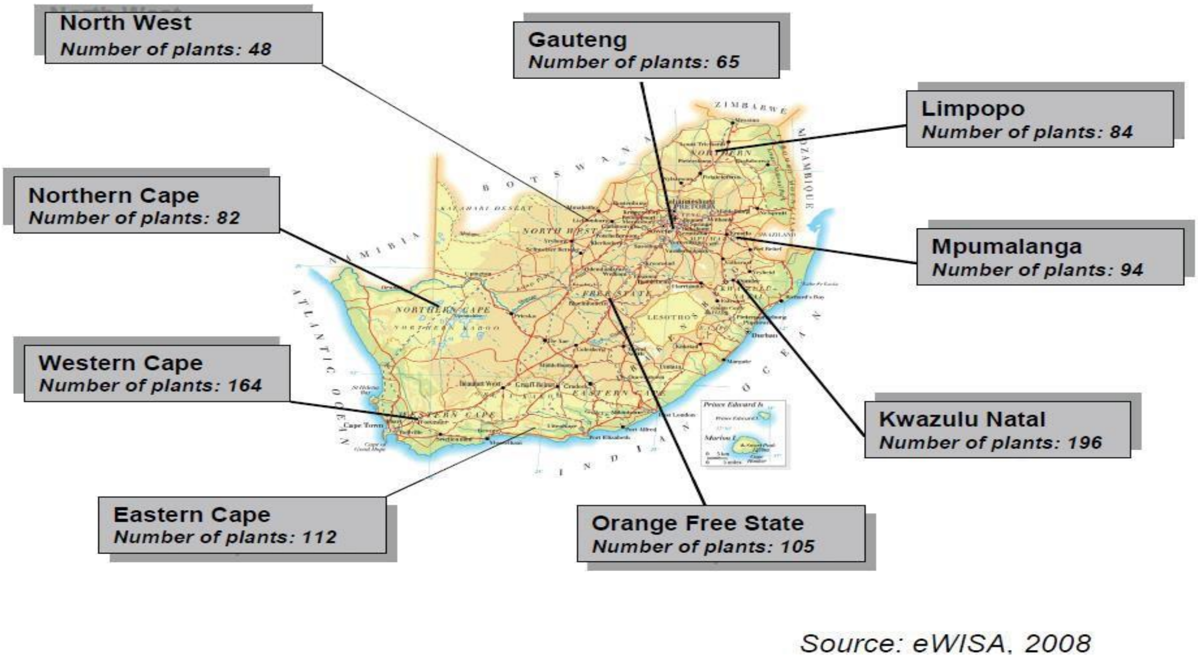

Figure 1 Distribution map of the wastewater plants.

The treatment processes are similar throughout the country, they range from basic processes such as anaerobic ponds, trickling filters to aeration basins to more developed enhanced biological nutrient removal (EBNR) systems (Nozaic *et al.*, 2008) in (Lutchmma-Dutoo, 2010)

1.2 Wastewater characteristics

Wastewater composition is becoming increasingly complex and this is a problem compounded by the fact that environmental are becoming more stringent with time. Some of the pollutants that are of great concern are encountered in pharmaceutical, distillery and molasses wastewater. Wastewater from a local distillery was characterized and the composition was compared to that of molasses wastewater (Table 1).

Table 1 Wastewater characteristics (Apollo et at., 2013)

Characteristics	Inoculum	Distillery	MWW	Inoculated distillery	Inoculated MWW
Total COD (mg/L)	2942± 127	5761± 105	4980± 117	5050 ± 59	4738 ± 56
Soluble COD (mg/L)	900 ± 35	4125± 87	3820± 64		
BOD (mg/L)	526	1160	1118	1701	1652
Total nitrogen (mg/L)	59	142	392	206	455
Total phosphates (mg/L)	36	34	7	72	40
Total suspended solids (mg/L)	112	87	62	205	181
pH	6.8-7.2	4.2-4.5	4.6-4.8	6.8-7.1*	6.8-7.1*

* Adjusted values

1.3 Pre-treatment

Pretreatment start with the removal of solid material from the feed stream (Figure 2). The composition of the feed stream depend on the upstream activities. Municipal wastewater treatment plants visited, the main source of pollution is abattoir waste as shown in (Figure 2). It is important to separate SS before feeding wastewater into a bioreactor owing to the fact that the SS limit mass transfer in the system. The separation can be achieved using settling, flocculation (Figure 3) and filtration (Figure 4) methods. It has been reported (Aiyuk et al. 2003) that during the pre-treatment, $FeCl_3$ or natural water of extract of seed of moringa oleifera can be used to remove PO_4^{3-} and SS.

Figure 2 Feed stream into wastewater treatment plant

Figure 3 Flocculation unit (pond)

Figure 4 Settling tank (Carolina)

1.4 Biological methods

The most widely used municipal wastewater treatment plants involve biological processes. (In such processes the biodegradation of the pollutants is carried out by microbes. Active microbes in the treatment of wastewater are either autotrophic organisms (Self-feeding) or Heterotrophs. The former obtain their energy from oxidation of inorganic compound such as hydrogen, Sulphur and nitrogen, while the later are sustained by oxidation and breakdown of organic compounds. The functioning of the said microbes is determined by several variables including temperature and pH, and these are among the listed parameters in terms Water Services Act (Act 108 of 1997). All wastewater treatment efficacies are measured by the parameters stipulated in the said act.

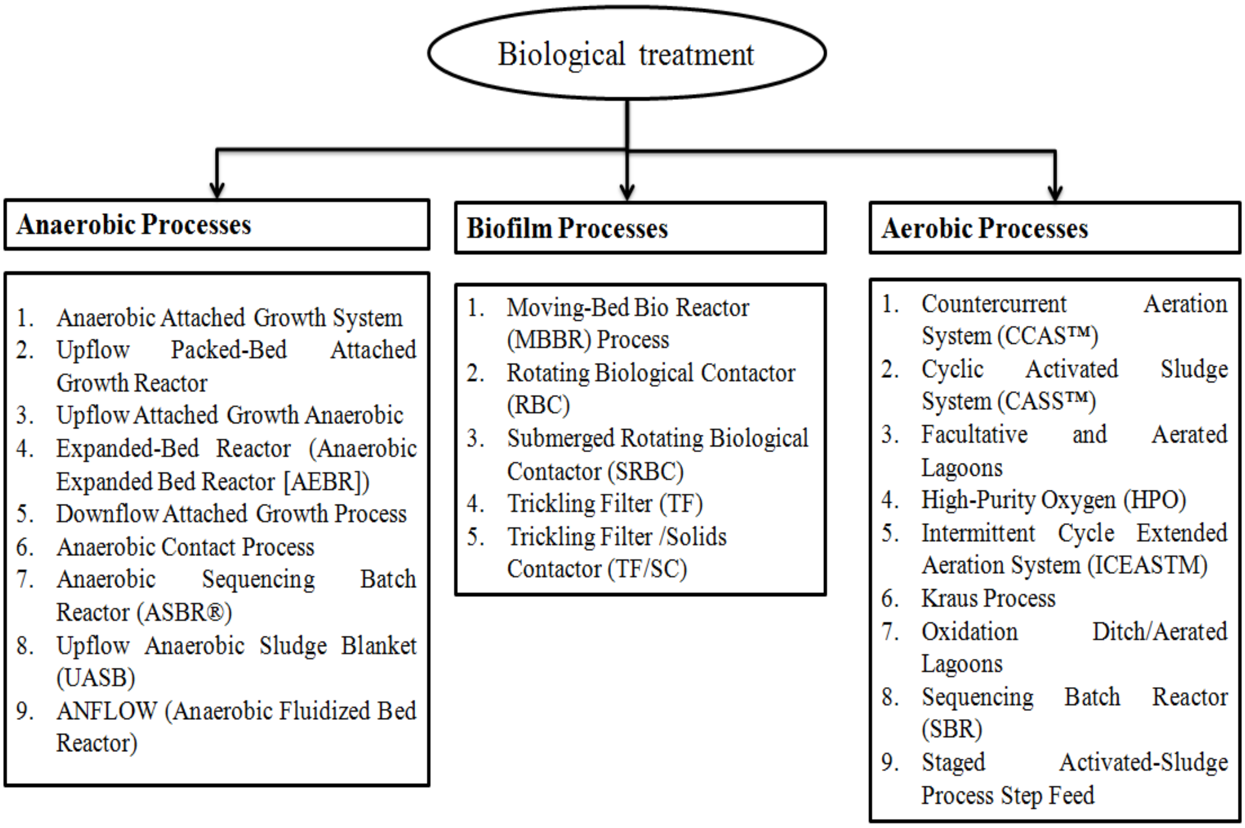

Figure 5 Stages of different biological processes, Kesi, 2016.

1.4.1 *Biofilters*

Biofilters have a dual purpose removing solids (filtration) and at the same time providing surface area for microorganisms to grow and degrade (biodegradation) organic pollutants. The systems combine the primary filtration process with the secondary biodegradation in one unit. These systems are however not very popular due to the high maintenance cost. As result, very few municipalities (Figure 6) the technology.

Figure 6 Biofilter unit at XFSA

1.4.2 *Aerobic processes*

The biodegradation process may be aerobic or anaerobic, where the former is without free oxygen but the presence of nitrates and the later means neither free oxygen nor nitrates. Aerobic systems (Figure 7) are relatively less challenging and most of them work well. As such there is no major concern as far as their operation is concerned. The major limitations are that they produce a lot of sludge and are costly to operate. The main cost component being the aeration such limitation can be addressed by using anaerobic digesters.

Figure 7 Aeration process, Plant XFSA

1.4.3 *Anaerobic digestion*

This study has shown that anaerobic digestion is not widely employed in most municipal wastewater treatment plants. This is most wastewater treatment process (Figure 8) is sparingly used in wastewater treatment plants across the country. Moreover the few ADs that are in use are either underutilized (Figure 9) or have completely collapsed. However there are municipalities that have demonstrated successful application of anaerobic treatment of wastewater in South Africa. Among the most successful cases are those that have incorporated technology to convert biogas into electricity. Known public entities utilizing anaerobic digestion are Joburg Water and PetroSA. Sasol Firm in Sasolburg had pilot plant in 2013 used for treating wastewater and flaring methane. South Africa Breweries (SAB) completed one treatment plant for the purposes of wastewater treatment and supplementing their boiler fuel.

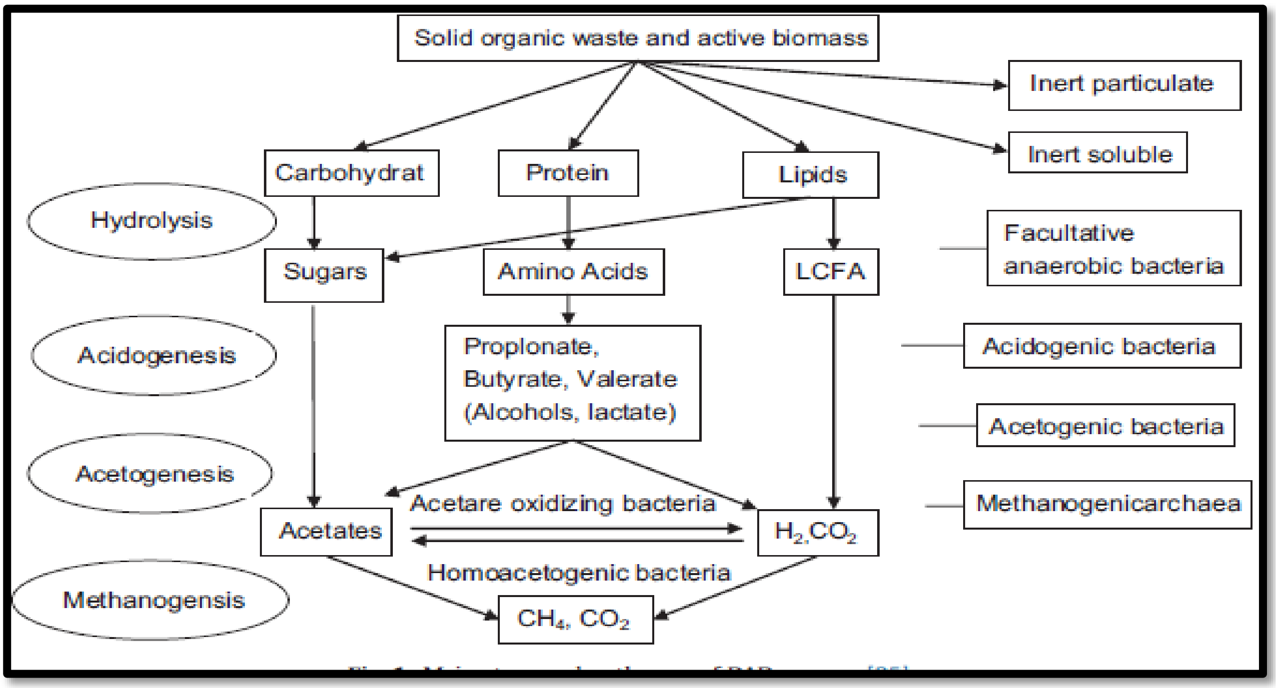

Figure 8 Schematic diagram of anaerobic digestion process.

The main driver for lack of the technology adoption is by and large finance and funding. Secondly, leadership priorities and capacity, thirdly, technical know-how and lack of incentives such as monitoring and enforcement is clouded by other equally demanding issues. Decentralized research and development is also not helping the situation. Figure 8 provides and illustrative schematic diagram of an anaerobic digestion.

Figure 9 Anaerobic digesters, Plant XFSA

The main challenge with regard to the production of electricity from biogas lies in the lack of skills the run such a process that requires multi- and trans-disciplinary advanced competencies. Considering the fact that most municipalities cannot successfully employ AD to treat even nutrient rich wastewater, it is critically important to equip municipal water technicians and engineers with skills needed to modern and green technology like that of biogas to electricity conversion (Figure 10).

Figure 10 Generation of electricity from biogas, Plant XEC

After a series of steps the wastewater (Figure 11) that is released into the water bodies should have pollution loads that are within the acceptable limits (Table 2).

Figure 11 Treated wastewater, Plant XFSA.

The process is temperature and pH sensitive. There are few digester types but the underlying principle is the same. A complete anaerobic process converts the digestate into a substrate that is almost odourless and stabilized. Despite the well-grounded knowledge of this technology it remains relatively neglected in many treatment plants. Water Institute of Southern Africa (WISA) provided a comprehensive operating guide for Anaerobic Digestion of Wastewater Sludge in 1992. However, even after the release of the guide adoption rate of the technology remains relatively erratic. There are more advantages favoring use of anaerobic digestion. One of the main problems in this regard is that the composition of the feed vary with time and space. Therefore, there is a need to develop systems on the basis of regional variations.

In plant where only primary and aerobic techniques are used to treat wastewater, the final effluent still remain heavily polluted (Figure 12) especially for overloaded systems. The COD concentration of this effluent was found to be up to 2000 ppm, which is way above the prescribed SA limits (Table 2).

Figure 12 Effluent from an underperforming treatment plant (Plant XAMP)

1.5 Conventional wastewater treatment methods

1.5.1 *Modern trends in wastewater management*

The onset of wastewater management can be traced back to 1500 BC when an ancient system was constructed in Mohenjo-Daro near river Indus in Pakistan. Since then classical and complex contemporary technologies evolved as the nature of wastewater characteristics changed with advent of industrial revolution. Even with the increase of complexity of treatment systems, the driving force remains the same: ameliorating water quality to specific standards for intended subsequent use.

Having understood that wastewater pollutants reduction had a biological phenomenon, the discharge into rivers was not a solution of the problem, if the amount of wastewater discharged was too great in comparison with the river flow rate. This marked the beginning of secondary treatment system. The first biological systems built in Germany consisted of radial systems in irrigation fields. These kind of systems could only handle very low loads typically 0.24-0.36 m^3 $(ha{\cdot}h)^{-1}$. Since then technologies evolved that could handle larger waste load. For example in 1903, continuously operated trickling filter was developed. One of the first large-scale plants was built in the form of contact beds using large pieces of coke and operated with intermittent filtration, in Stahnsdorf near Berlin. This kind of system could handle 500-2000 m^3 $(ha{\cdot}h)^{-1}$. Sixty years later (1960) high load trickling filter was adopted that could handle as high as 8000 m^3 $(ha{\cdot}h)^{-1}$ waste load.

In the early 1990s, it was realized that there was a lack of effective communication between the designers and the operators of digesters in South Africa. This was the motivation for the work done by Ross et al. (1993), through which the Sludge Management Division of the Water Institute of Southern African produced an operating guide to assist in training personnel. The operating guide gives detailed trouble shooting procedures that are required to diagnose a digester upset. Indicators of the upset of a digester include rate of biogas production, biogas composition, and production of odorous volatiles, increase in foaming, decrease in pH and increase in solids supernatant. Under a given set of operating conditions, these indicators vary with wastewater characteristics. Sudden changes in the operating conditions such as COD loading, mixing, temperature and toxicity may cause the upset. In their operating guide, one of the recommendations that Ross and co-workers made was that anaerobic digesters should operate in two stages and that one of the stages should be heated. Further, the authors recommended a high degree of mixing for the primary digester to reduce or eliminate dead zones. The optimal design should be such that the capital cost is minimized to the level that does not compromise efficiency.

1.5.2 *Capital and operating cost*

Wastewater treatment plants became large, complex facilities that required considerable amounts of energy for their operation. After the rise of oil prices in the 1970s, concern for energy conservation became a more important factor in the design of new pollution control systems. From the perspective of the wastewater industry therefore, five major trends are currently mandatory. These include nutrient removal and recovery, energy conservation and production, sustainability, treatment for non-traditional contaminants, and community engagement.

Rising energy costs seems to be directing new approaches in wastewater treatment, thus the trends are raising the bar for wastewater utilities toward being energy neutral or energy positive, whereby energy is not just managed, but instead recovered and reused. Current initiatives to increase biogas production, manage oxygen demand, and control equipment for efficient power use will move the industry into the right direction. A fundamental change in the use of aerobic biological treatment may be required to complete the transition from energy user to energy supplier. Moreover, future treatment plants may incorporate additional anaerobic processes, or chemical and physical barriers, to remove pollutants without aerobic bacteria thus creating energy rather than using energy. However, there are limits to the ability to increase the energy efficiency of existing processes, and there are budgetary limits for implementing new processes and technologies that help achieve an energy neutral target. A prudent strategy dictates that utilities work to achieve the energy neutral goal incrementally. Toward that end, there are five key components that can frame energy optimization strategies including: 1) maximize efficiency 2) provide more treatment for less power;

3) consider technologies to reduce or produce energy; 4) generate renewable energy; and 5) evaluate the plant carbon footprint.

1.5.3 *Effluent discharge limits*

Effluent discharge limits (Table 2) are imposed to deter the release of pollutants into water bodies. However, the conventional parameters such as pH, alkalinity, COD, colour and BOD are still important indicators of the level of pollution. However these parameters often do not give an indication of the toxicity levels.

Table 2 Effluent discharge limits (EMM, 2010)

Determinant	Lower limits of Concentration 1	2
Total solids (TS), mg l^{-1}	1000	
Nickel, mg l^{-1}	20	50
Zinc, mg l^{-1}	20	50
Cobalt, mg l^{-1}	20	20
Chromium, mg l^{-1}		20
Lead, mg l^{-1}	5	20
Copper, mg l^{-1}	5	50
Cadmium, mg l^{-1}	5	22
Boron, mg l^{-1}	5	50
Total COD, mg l^{-1}	500	
All sugars and starch (expressed as glucose), mg l^{-1}	1500	1000
Available chlorine	100	
Total phosphate mg l^{-1}	50	
Phenol, mg l^{-1}	150	10
Chloride	500	1000
Alkalinity, mg [$CaCO_3$] l^{-1}	2000	
Substances not in solution (including fats, oil, grease, waxes, etc. and where the volume of effluent discharged does not exceeding 10,000 kL, mg l^{-1}	500	
Fats, oil, grease, waxes, etc., soluble in petroleum ether	500	10
Sulphides, mg l^{-1}	10	1
Hydrogen sulphides, mg l^{-1}		5
Substances from which HCN can be liberated, in drainage sewer etc, mg l^{-1}	20	20
Ammonium nitrogen, mg l^{-1}		200
Formaldehde, mg l^{-1}		50
Non-organic solids suspension, mg l^{-1}		100
Fluorine containing compounds, mg l^{-1}	5	5
Sodium, mg l^{-1}	500	
Anionic surface active agents, mg l^{-1}	500	500
Sulphate, mg l^{-1}	1800	400
Electrical conductivity (EC) [redacted]	500	400
pH	6.0	6-10

1-EMM (2010); 2- Sacks and Buckley (2004)

Effluents that do not meet these limits must be treated at municipal treatment plants and the charges due per month for the treatment and conveyance (Ti) can be calculated as (EMM, 2010):

1.5.4 *Sustainability*

Another key characteristic of modern wastewater treatment facilities is the sustainable nature of the processes. At wastewater treatment facilities, this means reduced consumption of resources and increased recycling and reuse of water, nutrients, and other materials contained in wastewater. In some areas, the need to increase reuse will require some decentralization with construction of satellite treatment plants. Caps on greenhouse gas emissions affect the selection of treatment technologies and operating strategies particularly for sludge. Increased water conservation alters both the flows and pollutant concentrations in raw wastewater, potentially leading to new challenges and opportunities.

1.6 Conventional wastewater treatment methods

1.6.1 *Characteristics of the wastewater*

Wastewater can be characterised into three broad catagories as follows: 1. Physical, which deal with solid properties and thermal; 2. Biological which entails aspects such as pathgens, microbial ecology, biomarkers and antibiotics; 3. Chemical which is described in terms of pH, ions & metals, fats, oil & grease; organics and nutrients as well as micro constituents (Drexter *et al*., 2014). The characteristics of wastewater are important when considering the applicable treatment technologies and potential for re-use. The physical state of wastewater have impacts on its chemical behaviour and biological content.

Abattoir Wastewater refers to a mixture of organic and inorganic solids, suspended and dissolved in water. The wastewater from abattoirs constitute same chemical characteristics as those of domestic sewage only being highly concentrated to an extend that they are almost wholly organic. The organic loadings in the wastewater is highly variable as its constituents (proteins, carbohydrates, fats and other molecules) are not fixed in quantity and formulation. The measure of organic matter is oxygen demand (OD), which is the amount of oxygen required to break the organic matter down.

Waste and wastewater loadings composition are varied depending on the origin in the abattoir for instance paunch processing and slaughter floor wastewater is highly diverse (Jensen *et al*., 2014). Waste and wastewaters at the abattoirs are generated from processes such as resting animals; carcass dressing; slaughtering; reprocessing of by-products and is made up of animal dung, urine and water from washing lairages (Table 3). Agro-industrial and food processing usually leads to generation of wastewaters, the quantity and organic loading is determined by a number of factors, like the industrial or legal regulations guiding the specific industry processes and technology, feedstock/ raw material characteristics, and the need for cleanliness and sanitization (Petruccioli *et al*., 2011).

Table 3. Types and amount of wastes from an animal unit at red meat abattoirs.

Waste Type	Amount per Animal Unit (AU)
Rumen / stomach content	18 kg
Manure (Lairages)	4 kg
Condemned material/Trimmings	9 kg
Blood from bleeding area	12 L
Bloody water (rinse off)	2 L
Waste Water	(Inflow = 880 liter x 85%) 748 L

Red meat abattoirs association (2014)

An average number of animal units (AUs) slaughtered at the studied high throughput abattoirs is 198.6 on daily basis (Monday to Friday), with a minimum and maximum of 80 and 600 AU respectively. More than 25% of the examined abattoirs in the districts Fezile Dabi and Sedibeng Municipalities uses between 200-300 m^3 water daily and about 80% of the is outputted as wastewater. The volumes of wastewater produced are important with regard to wastewater treatment and water management.

The red meat abattoir wastewater shows highly variable amounts in biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solids, suspended solids, oil and grease, and nutrients level (nitrogen; phosphorus; potassium). The amounts of the loadings are influenced largely by the animal types, frequency of animals slaughtered and quantity of water used for various abattoir processes (Satyanarayan and Vanerkar, 2005). Secondly, wastewater from abattoirs are characterised by high organic loadings; relatively high temperature (20 to 30°C); organic biological nutrients; alkalinity (Chukwu *et al.,* 2011).

The effluent from abattoirs constitute surface cleaning water, diluted blood, dissolved solids, fats; manure, partially digested feed, urine and meat trimmings, paunch contents and the volume is determined by size of the abattoir, animal type, meat processing activities and technology in use at the individual abattoirs. Beef abattoir result in higher COD generation than is the case with piggery abattoir where the range is 1000 -11000 mg/l (Petruccioli *et al*., 2011). Studies from 1992 - 2000 by Jensen (2014) indicate that while the range is very wide, the loading are generalized at > 5000 mg/l COD.

Variations in organic loading have been reported (Johns *et al*., 1995) in Jensen (2014) where medium strengths were 1000 - 3000 mg/l COD to high strength at 5000 - 10000 mg/l COD. Wastewaters from food processing plants are characterized by high biological oxygen demand

(BOD) concentration, high levels of suspended solids, nutrients and minerals (Lee and Okos, 2011). The effluent is considered nontoxic; biodegradable; composition stable during the year and can be transferred to municipal after pretreatment (Petruccioli *et al*., 2011). There is an economic value, potential for energy generation, reduced agro-industrial waste that can be derived from improved production process design and value adding to waste from red-meat abattoirs (Petruccioli *et al*., 2011).

Animal's pens at the abattoir are used for holding animals prior to slaughter and generate substantial amount of wastes in the form of animal dung and urine that is usually cleansed by high pressured water (Figure 1). Another waste stream that is associated with the abattoirs is the feedlots that are usually affiliated to the abattoirs. The holding pens for pigs are normally equipped with the vaporised drizzling water to avert heat stress as pigs are highly vulnerable to heat. This is not only to avoid animals stress but an alignment with the humane treatment practice of the concentrated animals keeping.

Figure 13 F Animals in holding pens

Figure 14 **Water used for cleaning holding pens.**

Nearly 80% of the abattoirs under examination have their own feedlots which generate several tons of animal dung and wastewater used for cleaning the pens (Figure 13 F Animals in holding pensFigure 13). As such, abattoir businesses generate a significant amount of organic waste that requires specialized treatment and disposal procedures. One of the challenging wastes streams that require further in-depth research is on how cattle hooves can add value to the abattoir business or further down as useful resource.

The amount of water used is almost directly proportional to the number of animal units slaughtered at given abattoir. The various animal species were converted to animal units to standarise the numbers. However, animal type though may be converted to the animal unit have a varying degree of water use. Water is a critical resource at the abattoirs industry for both production and processing of the finished products. Tens of thousands litres of water are used daily at all red meat high throughput abattoirs. The mean water use per day is 110 m^3 in the study area, standard deviation is 78 m^3 and the range is 260 m^3. About 30% of the studied abattoirs did not quantify the amount of water they used daily. The sources of water used are mainly two, namely, boreholes and municipal water. Rain water harvesting is rarely practiced despite the large surface area of the abattoirs structures. For those that measures their water use daily, the averages are as follows: the lowest range are 40 - 55 m^3 (35%), the middle ranges are 85 - 150 m^3 (40%) and higher limits is 200 - 300 m^3 (25%).

The two main sources are municipal water (35%) and boreholes accounting for 65% of the water uses at the abattoirs. All the boreholes used by respondents in the study area were not registered. Those who acquire water from borehole do not account for the costs of sourcing the water. The costs are treated as overhead cost and as such it is challenging to establish water related cost structure. Municipalities are billing abattoirs on a monthly basis according to their water use. The average cost related to water use is R59, 912 per month, and the standard deviation is R49,165 and the range being R126, 140.

The study has identified four main water uses and rated them from the highest water user to the least using the scale of 1-4, where one is the highest use for water and four is the lowest water consuming activity. The following uses were idenetified: 1)cleaning offal; 2)lairages (flushing faeces from lines and holding pens); 3)ablution and laundry; and 4)slaughter and dressing carcass in no particular order. The said water uses impart either biological and or chemical loadings to the water which affect the quality or suitability of the water for reuse and treatment. The findings indicated that cleaning offal is the number one water user, followed by slaughter and dressing carcass, cleaning of the lairages and holding pens is the third ranked water use activity and the ablution and laundry ranked the last. A summary report (Table 2) provides of the water use ratings by the abattoirs. This is an important finding in the context of the loading and wastewater treatment.

Table 4 Water uses ratings

Water Uses	Rating
Cleaning offal	1
Slaughter and dressing carcass	2
Lairages (Flushing faeces from lines)	3
Ablution and laundry	4

Anaerobic wastewater treatment from abattoirs removes about 80 - 95% of COD; biological nitrogen and phosphorus and indications are that high efficiency can be achieved by treating the gains and healthy balance sheet and to some extend minimum compliance with the law.

1.6.2 *Treatment methods*

High quantities of water are used for various reasons such as cleaning facilities, carcass dressing, processing offal and this result in high volumes of wastewater. The water is used for some of the afore mentioned uses were rated in terms of the highest and the lowest water use since each process inputs a varying degree and type of organic loading. Again, when the highest and lowest water uses at the abattoir are known, it is relatively easy to identify the matching technology that can minimize water used and yet deliver the same or better results.

Static screens are prominently used as a major form of primary wastewater treatment (table…) whereby solids such as meat trimmings are separated from the wastewater. Disposal of wastewater in the studied abattoirs is shared equally (50/50) between channelling to the municipality wastewater treatment plant (WWTP) and irrigation of pastures thus natural or planted. In one incidence there was a contract between the abattoir owner and the landscaping company where the wastes and wastewater were used as an organic fertilizer. Overall, almost all abattoirs separated blood into different channel from the wastewater to avoid blood coagulating into a solid mass and blocking up drains. Static screens are similarly common for trapping trimmings, hair, small bones and other solid materials and this is achieved by embedded vertical sieves that act as filters that allow water through while catching solids. Only 11% of the abattoirs harvest blood and use it as fertilizer for lawns. Those that irrigate with the wastewater mix blood and wastewater at the settling ponds and irrigate with mixture of the two.

Settling ponds are used by 50% of the respondents and about 19% uses septic tanks as a form of primary wastewater treatment. The ponds are arranged differently; some in series while others are set randomly. The water is pumped from one pond to the next while the sediments are taken to cultivated pastures or lawns. In some cases, the sediments are only removed when the pond is filled up.

The environmental problem of eutrophication was observed around such pounds and over a period some traits of wetland emerge within the immediate environment of the settling ponds since they are largely on the ground surface. The study indicates those primary treatments of wastewater at red meat abattoirs involves practices such as solid separation; channelling and pumping to the municipal wastewater treatment plants.

Table 5. Waswastewater treatment unit operations and processes at red.

Treatment Units	Operations and Processes
Physical	Screening, Comminution, Flow equalization, Sedimentation, Flotation, Granular, medium filtration
Chemical	Chemical precipitation, Adsorption, Disinfection, Chlorination, Other chemical applications
Biological	Activated sludge processes; Aerated agoons; Trickling filters; Rotating biological contactors; Pond stabilization; Anaerobic digestion; Biological nutrient removal; enzymes addition

Source: Simate *et al.,* (2011).

Some of the surveyed abattoirs only apply physical wastewater treatment and very few apply any of the treatment methods cocurrently. Static screens and filtration are amongst the predominants treatment methods at abattoirs. Meat Safety Act (MSA) (Act no. 40 of 2000) is the key regulations for abattoirs and is generally concerned with hygiene and meat safety and very little to do with water besides prescribing the quality.

1.6.3 *Water/wastewater management policies and regulations*

Waste management generally refers to a number of activities such as waste generation; storage; transportation; treatment; re-use, recovery and where applicable the final disposal of various waste streams. The study found out that about 156 municipalities are water services authorities (WSA) and some of the 156 are also Water Service providers (WSP). This state of being the authority and the service provider may be interpreted as a conflict of interest. However, self-regulatory tools such as SANS 241 are widely adopted and used in most municipalities.

The high throughput red meat abattoirs are required to have waste management plans due to the number of activities entailed in the waste management. The competent authorities in dealing with waste management are primarily national government, secondly provincial and the local authority. The national sphere of government gives context to the legislation while the local government may impose own bylaws in their jurisdiction. The National Environmental Management Act, 1998 (Act

107 of 1998) (NEMA) forms the basis of environmental management in South Africa but other specific laws relating to conservation, water, waste and air quality are equally relevant in this case.

The National Water Act (NWA), 1998 (Act no. 36 of 1998), objects are to manage national water resources in order to achieve sustainable use of water for the benefit of all water users. Section 21(1) of the Water Services Act, 1997 (Act No. 108 of 1997) requires every water services authority to promulgate bylaws, which contains conditions for the provision of water services. The act is premised on the integrated natural resources framework and seek to ensure that quality of water resources is maintained and protected. The Act is aimed at ensuring that the water resources are protected, used, developed, conserved, managed in order to:

a) Meet the basic human needs sustainably;
d) Promote the efficient, sustainable and beneficial use of water in the public interest;
e) Facilitate social and economic development;
f) Provide for growing demand for water use
g) Protect aquatic and associated ecosystems and their biological diversity;
h) Reduce and prevent pollution and degradation of water resources;
i) Meet international obligations and
k) Manage floods and drought

The above listed aims of the NWA (1998) is where red meat abattoirs can play major role and potentially reduce their water and energy related bills by simply adopting South African waste management hierarchy.

All types of water uses are regulated by National Water Act (NWA), 1998 (Act no. 36 of 1998), in particular section 21 (e); (f); (g); and (h). Section 21(e), regulates irrigation of land with wastewater while, section 21. (f) is concerned with discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit. Section 21 (g) seek to protect the water resources at which water is discharged. Lastly, section 21 (h), may affect abattoir that generate steam or are in one way or the water independent power producers.

Abattoirs through their processing and waste management practices and do generate odour and that is controlled through Air Quality Act (AQA) (Act No.39 of 2004). Section 35 (1) of the Air Quality Act of 2004 enables the competent authority to take measures for the control of offensive odours emanating from specific activities. No such measures have been prescribed as yet. Again, Section 35(2) forces land owners or occupier of any premises to take reasonable measures to prevent gaseous emissions of any offensive odour caused by any activity on such premises. The waste management and facilities are also regulated by this section.

The abattoir effluents are subjected to the municipal by- laws which stipulates the acceptable values key parameters values (Tab. 4) of the effluent that are deemed acceptable for discharge into the municipal wastewater treatment plant (MWWTP). The authorities conduct a periodic random sampling of the abattoir effluents that comes into their system and where the values may exceed the stipulated amounts abattoirs are fined to pay a predetermined amount of money. Abattoir apply some form of pretreatment to their wastewater in order to meet some minimum requirements of the by-laws and avoid paying penalties.

Table 6. Upper limits for wastewater discharge MWWTP

Key Parameter	Acceptable values in Gauteng
COD	3000 to 5000 mg/L
TSS	500 mg/L
NH3-N	200 to 300 mg/L
pH	6 to 10.

The available pretreatment facilities are hardly sufficient to also meet the requirements of the by-laws quality standard for suspended solids, fats, oils and grease. The volumetric and cumulative aspects of the abattoir wastewater do not seem to have been considered in terms of the municipal by-laws. The high volumes of abattoir wastewater may cumulatively increase the concentration of

Conservation of agricultural resource act (CARA), 1983 (act no. 43 of 1983) objectives are to provide for the conservation of the natural agricultural resources of the Republic by the maintenance of the production potential of land, by the combating and prevention of erosion and weakening or destruction of the water sources, and by the protection of the vegetation and the combating of weeds and invader plants. The common wastewater management identified in the study area are largely in contravention of the objectives of this act, as they are more likely to contaminate water resources and are largely contributing to eutrophication.

In terms of the Act agricultural resources refers to the soil, the water sources and the vegetation. In order to ensure the protection of agricultural resources CARA (Act. No 43 of 1983) makes provision for the control of the following aspects that were identified to relate to water and or wastewater management from the sampled abattoirs:

(1) In order to achieve the objects of this Act the Minister may prescribe control measures which shall be complied with by land users to whom they apply.

(2) Such control measures may relate to-

(b) the utilization and protection of land which is cultivated;

(c) the irrigation of land;

(d) the prevention or control of waterlogging or salination of land;

(e) the utilization and protection of vleis, marshes, water sponges, water courses and water sources;

(n) the protection of water sources against pollution on account of farming practices

All the studied abattoirs do not recycle or recover anything from their wastewater, while the CARA (Act 43 of 1983) seem to suggest that material reuse and recovery of useful material by defining conservation "*in relation to the natural agricultural resources, includes the protection, recovery and reclamation of those resources*". It can therefore be considered mandatary that nutrients are such as nitrogen, phosphorus and potassium (NPK) are recovered from wastewater and also that water should be reused. Recovery of energy from wastewater may also be empowered in terms of this CARA.

The current waste management practices of organic waste streams at abattoirs enables soil contamination by way of leachate infiltration into the soil. Land contamination through eutrophication can lead to the spread of invader plant species. This invader plants may in turn outgrow some indigenous or even endemic plants in their habitat, leading or contributing to their extinction. Invader plants species lack natural enemy due to the fact that they grow outside their territories. Again, spread artificial wetlands as prominently observed in one piggery abattoir may be experienced as the contaminants are in at times dissolved in water.

In brief, wastewater resources play important roles in improving fertility of the soil and act as fertigation as opposed to rain water that only irrigates crops without enhancing any nutrients to the plants, however, different streams of wastewaters require some treatment prior to being applied to the soil to ensure proper soil functionality and quality of crops. Various wastewater streams can adversely affect cation exchange capacity, soil water holding capacity,

Meat Safety Act (MSA) (Act no. 40 of 2000) was promulgated to provide for measures to promote meat safety and the safety of animal products; to establish and maintain essential national standards in respect of abattoirs; to regulate the importation and exportation of meat; to establish meat safety schemes; and to provide for linked activities such as the management of waste and condemned material from abattoirs. The regulations requires that water quality be compliant with SANS 241: ii. The whole specifications of different abattoirs units are contained in the act.

1.6.4 ***Sustainability***

Sustainability pillars are premised on three pillars namely, people, environment and economy. The sustainability paradigm is by and large an effort to recognize the value of environmental services and products. Daly (1990b) defined environment sustainability in three parts: 1. The rate at which resources are utilized does not surpass the rate of regeneration, 2. The rate of waste generation from diverse uses should not exceed the assimilative capacity of the environment, and 3. The depletion of non-renewable resources should be weighed against the development of renewable substitutes for the resources. Water is not substitutable and water resources flourish in well balanced functional ecosystem. However, the rate of use and management of wastewater disposal to the environment is within human capacity to manage and should be in manner that addresses the economic aspects as enshrined in the broad definition of sustainability.

Water issues relate to sustainability at many levels, one being that water is the source of life and basic right as enshrined in the bill of rights. However, the challenges regarding quantity, quality and biodiversity are central to how water ought to be used and managed. South African national development plan talks to green economy development and alternative waste management and treatment can be turned into one of the pillars to achieve the envisaged development. Some of the outlines technologies in previous section are clear ways by which wastewater can be managed sustainably and at the heart of such technologies is the thrust for green economic development that encapsulate water, energy and food nexus. Wastewater treatment is considered as bulk energy user while in actual fact have the potential to generate about 9.3 folds of the processes energy needs (Shizas and Bagley, 2004).

Abattoirs and MWWTP have uncovered anaerobic digester which allows methane and other greenhouse gases to escape into the atmosphere. The main three GHGs are namely Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O). CO_2 is the most significant emissions in RSA and the main source of the emissions is the energy sector (Country Report, 2010; Davidson and Winkler, 2003). Alternative energy and energy production are then key aspects in an effort to avert the GHG effects and production. Methane is energy rich gas and if harvested and harnessed can form the part of Integrated Energy Resources Plan as envisioned by Department of Energy (DoE, 2010).

In the case of water and wastewater management and treatment, there is an opportunity for individual abattoirs to be energy sufficient while being environmentally responsible by adding value to their waste. There are few entities in the country that uses or have commercial waste and wastewater to generate own bioenergy for instance, Sedibeng Brewery, City of Johannesburg’s Northern WWTP, BMW South Africa’s Rosslyn uses energy generated from feedlot waste. There is potential to generate 1.9 jobs for every MW generated from Biogas according to the engineering news (22 Oct, 2013), table 5 provide energy potential of the common wastewater treatment technologies. This then means biogas technology amongst the known treatment technologies can enhance the sustainability capacity of WWTP by cutting electrical bill, provide jobs and preventing potential pollutants reaching our water resources. Sustainable development therefore is when the need of the people is addressed in a manner that does not inhibit natural cycle but rather enhances it.

Table 5 Energy potential of various feedstock (Adapted from Boyd, 2012)

Feed stock	Quoted potential capacity	Reference	Notes
Wastewater to wwtp	850 MWth	Essence Report	Municipal wastewater WWTP load consists of captured domestic black water, domestic greywater and industrial wastewaters
Households (rural)	310000 households*estimate: Approximately 680GWh/year of thermal energy	Biogas for Better life	I.e. rural cattle *Assume 6m³ digesters, produce 1m³ biogas/day, 1m³ biogas = 6kwh thermal energy
Agricultural Cattle in feedlots Piggeries Poultry farm	3906 MWth 79 - 215 18 - 715 940 - 2976		Excluding rural cattle use high range

1.6.5 *Evaluation of emerging water/wastewater treatment technologies*

The environmental sustainability concept is centred around the realisation that natural resources are finite and ecological services are derived from a functional ecosystem. Progressive emerging technologies ought to aim at imitating the natural cycles and consider product life cycle as a priority in order to achieve zero waste. However, some of the best technologies are not yet used by the relevant end users such as the municipalities and abattoir owners. Table 6 outlines some of the common technologies in the wastewater industries. There is a varying degree of wastewater and water treatment technologies efficacy of the outlined technologies and the applicability has to be largely guided by the wastewater stream. The use and adoption of a particular technology is ideally underpinned by three main things, namely characteristics of wastewater; available technology and the compliance with the applicable legislation. However, political by-in, incentives and funding are the main drivers of certain technology adoption.

Table 6 Wastewater treatment technologies and the advantages and disadvantages

Technology	Wastewater characteristics	Advantages	Disadvantages
Fermentations for biomass and secondary products	· Nutrients (C, N) · Non-toxic effluent for microbial growth · Dissolved or suspended organic	· Can produce high value secondary metabolites as by-products · Can remove toxic and recalcitrant chemicals	· Chemicals such as phenol are inhibitory. · pH, salinity, aeration need to be adjusted for growth of the microbe.
Anaerobic Digestion · Works best at warmer temperatures (30 to 60°C)	· pH: 5.5 – 8.5 · Good design to control digestion and collection of gas Dissolved or suspended Organic	· Suitable with most substrates · Can achieve 90% conversion · Help contain odour · Produces biogas for heating, electricity generation and steam · Produces less biomass than aerobic fermentation	· H2S oxidised to SO2. and when combined with water vapour can form suphuric acid which is corrosive · High capital investment
Combustion Gasification	· Biomass · Low water content and Suspended organic matter	· Heat energy · Destruction/conversion of all hazardous material · Mature technology available · 95% fuel-to-feed efficiency	· Electricity costs are higher than for a coal-fired power station. · Could produce hazardous off-gases
Algal growth for biodiesel production	· Carbon and nitrogen sources, oxygen · Non-toxic effluent for growth · Dissolved organic – limited COD	· Low energy requirements- use energy of sunlight for algal growth. · Can result in carbon dioxide sequestration · Can utilise dilute wastewater streams	· Algal ponding area can represent considerable land area. · Photobioreactors have large capital costs. · No suspended solids · Evaporation, dilution, contamination
Bioethanol production	· Carbon and nitrogen sources · Non-toxic effluent for microbial growth · Carbohydrate (sugar) rich · Dissolved organics (or suspended with emerging technology)	· Established technology producing fuel suitable for a variety of combustion engines	· Cost of carbohydrate rich raw materials · Large volumes of bioreactors needed · Non-dilute wastewaters required

Microbial Fuel Cells	· Non-variable wastewater sources · Non-toxic effluent for microbial growth · Dissolved organics	· Can be used at less than 20°C · Suitable for use with low concentration of organics in wastewaters · Efficient (direct conversion to electricity)	· Capital intensive · Still in development · Variable COD reduction depending on wastewater
Heat recovery	· Wastewaters with temperature above ambient	· Direct heat recovery	· Heat above ambient and the need for heat energy.

Adapted from Burton et al., 2009

Anaerobic waste stabilisation ponds are among treatment methods used for treatment of agricultural wastes and the disadvantage is that the ponds are uncovered and allow CH_4 and CO_2 to escape to atmosphere. This is not only waste of potential energy resource but also have negative impact on global warming. More 50% of the surveyed abattoir expressed interest in adopting biogas technology. Biogas technology is perceived as waste management strategy and potential renewable energy source.

1.6.6 *Skill needs*

Number of skills related challenges were mentioned during data collection at the municipalities and also during the round table consultative session. The shortage of skill is on both soft skills like management and hard skills like engineers. For instance, there is relatively lack of understanding regarding the financing of water infrastructure as well as institutional governance water. Some of the identified skills shortages includes.

There is intra and inter municipalities competition for skilled labourers. Graduates are leaving the government sector to work as consultant or be absorbed by the industries. There are few individual who studied water management at honour degree levels and largely responsible for taking random samples at the predetermined spots. The water division are largely headed by civil engineers who oversees the water reticulation and maintenance. The structure of the section is not uniform but most affluent municipality afford to hire chemists and microbiologist to deal with water related subject matters. Predominantly the labuor force constitute National Qualification Framework (NQF) levels 3 to 6.

Table 7, Diversity of skill requirement at municipalities

City Name	Water Division Name	Responsibilities/Divisions
Cape Town	Water and Sanitation	1. Water Demand Management 2. Bulk Water 3. Finance and Commercial 4. Waste water Management 5. Wastewater operations
Magaung Metro	Water and Sanitation	1. Engineering (not specific) 2. Operations & maintenance 3. Demand management 4. Purification 5. services
City of Johannesburg	Contracted private company (Johannesburg Water): Water and Sanitation	The services are completely outsourced to the contractor and the contract account to the municipality through the board of directors.

The municipalities are highly diverse and the manner in which they execute their water related responsibilities. As a results each municipality will have different skills requirements. It may be recommended that SALGA provides guidelines in terms of the hierarchy or structure for water and sanitation. All levels of water service complain about the “over supply of unskilled individuals” and it is really challenging to identify where the skills are lack. There is probably a need to conduct an in-depth study ton identify the gaps as juniors are complaining that the superiors do not understand their jobs and verse versa.

For instance, many municipalities have only civil engineers who are overseeing technicians. Municipalities are largely dependent service providers in the water management, services and treatment. There a concern that the hired services providers do not partake in skills transfers despite that being part of their contractual agreement. The skilled personnel are leaving poor municipalities to higher paying owns and or are leaving the local government sector only to come back as consultants.

- local government’s capability to deliver

The local government is characterized by high degree of diversity and as a result a one size fit all approach in their ability to deliver services may not work. Local municipalities are to a large extent autonomous bodies and their proximity to where service delivery is required is an added advantage.

However, majority of the local government are unable to deliver services to their own satisfaction, due to a number of factors, such as funds and funding; improper placements; skills; Municipal Finance Management Act (MFMA) (Act 56 of 2003) are said to be among of the issues ability to render services. Political leadership and buy-in of some projects are some of the issues that affect the efficacy of the local government.

- strengths, challenges and opportunities

Local authorities have an ideal opportunity flourish in the green economy as anticipated by the national development plan. The opportunity is embedded in environmental management stewardship.

There is lack of alignment between the local government and affiliated institutions that are meant to lessen the work load of municipalities such as South Africa Local Government Association (SALGA) and Local Government Sector Education and Training Authority (LGSETA). For instance, SALGA has been working with South African Biogas Industry Association (SABIA) to among other things create employment by training biogas technicians and using the wastewater to generate electricity for running of MWWTP but this has not had any in routes to the local authorities.

1.6.7 *Conclusion and recommendations*

One of the major challenges facing local government is enforcement, monitoring and evaluation of the projects. The wastewater from the abattoirs is rarely sampled and in some local municipalities while other never sample wastewater from abattoirs in the Free State. Some local municipalities in Sedibeng are largely depending on rand water for the sampling and testing of water. The municipalities largely rely on the services of contractors do draw specification and execute the actual work, this creates a problem when it comes to monitoring and payments of the since more often than not there is no verification of the quality of work done due to capacity.

It is finally recommended that professional body guidelines be utilized in terms of structures or organogram of the technical departments. Position of seniority should be aligned to professional seniority and senior people be accountable to the professional bodies as is the case with lawyers; nurses and accountants. Some of the people working in what ought to be a technical department are neither registered nor affiliated to a professional body. This model is already working with some municipal department such as Public Health, where practitioner are registered. That will influence the conduct beyond moral obligation but to professional accountability.

The institutions are of higher learning are continually building some of the best technologies that continue to utilized. It is therefore recommended that municipality head of departments to periodically identify the gaps in their sections and one of the best ways is some periodic seminars with the institutions of higher learning, whereby they can display what they have developed and get to understand the challenges at government level. Human resources development should compile a training needs list from the sections concerned and be followed through.

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CHAPTER 2

2 Acid mine drainage

2.1 Introduction

South African mines have generated a vast economic benefit and still play an important role in ensuring the country's position in the global market. However, despite such benefits, the operations and ceasing of mines have become a major concern. Mining activities have produced a vast amount of hazardous waste throughout the world, which are commonly associated with high content of acid generating sulfide minerals, in particular acid mine drainage (AMD).

Acid mine drainage is a significant and costly environmental impact of the mining industry worldwide. Over the last few decades there has been an increasing public awareness of the potential environmental hazards arising from mining activities, in particular acid mine drainage (AMD). Although any mineral deposit which contains sulphide is a potential source of AMD, certain types of mining are more prone than others. There are records of acid drainage where coal, pyritic sulphur, copper, zinc, silver and lead among others have been mined. Every mine is unique in terms of its AMD potential; thus, the nature and size of the associated risk and feasibility of mitigation options will vary from site to site. Also, the impact of AMD is dependent on local conditions and geomorphology. There are no standardized methods from ranking, measuring and reducing the risk of AMD.

The provinces that are mainly affected by AMD in South Africa are Mpumalanga, North West, Gauteng and Free State. Gauteng, the Witwatersrand Basin, has received much attention due to the decanting of contaminated water from the old mines in the Krugersdorp area into the Cradle of Humankind. This interest then led to the establishment of an inter-ministerial committee on AMD in late 2010. A technical task group was formed to investigate the problem and to recommend possible solutions The report was focused mainly on the immediate problems arising from gold mining in the Western Basin , the Central Basin and Eastern Basin (McCarthy, 2011).

Acid mine drainage treatment can be divided into active and passive methods. Passive methods include biological treatment with constructed wetlands and chemical treatment with limestone drains. Active treatment methods include chemical precipitation with alkaline chemicals, biological treatment with bioreactors, and other techniques such as adsorption, ion exchange and reverse osmosis. Commonly used treatment method for AMD is neutralization by limestone to neutralize the acidity and remove the metals by forming their insoluble hydroxide precipitates. Although this method is an effective method for AMD treatment, the main setback of this method is the huge amount of sludge produced which has costly disposal requirements (Nleya et al., 2015, Wang et al., 2013).

A number of approaches have been proposed to control and manage AMD. These include: decant prevention and management, ingress control — reduction of the rate of flooding and the eventual decant volume and water quality management. The latter approach proposes the use of active, passive and in-situ treatment technologies that are tailored designed for specific AMD since water quality of AMD varies from one source to another. Treatment technologies are very expensive and require a thorough appraisal before adoption. Because of the stringent nature of environmental regulations, advanced potential technologies such as adsorption and membrane technologies are being explored. Skills development plays an important role in the growth of every country's economy, service delivery and technology improvement. It builds confidence in people, hence it is crucial to ensure that the people in water sector are well-skilled and developed. In order to develop and implement a coordinated approach to the skills gaps, it is necessary to quantify and specify the water sector skills needs, quantity and specify the current system outputs, therefore establish the gaps and give recommendations on how to bridge skills gaps and address skills shortages.

2.1.1 *Occurrence and composition of acid mine drainage*

Underground mine workings, mine waste dumps, tailing and ore stockpiles are the major sources of acid mine drainage. Iron disulphide (FeS_2), or pyrite, is the most important mineral associated with acid mine drainage generation. According to Gray (Gray, 1997) the breakdown of pyrite is affected by its morphology, such as crystallinity, particle size, and reactivity. Acid mine drainage results from a series of reactions starting with the oxidation of pyrite in the presence of oxygen and water to form ferrous ions and sulphuric acid (Kalin et al., 2006, Nengovhela et al., 2007, Salomons, 1995). According to Akcil and Koldas (Akcil and Koldas, 2006), the first most important reaction is the oxidation of pyrite into dissolved iron, sulphate and hydrogen. The rate of pyrite oxidation is dependent on solid phase compositional variable, microbial activities, and availability of oxygen and water (Lapakko, 2002).

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2\,Fe^{2+} + 4SO_4^{2-} + 4H^+ \qquad (1)$$

The present of sulphate in mine waste drainage is typically the first indicator of sulphide mineral oxidation. In a sufficiently oxidation environment (dependent on O_2 concentration, pH greater than 3.5 and bacterial activity) ferrous iron released in Eq. (1) may be oxidized to ferric iron, according to the following reaction (Akcil and Koldas, 2006, Blowes et al., 2003):

$$4Fe^{2+} + O_2 + 4H^+ \leftrightarrow 4Fe^{3+} + 2H_2O \qquad (2)$$

If oxygen is low, Reaction (2) will not occur until the pH reaches 8.5. Under any conditions, Reaction (2) is the rate-limiting step in pyrite oxidation because the conversion of ferrous to ferric is slow at pH values below 5 under abiotic conditions (Skousen and Association, 1998).

At pH values between 2.3 and 3.5, ferric iron precipitates as $Fe(OH)_3$, leaving little Fe3+ in solution while simultaneously lowering the pH (Akcil and Koldas, 2006). The remaining ferric iron reacts directly with pyrite to produce more ferrous iron and acidity.

$$Fe^{3+} + 3H_2O \leftrightarrow Fe\,(OH)_3(s)\downarrow + 3H^+ \quad (3)$$

If pH is less than 2, ferric hydrolysis products like $Fe(OH)_3$ are not stable and Fe^{3+} remains in solution (Dold, 2010). Nevertheless, any remaining Fe^{3+} from Eq. (2) that does not precipitate into $Fe(OH)_3$ from solution through Eq. (3) may be used to oxidize additional pyrite, according to the following reaction:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

From Reaction (4) the oxidation of pyrite by ferric iron results in further decrease in pH (Singer and Stumm, 1970).

While oxygen is a primary oxidant, the ferric iron (Fe3+) resulting from the oxidation of ferrous iron (Fe^{2+}) is now recognized as a more potent oxidant than oxygen even at circumneutral pH (Zdun, 2001).

From the discussion above the formation of AMD may be considered to take place in three major steps:

1. Oxidation of iron sulphide (Eq. (1)), and enhanced oxidation of sulphide minerals by ferric iron (Eq. (4))
2. Oxidation of ferrous iron (Eq. (2)), and
3. Hydrolysis and precipitation of ferric iron and other minerals (Eq. (3))

The primary factors that determine the rate of acid generation are:

- pH;
- Temperature;
- Oxygen content of the gas phase, if saturation is less than 100%;
- Oxygen concentration in the water phase;
- Degree of saturation with water;
- Chemical activity of Fe3C;
- Surface area of exposed metal sulfide;
- Chemical activation energy required to initiate acid generation; and
- Bacterial activity.

Reaction (2) and (4) can be significantly accelerated by the presence of acidophilic bacteria such as Thiobacillus ferroxidans (Jennings et al., 2008, Singer and Stumm, 1970). This bacterium and several other species through to be involved in pyrite weathering are widespread in the environment. Thiobacillus ferroxidans has been shown to increase iron conversion rate by a factor of hundreds to as much as a million (Blowes et al., 2003, Singer and Stumm, 1970).

2.1.2 *Environmental impact of acid mine drainage*

Acid mine drainage affects lotic ecosystems in numerous and interactive ways. The overall impact of AMD is dependent on local conditions, climate and the extent and distribution of the AMD generation deposits. These effects can be categorized as chemical, physical, biological and ecological. The increased acidity caused by acid mine drainage has a range of negative effects depending on the severity of the pH change. These changes have an effect on the aquatic life and get to the food chain. It may disturb the reproduction system of aquatic life such as fish and therefore may decrease their population. It also affects the infrastructure by corrosion.

- Lowering of the pH of water to a point where it is unsuitable for domestic or other uses.
- The reactions which produce acid mine drainage results in a high sulphate content in the resultant water that will remain high even after the acid is neutralized. This water is unfit for domestic, agricultural and some industrial uses and will increase the salinity of the receiving aquatic environment.
- The acidity of the water liberates metals, including toxic metals and radionuclides from the rocks which it interacts with. This may result in acute and chronic toxicity to both humans and environment.

2.1.3 *Management approach to remediation*

Acid mine drainage is a significant and costly environmental impact of the mining industry worldwide. The mining continues to affect surface and groundwater resources even long after mining operations have ceased. Not only does the mining operation have an impact on the environmental; the excavation process also exposes sulphides in the walls of the opencast allowing the ingress of water and oxygen.

According to a report by the Inter-Ministerial Committee on AMD, it has been reported that estimated

The key factors which differentiate the developing problem in South Africa from international examples reported in Inter-Ministerial Committee on AMD report is the interconnection of large voids, the sheer scale of the Witwatersrand operations and the fact that many of the problem areas are located in or close to the major urban areas. In other countries, mine flooding was planned to minimize impacts, while in South Africa this has not been done and in this would not have been possible owing to the closure of older mines within a basin long before flooding was contemplated.

According to a report by the Inter-Ministerial Committee on AMD, international experience reveals a number of factors that leads to the successful implementation of programmes dealing with mining legacies, including AMD:

- Acceptance that there is a problem that needs to be addressed in a coordinated programme between government and the mining industry.
- High-level coordination between ranges of stakeholders, with government playing the leading role.
- Decisive action by the State to secure and provide funding.
- Ongoing research optimal and sustainable short-, medium-, and long-term solution

Principles and actions for mine water management in the Department of Water Affairs (DWA) Best Practice Guidelines for Mine Water Management are defined in the following steps:

1. Pollution prevention
2. Minimization of impacts: water reuse and reclamation water treatment
3. Discharge or disposal of waste and/or wastewater

In order to develop cost-effective and environmental sound management strategy of AMD discharges from abandoned and active mines, the problems were split into two components: management of flooding and management of water quality.

Assessment of technologies for the treatment of AMD

Acid mine drainage has significant economic and environmental impacts owing both the corrosive effects of acid water on infrastructure and equipment, and the severe environmental impacts related to the low pH and high metal and salt loadings. These impacts continue long after mine has ceased and can have adverse impacts on the ecology of streams, affecting the beneficial use of waterways downstream of mining operations.

Contamination of AMD ranges from location to location, therefore there will not be one single treatment method that can be used in every situation and that appropriate treatment methods need to be selected from the range available for each mine water type encountered. Analysis shows that there is a wide variation in water quality from different basins, for example, the Eastern Basin produce near-neutral water with a sulphate content of around 1 000 – 1 500 mg/L, and the Western Basin produce a highly acidic water with sulphate content as much as 5 000 mg/l (Committee, 2010). An appropriate technologies will need to be identified for each and the different waters.

The current methods used in South African for acid mine drainage treatment are neutralization and reverse osmosis method.

2.1.3.1 Neutralization method

One of the most environmentally effective techniques available for mitigating AMD is internal neutralization methods. Although neutralization is an effective method for AMD treatment, it is also accompanied by the treatment of produced metal hydroxide precipitate which has costly disposal requirements. The acid is neutralized by dosing the AMD with lime or limestone, then passing it through settling tanks to remove sediments and particulate material. The effluent produced often contains more sulphate than is acceptable to discharge to the environment. A neutralization plant is build and in operation in Randfontein for treatment of waste water from Sibanye Gold mining void. The treated water is recycled back to the mines.

Process:

Slurry of lime is dispersed into a tank containing acid mine drainage and recycled sludge to increase water pH to about 9, **Figure 1**. At this pH, most toxic metals become insoluble and precipitate, aided by the presence of recycled sludge. Air is introduced in this tank to oxidize iron and manganese and assist in their precipitation, **Figure 2**. The resulting slurry is directed to a sludge-settling vessel, such as a clarifier. In that vessel, clean water will overflow for release, whereas settled metal precipitates (sludge) will be recycled to the acid mine drainage treatment tank, with a sludge-wasting side stream.

Figure 15: Acid neutralization plant, mixing tank.

Figure 16: Aeration tank.

2.1.3.2 Reverse osmosis

Reverse osmosis is one of the technologies currently being implemented and evaluated at a range of pilot and operational scales at a number of locations. The operation is taking place at the eMalahleni and Optimum Water Reclamation Plants in Mpumalanga. Acid mine drainage from coal mines is treated to potable quality and used to supplement the local municipal water supply.

Process:

Reverse osmosis (RO) is a water purification technology that uses a semipermeable membrane to remove ions, molecules, and larger particles from drinking water. It is the process of forcing a solvent from a region of high solute concentration through a semipermeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. Reverse Osmosis works by using a high pressure pump to increase the pressure on the high solute concentration side of the RO and force the water across the semi-permeable RO membrane. The amount of pressure required depends on the contaminants concentration of the feed water. The more concentrated the feed water, the more pressure is required to overcome the osmotic pressure. **Figure 3** demonstrate how contaminated water moves through semipermeable membrane.

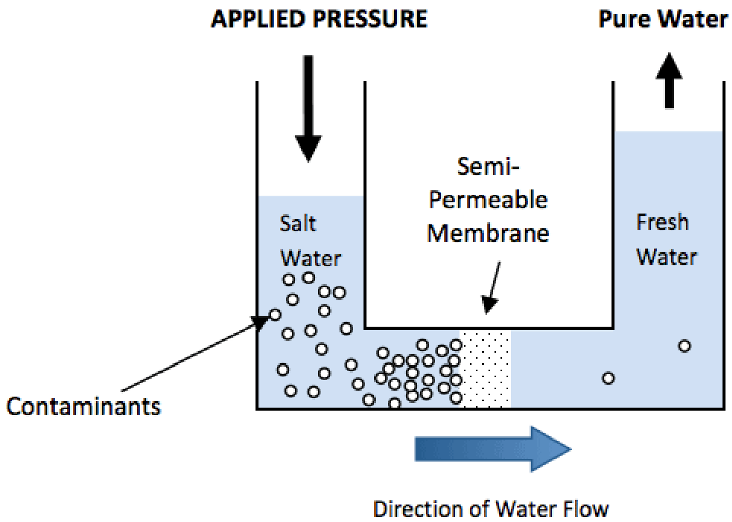

Figure 17: Reverse osmosis

2.1.4 *Emerging trends and challenges*

In South Africa there are currently two plants for treating AMD to portable quality at full scale. These plants are not financially self-sustaining. Internationally experience has shown that AMD treatment is unlikely to be financially self-sustaining (Committee, 2010). The costs of this treatment are estimated at around R11 per cubic meter, with a capital of treating 20 Ml/day (20 000 m^3/day) at each plant, including amortization of the capital costs of the plant over a projected 20 year design life of the plant (Committee, 2010). This is not economically self-sustaining and relies on a subsidy from the mining companies.

By-product from these treatment methods (neutralization and reverse osmosis) is also a problem. Waster sludge and brine are produced, depending on the level of treatment, requiring disposal. The water quality from the Central and Eastern Basin is expected to be better than that from the Western Basin and therefore needs less pre-treatment; however, none of the water measured in the different basins is suitable for discharge to the river systems.

Environmental protection and rehabilitation are fast becoming a priority. Economic sustainability and technical feasibility become key drivers in determining the sustainability of any proposed method or system for any application. It is imperative that the acidity is removed in order to minimize the environmental impact. However, the sustainable way will be the removal of the acid with the focus being on recovery and reutilization of the acid. Recovery of acid from acid mine drainage water will not only produce potable water for reuse, but will also recover a valuable resource. There is an ongoing study on the sustainability assessment of the recovery and utilization of acid from acid mine drainage (Nleya et al., 2015). Effects have been directed towards the recovery of sulphuric acid due to the economic and environmental benefit of this approach. The recovery of acid will be integrated with adsorption technique to remove the metals (e.g. iron, manganese, copper and etc) after the recovery of acid.

2.1.5 *Skills development*

Water engineering jobs in particular play a crucial role in finding new technology innovations for critical areas such as purifying water and maintaining existing water infrastructure that is under pressure of population growth in emerging markets such as South Africa. South Africa is looking for holistic solutions of skill gaps by starting with the educational system that is supposed to produce a sustainable stream of engineers and engineering technologists. Increased need for water engineers and technologists is also due to the growing focus on the environment due to the threat posed by climate change. The shortage of engineers is not a problem in South Africa only; it is a global shortage which has affected developed and developing economies alike.

The United States of America (USA) produces 60 000 engineering graduates a year through STEM (Science, Technology, Engineering and Mathematics) Education and Training which is a far less number of engineers need yearly, of about 200 000 engineers are needed yearly. The focus, currently, in Australia is on the water sector. The water sector has to recruit up to half of their 80 000 strong technical workforce within the next decade to replace the ageing workers. Like other countries in the world, South Africa is experiencing shortage of qualified, experience, registered engineers. South Africa is looking for solutions of shortage of engineers by starting with the educational system that is supposed to produce a sustainable stream of engineers and engineering technologists (Affairs, 2009).

Methods that have been developed for the recovery of sulphuric acid from industrial water solutions include rectification processes, membrane process, ion exchange, solvent extraction, rectification, crystallization and acid retardation process. These processes require engineering skill of distillation process, the use of membranes and adsorption techniques.

2.1.6 *Conclusions*

Currently in South African there are two reverse osmosis treatment plant for treating AMD to potable quality at full scale. The other treatment plant is the neutralization plant which is not able to produce water suitable to discharge to river systems. The amount of sludge produced from this treatment method presents a serious disposal challenges. The water qualities of different basins vary from one basin to another; hence it is not possible to recommend one single treatment method suitable for all types of mine water. Mine water can be acidic or neutral, have high or low metals content, have high or low sulphate and these characteristics determine which treatment methods are appropriate. It is possible that water quality in the mine voids will improve over time, given proper water management and a suitable treatment technology. It is imperative that the acidity is removed in order to minimize the environmental impact, however it might be more economically attractive to consider the recovery of acid from acid mine drainage. The acid recovery methods can be integrated with adsorption technique for the removal and metals and heavy metals. The required skills will be expects engineers in distillation process, the use of membranes and adsorption techniques.

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CHAPTER 3

3 Advanced oxidation process

3.1 Introduction

New techniques for wastewater decolorization have emerged with improved performance and are also environmental friendly. An example is advanced oxidation processes (AOPs) such as heterogeneous photocatalysis, Fenton, photo-Fenton and ozonation. These techniques have received attention due to their 'green' nature in that they eliminate or reduce the use or generation of hazardous substances (Navgire et al. 2012). The main challenge with the use of AOPs is production of intermediate compounds, which affect the performance of the photo reactors. Most of the technical difficulties associated with AOPs arise from the fact that oxidation processes are non-selective with the potential for significant interference (Stocking et al., 2011). One of the most widely used AOP include photocatalysis.

Among the most promising technologies for the removal of recalcitrant pollutants are the AOPs such as photolysis, ozonation, electrochemical oxidation, ultrasound irradiation (sonolysis), sub-critical wet air oxidation, homogeneous photo-Fenton oxidation and heterogeneous semiconductor photocatalysis (Klavarioti et al., 2009). The use of AOPs is advantageous in that they destroy pollutants instead of simply transferring the pollutant to a different phase (Fernández-Ibáñez et al., 1999). This eliminates the need to regenerate or dispose of sludge produced in the process of treating wastewater (Zainudin et al., 2010). Of the many AOPs, heterogeneous semiconductor photocatalysis has attracted a significant attention as a potential commercial system for the treatment of pharmaceutical wastes due to its low energy and chemical input requirements especially when powered by sunlight (Klavarioti et al., 2009).

3.2 Application of photodegradation techniques

Photodegradation is typically conducted using solar irradiation or ultraviolet (UV) lamps. The use of solar irradiation is constrained by the limitation of the intensity and reliability of the irradiation. The UV lamps can produce reliable source of irradiation, however, the main limitation associated with the use of these lamps is the energy cost. In South Africa the data on the amount of irradiation produced per year indicate that there is a potential for this technology both in South Africa and the continent of Africa in general.

3.2.1 *Photodegradation of pharmaceutical waste*

Photocatalytic degradation involves the use of a semi-conductor (photocatalyst) in the presence of a light source to degrade such complex hydrocarbon compounds into simpler organic compounds. The semiconductors that can be used as photocatalyst are TiO_2, WO, FeTiO and SrTiO. The success of photocatalysis is dependent on the toxicity of the intermediate compounds. The identity of the intermediate compound can give an insight into the mechanism of the photodegradation process. There has been an increasing interest in photocatalysis evidenced by increasing number of scientific publications in this area. Over the last few decades, the scientific and engineering interest in the application of heterogeneous photocatalysis using TiO_2 powder for the decomposition of organic hazardous materials in liquid phases has grown exponentially (Brosillon et al., 2008; Shan et al., 2010; Nawi et al., 2012).

Zeolite is a promising support material for TiO_2 photocatalyst due to its regular pores and channel sizes, and good adsorption ability. In South Africa zeolite (clinoptilolite) exists naturally and this can make the process less costly. Titanium dioxide supported on zeolite integrates the photocatalytic ability of TiO_2 with the adsorption properties of zeolite, which induces a synergistic effect, resulting in enhancement of photocatalytic efficiency (Huang et al., 2008). However, preparation of the catalyst coated support material (zeolite) should be carefully done to limit the interaction between the active sites of the material and the catalyst as this greatly affects performance of photodegradation (Durgakumari et al., 2002).

Photodegradation performs well in mineralization of toxic and biorecalcitrant organic compounds, however, it is faced with some challenges. In the first place, the major challenge of this process is high energy requirement in cases where artificial irradiation such as UV light is used. In this case, the associated cost can often be prohibitive for wastewater treatment. Another problem is encountered in the treatment of wastewater with high colour intensity such as distillery and textile industry effluent. In this case, the high colour intensity hinders the penetration of light rays thus lowering the performance of the process. It therefore means that for photocatalytic degradation to perform well in the treatment of such wastewater high dilutions are required. This again is not economical as a larger reactor volume is required. Studies of solar photodegradation requires accurate information on the solar irradiation available as this is one of the major determinants of the performance of any solar photoreactor.

3.2.2 *Monthly solar irradiation data*

Solar radiation data was collected from the month of May to November 2012. The irradiation data (Figure 18) shows an increase in irradiation from the months of June to November at VUT. This is due to the fact that VUT is located in the southern hemisphere (26.7000° S, 27.8167° E) in the South Temperate Zone where winter starts late May as the sun moves towards the northern hemisphere of the earth. By October, summer begins as the sun comes closer to VUT resulting in high radiation and longer days. The combination of high radiation intensity and longer days results in high daily radiation at VUT. Since solar photodegradation depends on the intensity of solar radiation, higher degradation is expected in the summer months than during winter. Therefore, photodegradation experiments were carried out during summer when the solar intensity was highest.

The preliminary data obtained at the VUT are significantly higher than those reported by Dekker et al. (2012) for the University of Kwazulu Natal (UKZN) and University of Stellenbosch (US). In May, for example, the irradiation was 825 MJ/m^2 for VUT, and the figures are 387 MJ/m^2 and 291 MJ/m^2 for UKZN and US, respectively (Dekker et al., 2012). This shows a logical decreasing trend in the amount of radiation with an increase in the distance from the equator, US being the furthest from the equator compared to the other two locations.

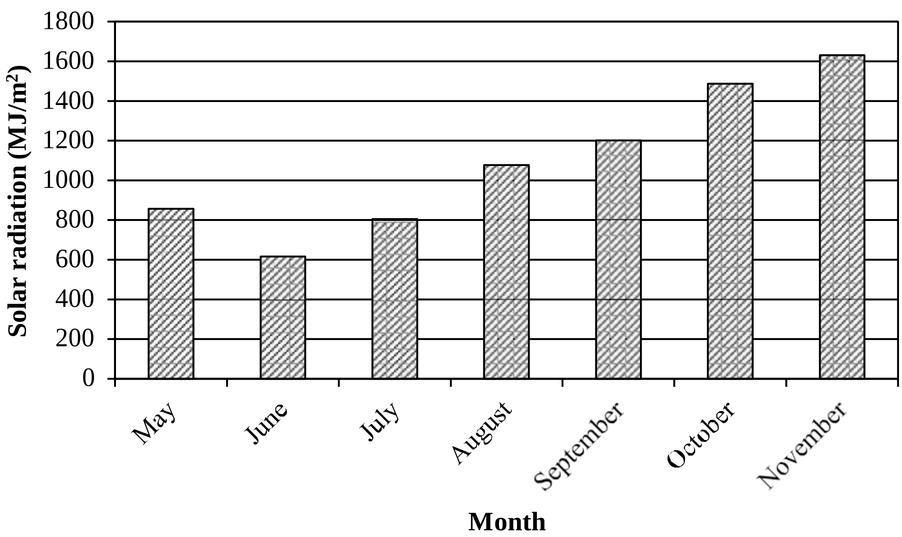

Figure 18: Monthly solar radiation for May to November 2012 at VUT

3.2.3 *Photodegradation ofemerging contaminants*

Studies were conducted using a battery of reactors (Figure 19) to investigate the solar biodegradability of recalcitrant waste such as pharmaceutical waste. The composite catalyst was then used to adsorb and photodegrade the pharmaceuticals sulfamethoxazole (SMX), diclofenac (DCF) and carbamazepine (CBZ) in a three phase fluidised bed photocatalytic reactor using sunlight to activate the TiO_2. The effect of the initial pH of the substrate solution on the adsorption and photodegradation of the substrates was determined by varying the pH of the substrate solution from 4 to 10. The results (Figure 21) show an increase in the adsorption and photodegradation of SMX with a decrease in solution pH. Results in Figure 18 show that solar irradiation is very low in winter, and there was a variation in irradiation on a daily basis and throughout the year. To address the problem of this periodic fluctuation, a high precision solar simulator unit (Figure 20) was purchased which will give consistent and reliable irradiation data.

Figure 19 Battery of solar reactors in use

Figure 20 Solar simulator, research progress.

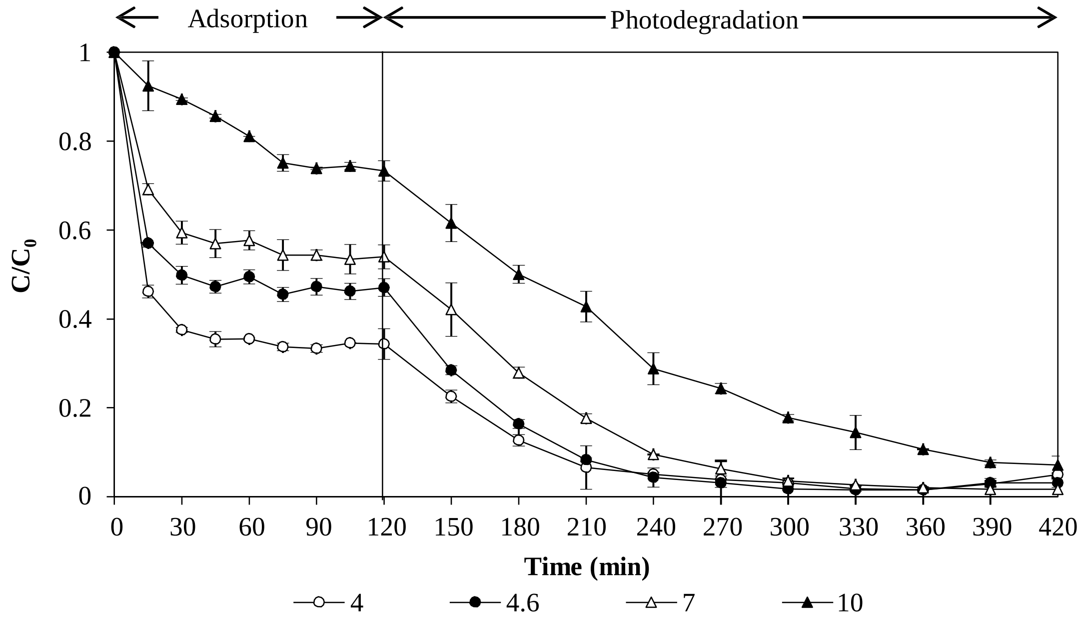

Figure 21 Photodegradation of SMX with a decrease in solution pH.

However there was some adsorption due to hydrophobic interactions of the SMX molecules and the PAC surface. Increasing the solution pH to 7 and 10 resulted in a decrease in adsorption of SMX on the PAC surface due the repulsion between the positively charged SMX molecules and the positively charged surface of the PAC. This repulsion reduced the adsorption due to hydrophobic interactions since the SMX molecules were repelled from the surface of the PAC.

3.3 Conclusion

Pharmaceutical pollutants in wastewater have become an increasing concern in recent years. Adsorption and photocatalytic degradation of pharmaceutical pollutants have proved to be very efficient in the removal of pharmaceutical contaminants. The results show that an increase in the adsorption and photodegradation of SMX with a decrease in solution pH. These results show that the use of the synthesised composite catalyst in the fluidised bed reactor provided a stable and efficient system capable of long term use. The results from this work also show that this system can be used for the removal of pharmaceutical substrates at low concentrations. Fluidized bed reactors have been applied in many counties including China and the USA but very little has been reported on its application in South Africa. It is therefore recommended that efforts should be made to explore the feasibility of applying this technology in this country.

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CHAPTER 4

4 Emerging challenges

4.1 Introduction

In recent days, the emerging challenges with regard to wastewater treatment include emerging biorecalcitrant compounds and increasing volumes of pollutants getting into municipal wastewater treatment plants. Further, the high cost of reducing or removing toxic compounds in wastewater is the main problem encountered by many industries and municipalities in their efforts to treat wastewater. Treatment of wastewater is an industrial cost component that many industries would be happy to avoid since it requires energy but may not generate capital. In particular, for industries that produce effluents that are not easily biodegradable, aerobic biodegradation which is a relatively expensive biological process is the typical method to use. In this process, aeration accounts for 55% of the process energy requirement (Essam et al., 2007).

From local government perspective, most of the municipal water technologists and an engineers are not adequately equipped with skills required to implement new techniques, which these technical staff working in the local government may not have had any prior training. Efforts to address these challenges, which include both emerging contaminant and the corresponding technologies, inevitable require skill development.

4.2 Emerging contaminants

Emerging pollutants have only become an issue in recent years with the development of better analytical techniques that are capable of detecting chemicals at low concentrations of up to ng/L level. The environmental toxicity of emerging pollutants to humans and wildlife is still not well understood. For this reason, most countries currently have little or no relevant legislation regulating the release of these contaminants into surface water. However, widespread production, use and continuous input into the environment, their persistence in the environment, bioaccumulation and potential chronic toxicity to aquatic biota even at low concentrations have raised concerns over emerging contaminants in recent years (Houtman, 2010). With increasing research on the effects of emerging contaminants on the environment, these wastes are expected to be under regulation soon (Malato et al., 2009). Therefore there is a need to develop appropriate methods for treating emerging contaminants to be used when regulation starts. The main emerging contaminants are associated with pharmaceuticals, textile and mineral processing.

4.2.1 *Textile industry wastewater*

The textile industry is considered as one of the largest water consumers in the world (Wouter et al., 1998). Ramigi and Buckely (2006) reported that in the current environmental legislation, textile industries have been labelled as high priority industry with respect to pollution and with specific regard to toxicity caused by recalcitrant wastes, high salt and heavy metals in their effluent. Wastewater which contains various pollutants is generated during various stages of the textile manufacturing process. Specifically, the major sources of wastewater generated by the textile industry originate from the washing (scouring) and bleaching of natural fibres and from dyeing and finishing steps (Chen et al., 2008). Robert & Sanjeev (2005), reported that out of more than one million tons of dyes produced, about 280,000 tons are annually discharged as effluent worldwide.

4.2.2 *Emerging pharmaceutical contaminants*

Emerging environmental contaminants are mainly organic micropollutants produced by human activities such as pharmaceutical and personal care products (PPCPs), Endocrine Disrupting Compounds (EDCs), illicit drugs, sweeteners, nanoparticles, flame retardants, perfluorinated compounds, organic solvents, complexing agents, plasticizers, pesticides and surfactants detected in trace amounts of several ng/L up to low µg/L in wastewater treatment effluents and water sources (Houtman, 2010). From domestic, agricultural and industrial sources, these emerging contaminants enter wastewater treatment plants (WWTPs) where their removal is usually incomplete mainly due to their biorecalcitrant nature. Wastewater treatment facilities have therefore been identified as the main pathway through which emerging contaminants enter surface and ground water (Baeza and Knappe, 2011).

Pharmaceutical products form a class of emerging pollutants which include human and veterinary medicines and their metabolites. To achieve their function, pharmaceutical drugs are designed to persist in the body in the form in which they were ingested and are often only slightly altered before excretion in urine and faeces (Fent et al., 2006). These drugs and their metabolites, once excreted, maintain their persistence in the environment, resisting degradation in WWTPs and surface waters. As a result, residues of pharmaceutical drugs have been ubiquitously detected in treated waters and surface waters in North America, Europe and Asia (Monteiro and Boxall, 2010).

4.2.3 *Acid mine drainage treatment using adsorption method*

Over the last few decades there has been an increasing public awareness of the potential environmental hazards arising from mining activities, in particular acid mine drainage (AMD). Although any mineral deposit which contains sulphide is a potential source of AMD, certain types of mining are more prone than others. There are records of acid drainage where coal, pyritic sulphur, copper, zinc, silver and lead among others have been mined. Acid mine drainage affects lotic systems in numerous and interactive ways. This results in multiple pressures, both direct and indirect, on the organisms comprising the community structure of the ecosystem. These effects can be loosely categorized as chemical, physical, biological and ecological, although the overall impact on the community structure is the elimination of species, simplifying the food chain and so significantly reducing ecological stability.

The impact of acid mine drainage on water quality in South African relates to gold and coal minings. Gold tailings dumps have been a feature of the landscape around the large gold mining towns since mining began and have been discharging polluted water for decades. The effect of this so-called diffuse pollution has been particularly pronounced in the case of the Blesbokspruit in Springs and the Klip River (which drains the southern portion of the Witwatersrand escarpment) because tailings dumps abound in their upper catchments. The effect of the diffuse and point source pollution arising from gold mines of the Central and Western basins is well illustrated by the salinity of the Vaal River, which more than doubles between the Vaal Dam and the Barrage as a result of the inflow of water from the Klip River and the Blesbokspruit (via the Suikerbos River). The low quality of water at the Barrage necessitates the periodic release of water from the Vaal Dam to reduce the salinity for the downstream Vaal River users. According to the inter-ministerial document of 2010, the Western, Central and Eastern Basins are identified as priority areas requiring immediate action because of the lack of adequate measures to manage and control the problems related to AMD, the urgency of implementing intervention measures before problems become more critical and their proximity to densely populated areas. The situation in other mining regions of the country requires additional information, monitoring and assessments of risk, particularly in vulnerable areas such as the Mpumalanga Coal Fields, where the impact of mining on the freshwater sources in the upper reaches of the Vaal and Olifants River Systems is of serious concern.

A number of approaches have been proposed to control and manage AMD. These include: decant prevention and management, ingress control — reduction of the rate of flooding and the eventual decant volume and water quality management. The latter approach proposes the use of active, passive and in-situ treatment technologies that are tailored designed for specific AMD since water quality of AMD varies from one source to another. Treatment technologies are very expensive and require a thorough appraisal before adoption. Because of the stringent nature of environmental regulations, advanced potential technologies such as adsorption and membrane technologies are being explored.

4.2.4 *Other emerging pollutants in wastewater and sewage treatment plants*

The wastewater treatment plants were solely meant for the treatment of domestic sewage and grey water. However, industries emerged overtime and depending on their scales of operations some discharged their wastewater directly in the municipal line with only primary treatment. This broad about extra burden in terms of the infrastructure capacity, for instance almost all abattoir on the immediate periphery of towns discharge their wastewater directly in to the municipal line. The challenge is further intensified by the apparent lack of bylaws say for instance in Free State as compared to Gauteng. Table 7 and Table 8 show typical emerging contaminants at the municipal wastewater treatment plants per industry.

Table 7 Industries and their potential pollutants (Kesi, 2016)

Industry	**Inorganic pollutants**
Gas and coke and chem. Manufacture	Ammonia
Sheep dipping	Arsenic
Plating	Cadmium
Plating, chrome tanning, alum anodizing	Chromium
Copper plating, copper pickling	Copper
Gas manufacture, plating, metal cleaning	Cyanides
Scrubbing of flue gases, glass etching	Fluorides
Laundries, paper mills, textile bleaching	Free chlorine
Plating	Nickel
Textile industry, tanneries, gas manufacture.	Sulfides
Tanning, sawmills	Sulfites
Fertilizer industry, steel works	Mercury

Cyanides, sulfides and ammonia are among the relatively new contaminants to the municipal wastewater treatment plants in Emfuleni local municipality. The Emfuleni Local municipality in Gauteng took that aspect into consideration and enlisted the services of Rand Water to monitor the emerging contaminants. Industrial inspection is done by Rand Water on behalf of the municipality. Samples are taken randomly on a monthly basis. For instance, at the abattoirs they analyse for fats and oil. Table 3 highlights industries in Emfuleni and Metsimaholo local municipalities.

Table 8 Industries and pollutants (organic) (Kesi, 2016)

Industry	Organic pollutant
Acetate rayon, beet root manufacture	Acetic acid
Soft drinks and citrus fruit processing	Citric acid
Wool scouring, laundries, textile industry	Fats, oils, grease
Synthetic resins and penicillin manufacture.	Formaldehyde
Petrochemical and rubber factories	Hydrocarbons
Oil refining, pulp mills	Mercaptans
Explosives and chemical works	Nitrocompounds
Distilleries and fermentation plants	Organic acids
Gas and coke manufacture, chem. plants	Phenols
Food processing, textile industries	Starch
Dairies, breweries, sweet industry	Sugars
Dyeing, wine,$ leather, chem. manufacture	Tartaric acid
Cosmatatics industry	Synthetic estrogens

The management of wastewater from the above mentioned industries is regulated by water use license. But where the industry is using municipal sewer line, some of these pollutants may go unnoticed since they are not analysed.

4.3 Emerging treatment technologies

A single wastewater treatment unit can hardly remove complex contaminants encountered in the present day wastes generated by industries and domestics. Consequently, the construction of centralized sewage treatment plants began in the late 19th and early 20th centuries, principally in the United Kingdom and the United States. Instead of discharging sewage directly into a nearby body of water, it was first passed through a combination of physical, biological, and chemical processes that removed some or most of the pollutants. Also beginning in the 1900s, new sewage-collection systems were designed to separate storm water from domestic wastewater, so that treatment plants did not become overloaded during periods of wet weather. After the middle of the

20th century, increasing public concern for environmental quality led to broader and more stringent regulation of wastewater disposal practices. Higher levels of treatment were required. For example, pre-treatment of industrial wastewater, with the aim of preventing toxic chemicals from interfering with the biological processes used at sewage treatment plants, often became a necessity. In fact, wastewater treatment technology advanced (ion exchange, advanced oxidation processes, adsorption, and membrane technologies, among others) through use to the point where it became possible to remove virtually all pollutants from sewage. This was very costly, however, such high levels of treatment were not usually justified.

4.3.1 *Integrated adsorption and photodegradation*

In adsorption, the pollutants in the wastewater accumulate on the surface of a solid (adsorbent) as a result of intermolecular attractions. Adsorbents are some of the best support materials for TiO_2 powder due to their capacity to adsorb and therefore concentrate reactants near the TiO_2 attached onto their surfaces. This concentration of reactants near the TiO_2 is especially advantageous when dealing with reactants at very low concentrations (Augugliaro et al., 2006). Since both the initial pollutant and degradation products are to be photodegraded, the adsorbent support would need to have a high affinity for a wide range of pollutants. As hydroxyl radicals produced by TiO_2 are very reactive, the adsorbent combined with TiO_2 must be inert to these radicals. If the adsorbent is not inert, its structure would be broken down and it will also compete with the pollutants for the hydroxyl radicals thus reducing the rate of the photocatalysis reaction.

The AC has been widely applied for the adsorption of a wide range of organic pollutants in wastewater and air. The major drawback of using AC for adsorption has been the fact that commercial AC is relatively costly as compared to other adsorbents. Two modes of AC regeneration using photocatalysis have been investigated: desorption of the pollutants from the AC followed by pollutant photodegradation and combination of the AC and TiO_2 in which the TiO_2 photodegrades the pollutants adsorbed on the AC (Sheintuch and Matatov-Meytal, 1999). The former method suffers from long regeneration cycles due to the slow rate of desorption of the pollutants from the AC. The combined AC and TiO_2 system is advantageous due to the short diffusion paths of the pollutants from the AC to the TiO_2 which increases the rate of regeneration.

4.3.2 *Integrated photodegradation, adsorption and biodegradation (IPB)*

Integration of the photodegradation and anaerobic digestion seems to have a high potential in the treatment of wastewater streams containing recalcitrant organic compounds. However, as much as the photocatalytic pre-treatment can lead to increased biodegradability of some recalcitrant organic contaminants, it can also produce some more toxic products which can be more difficult to biodegrade. It is therefore very important to determine whether the photodegradation should be conducted before the anaerobic degradation, or to be employed to finally polish the anaerobically treated wastewater, in order to get rid of the biorecalcitrant component of the wastewater in question. This choice, however, depends on the type of wastewater to be treated. Improvement of the integrated photodegradation/biodegradation system can be achieved by using a porous adsorbent as a support material for microbes and the photocatalyst.

It is a fact that photodegradation of organic pollutants is a competitive technique for wastewater treatment for the removal of those organic pollutants that are not easily treatable using biological methods due to their high chemical stability, high toxicity and/or low biodegradability. Although photodegradation for complete mineralisation can be expensive, its combination with biological treatment is reported to reduce operating cost (Oller et al., 2011). On the one hand, such a system can lead to an increase in methane yield if photodegradation is preceded by biodegradation. On the other hand, employing photodegradation as a post-treatment for an anaerobic degradation system may lead to thorough removal of traces of organic contaminants which might need long biodegradation time.

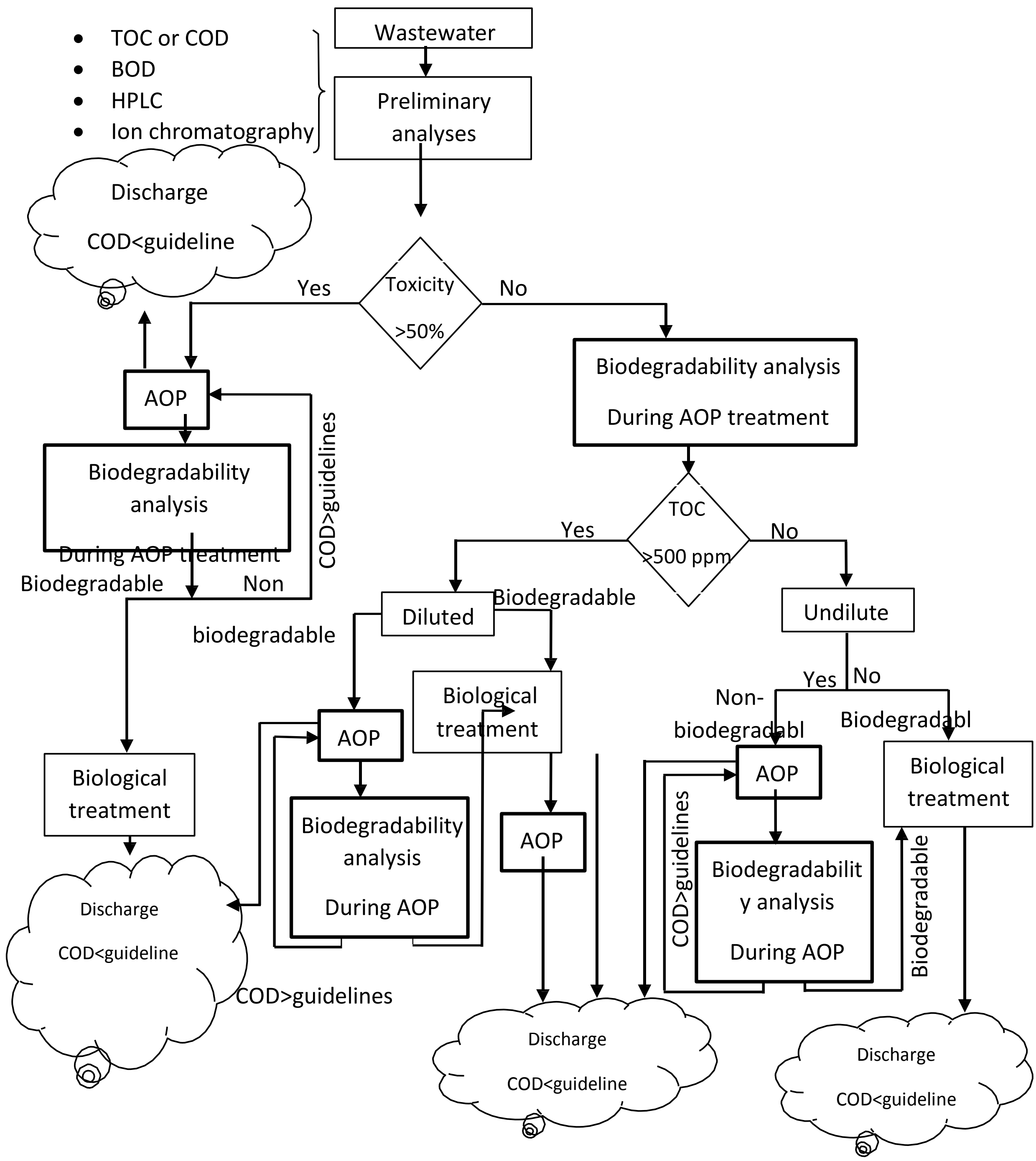

Figure 22: Integrated biological and photodegradation, adopted from Oller et al. (2009)

(a) Efficiency of the integrated biological and photochemical process

The photodegradation (AOP) and AD processes were integrated in two ways; in the first case, AD was performed before the AOP (AD-AOP) while in the second case the AOP was conducted before the AD (AOP-AD). In Figure 23, the results for colour and COD reduction are shown. In the first place, results for AD system as a single treatment process is shown, the effluent from the AD system was then fed into the AOP system and the additional pollutant removal was recorded. The sum of removal by AD and AOP is then presented as the overall removal by the AD-AOP system. Removal by the AD-AOP system is then compared with that of the AOP-AD system. In both cases AD was conducted for a period of 28 days while AOP was carried out for 60 minutes since this was the optimum irradiation time.

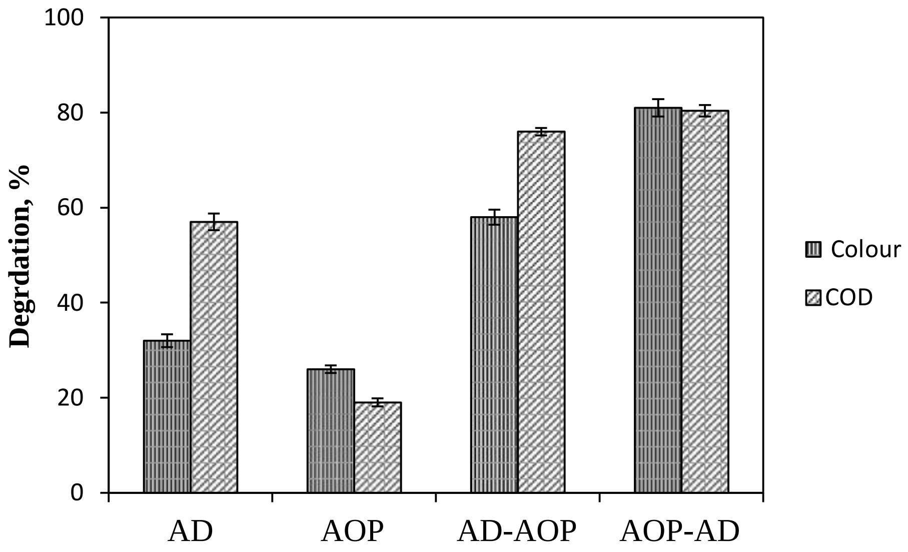

Figure 23: Overall COD reduction for the integrated system

Figure 23: Overall COD reduction for the integrated system shows that AD treatment alone achieved colour removal of 32% and COD reduction of 57%. For the integrated process in which the AOP was followed by the AD process (AOP-AD) an improved colour removal of 81% and a COD removal of 73% was achieved. It can therefore be deduced that photodegradation pre-treatment of MB converted the MB molecules into a form that could easily be degraded by the consortia of microbes in the bioreactor. Also, the good COD reduction efficiency of the AD-AOP (76%) can be attributed to the fact that the initial AD step reduced the colour of the sample and this reduced light attenuation in the subsequent AOP unit.

(b) Energy consumption

If UV photodegradation (AOP) was employed as the only treatment method to reduce colour and COD to above 75% as was achieved by the integrated AOP-AD system, then higher energy would be required to drive the process. It required irradiation time of 120 minutes to achieve colour and COD reduction of about 75% using 15 W UV lamp and this consumed 108 kJ of energy. However, in the AOP-AD integrated system an overall COD and colour removal of above 80% was achieved with shorter irradiation time of 60 minutes and this consumed 54 kJ. Therefore, the AOP-AD integration consumed 50% less energy to achieve same pollutant removal than if AOP was applied as a stand-alone process. Moreover, considering that the energy content of methane is about 38

MJ/m^3, the energy produced by the AD process was about 3.06 kJ and this can further reduce the energy consumption of the integrated AOP-AD system. However, it is important to note that energy consumed by the pumps and other units was not considered in these calculations.

4.4 Conclusion

Anaerobic up-flow fixed bed reactor and annular photocatalytic reactor were used to study the efficiency of integrated anaerobic digestion (AD) and ultraviolet (UV) photodegradation of real distillery effluent, raw molasses wastewater (MWW) and methylene blue textile dye. It was found that UV photodegradation as a stand-alone technique achieved colour removal of 54% and 69% for the distillery and MWW, respectively, with a COD reduction of < 20% and a negligible BOD reduction. On the other hand, AD as a single treatment technique was found to be effective in COD and BOD reduction with efficiencies of above 75% and 85%, respectively, for both wastewater streams. However, the AD achieved low colour removal efficiency, with an increase in colour intensity of 13% recorded when treating MWW while a colour removal of 51% was achieved for the distillery effluent. The application of UV photodegradation as a pre-treatment method to the AD process reduced the COD removal and biogas production efficiency. However, an integration in which UV photodegradation was employed as a post-treatment to the AD process achieved high COD removal of above 85% for MWW and distillery wastewater samples, and colour removal of 88% for the distillery effluent. Thus, photodegradation can be employed as a post-treatment technique to an AD system treating distillery effluent for complete removal of the biorecalcitrant and colour imparting compounds.

For the textile dye, it was found that anaerobic degradation performed better in COD reduction than in colour reduction, achieving 57% and 32% reduction, respectively. In contrast, photodegradation performed better than the AD in colour reduction achieving 70% efficiency but achieved a lower COD reduction of 54%. The efficiency of the two processes applied separately in the degradation of MB dye was generally low. However, integrated AOP-AD system achieved better degradation with colour and COD reductions of 81% and 80%, respectively. Moreover, it was found that UV photodegradation pretreatment improved the biodegradability of the MB dye by 3- folds after irradiation time of 60 minutes. Thus integration of the two processes in such a way that UV photodegradation precedes the AD process led to higher biogas production than that of the stand-alone AD process.

All the results reported up to this stage are from batch processes. Batch operation of reactors is important for validation of technology and optimisation of basic operating parameters. However, batch reactors are not efficient and cost effective and are therefore seldom used where continuous reactors can be employed. The use of batch systems for photocatalysis has been extensively studied. However, there is very little data on the use of continuous reactors for photocatalysis.

Bioenergy is a field that a lot of research efforts need to be focussed in response to the increasing energy demands. In this regard, process optimization and catalyst development are research areas that are attracting a lot of attention. In this context, literature shows that there is an increasing application of computational fluid dynamic simulation technique and photocatalysts to biological systems. This technique will provide more insight into the hydrodynamics and kinetics of biological processes and the photocatalyst will improve bioenergy production and yield.

Projection

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CHAPTER 5

5 Water re-use

5.1 Introduction

Recent trends have focused on looking at the connections that exist between water and energy in industries for sustainable operation. Global shortages of energy and water have rendered comprehensive approaches to water and energy optimization even more important than ever before, hence the work presented in this report.

Process industries have recently committed and allocated resources to mitigating the detrimental impact on the environment due to their activities. They have made significant progress, in conserving resources, and reducing the intensity of energy usage. These efforts have gradually shifted from a unit-based approach to a systems-level paradigm. Process integration is a holistic approach to process design and operation which emphasizes the unity of the process. Process integration design tools have been developed over the past two decades to attain process improvement, productivity enhancement, conservation in mass and energy resources, and reductions in the operating and capital costs of chemical processes. This technique has been successfully applied in many industries world-wide and particularly in Europe and USA. In the case of USA processing industries, the amount of reuse and recycle of wastewater has been tremendous - gross water use to water intake ratios exceed 7.5 in petroleum refining and 3 in chemical production. The gross water is the amount of water that would have to be used if there was no reuse and recycle.

5.1.1 *Water-energy nexus concept*

Whilst the concept of water-energy nexus is inherent in most systems, it has been ignored for many years, thereby leading to missed opportunities. In the past, energy and water systems have been developed and managed independently. Water plays a critical role in the generation of electricity and energy is required to treat and distribute water. This has been true for many decades, but the water and energy systems have investigated and developed independently.

Recently, process integration techniques have been applied in a South African main power plant with the objective of reducing the water intake. This objective can be achieved by identifying water sources (providers) and sinks (users) in the water network, followed by matching appropriate sources and sinks as water quality allows. The water network, therefore, first has to be compiled and flow and quality data can subsequently be allocated to process units in the network. The process integration tool showed savings of between 4% and 13% of the water intake by changing the way water is currently utilized and reused at the station. Management of the cooling cycle, and especially blowdown water, together with related procedures have a significant impact on the amount of freshwater intake and are responsible for the bulk of the possible savings identified by the work since most of water used at the station is supplied to the cooling towers. Optimization of water utilization in the power station has a direct impact on the amount of waste produced, which translates into at least 50% (or more) reduction in wastewater management costs. This is mainly due to savings in freshwater consumption.

5.1.2 *Background on water-energy nexus*

Water plays a critical role in the generation of electricity and energy is required to treat and distribute water. This has been true for many decades, but the water and energy systems have been investigated and developed independently. Recent trends have focused on looking at the connections that exist between water and energy in industries for sustainable operation. The water-energy nexus has recently become more important since water resources are also becoming scarce. For instance, drought in the United States recently resulted in limited availability of water affecting operation of some power plants and other energy production activities. The recent unconventional oil and gas production using hydraulic fracturing, so called fracking, has also showed the strong interdependence between water and energy resources. Climate change, population growth and uplifting people from poverty mainly require managing water and energy in an integrated manner. Policies addressing water rights and water impacts of energy further bring incentives to study the water-energy nexus.

These trends may present challenges, but they also present opportunities. They can result in strategic approaches for technology research and development (R&D) to address regional water-energy issues and also have impact at the national and global scale. Enhancing and integrating data and models will better inform researchers, decision makers and the public. **Figure 24 s**hows the macro scale water-energy flow in the United States on a national scale, where water is used for producing energy and energy is used to treat and distribute water for human use. Thermoelectric power generation withdraws approximately 40% of freshwater for cooling and dissipates significant quantity of energy due to inefficiencies in converting thermal energy to electricity. Agriculture competes directly with the energy sector for water resources. However, agriculture also contributes to the energy sector via production of biofuels. These clearly signify the clear connection between energy and water. Future technologies for carbon capture and sequestration could further increase the water intensity of most energy systems, whereas the use renewable energy sources, such as solar and wind can lower it.

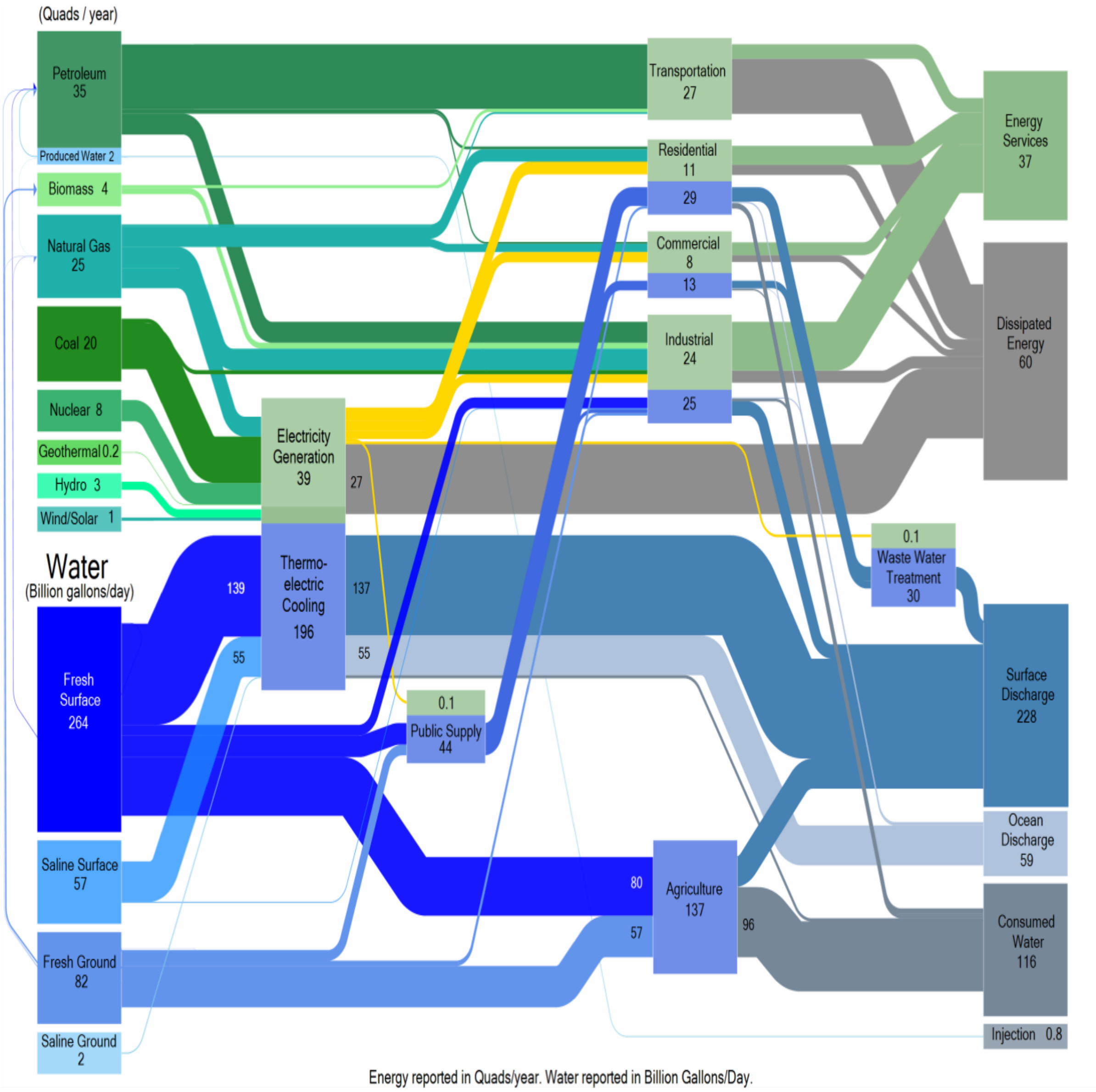


Figure 24 Hybrid diagram of 2011 US interconnected water and energy flows

Source: US Energy Information Administration (EIA) 2011 Annual Energy Review (AER) report.

5.1.3 *Process integration*

The major consumers of water in the process industries in South Africa are chemical, petrochemical, textile, paper, cellulose, food and beverage industries, as well as power plants. As water resources are becoming scarcer, these industries are under increasing pressure to minimize water consumption. Water minimization initiatives are also driven by strict environmental regulations, rising public awareness and increase in the cost of freshwater and effluent treatment. It is also worth mentioning that the South African agricultural sector consumes more than 60% of water. However, a larger part of this water is recovered through boreholes, thereby rendering this sector almost self-sufficient.

Pollution of global water bodies is becoming an international concern due to its noticeable effect on human health. Processing industries are at the forefront when it comes to water pollution since they produce hazardous waste. Industrial facilities require large quantities of freshwater and thus produce considerable amounts of wastewater. The traditional method of water pollution control in industry is the use of end-of pipe (centralized) treatments, where all effluent streams are combined and sent to a common treatment system. However, this approach tends to increase the treatment cost and results in a higher capital cost to build the treatment facility. The current trend is to reduce freshwater consumption and wastewater generation within the chemical process, which can be achieved by using process integration.

Process integration is a systematic and general method for designing integrated production systems, ranging from individual processes to total sites, with special emphasis on the efficient use of energy and reducing environmental effects. The first trend of process integration emerged as pinch analysis (PA), which was developed in the 1970s/1980s based on the discovery of a heat recovery pinch. The main motivation was to give solution to the process industries to reduce their energy requirements due to the energy crises the world faced during the well-known energy embargo of the seventies... Based on the analogy of heat and mass transfer, the second trend, i.e. mass integration was then established in late 1980s for the synthesis of mass exchange network (MEN), and many other pollution prevention practices (El-Halwagi, 1997). The most important special case of mass integration that received good attention from both academic and industrial practitioners is water minimization. Process integration technique for water minimization is initiated by identifying water sources (providers) and sinks (users) in the water network, followed by matching appropriate sources and sinks as water quality allows. This implies that the water network has to be confirmed a priori, with flow and quality data subsequently allocated to process units in the network.

In the context of water minimization, process integration could be described as a systematic technique used to analyze, synthesize, design and optimize a water network system for reducing freshwater consumption and minimize wastewater generation. Typical steps involved in any industry related to freshwater and wastewater minimization include:

a) Identification of sources, sinks and characteristics of wastewater

b) Volume and strength reduction of wastewater at the source

c) Segregation of wastewater sources

d) Reuse of wastewater within the process where feasible

e) Final disposal

In the first step, sources of wastewater are identified and the nature of contaminants determined. This is followed by volume and strength reduction of wastewater. The reduction at the source can be achieved through reduction of water use, changes in operational procedures, reformulation of products, modification of equipment and purification of raw materials. In most cases there will be some effluent generated even after applying volume and strength reduction. This wastewater has to be segregated depending on the characteristics of the individual waste streams. The next step is to investigate the reuse options for each of the individual waste streams after a certain level of treatment. Finally, if the reuse option is not feasible for any of the streams, they must be disposed of suitably after appropriate treatment.

The reuse option of wastewater inside the plant can be achieved via the following techniques.

Reuse: reuse of wastewater directly in another operation or process as shown in Figure 25.

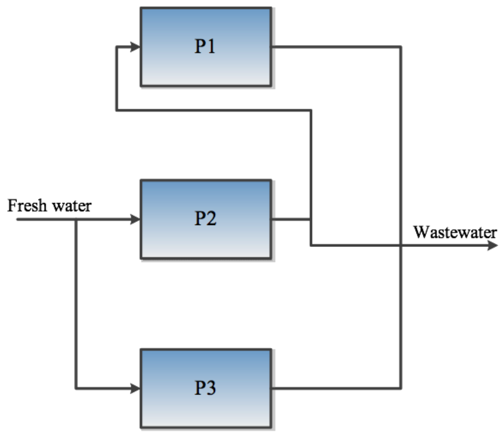


Figure 25 Reuse of water from one process to another

Reuse with regeneration: total or partial removal of contaminants, so called regeneration, from the wastewater to reuse this stream in another operation or process as shown in Figure 26. A regenerator is a piece of equipment that removes contaminants from an effluent stream. Membrane processes, in particular, have proven to be technology of choice for regeneration.

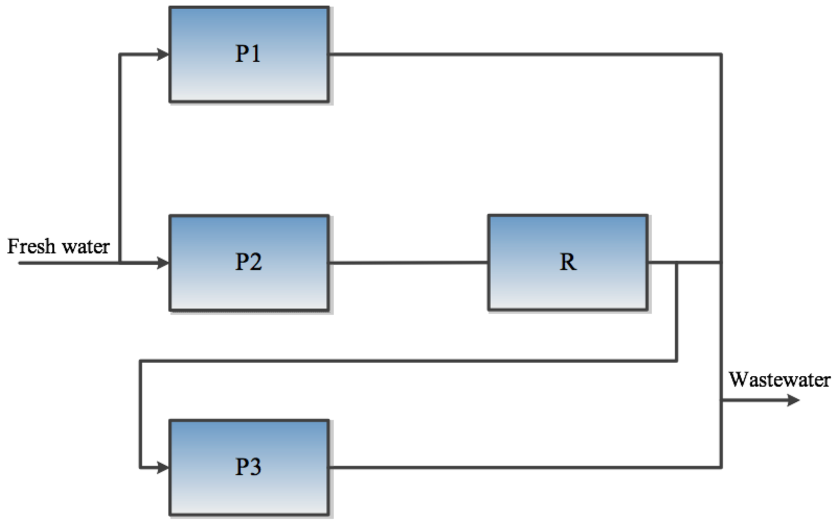


Figure 26. Reuse with regeneration

Recycling with regeneration: total or partial removal of contaminants (regeneration) from wastewater to reuse it in the same operation or process where it was produced as shown in Figure 27.

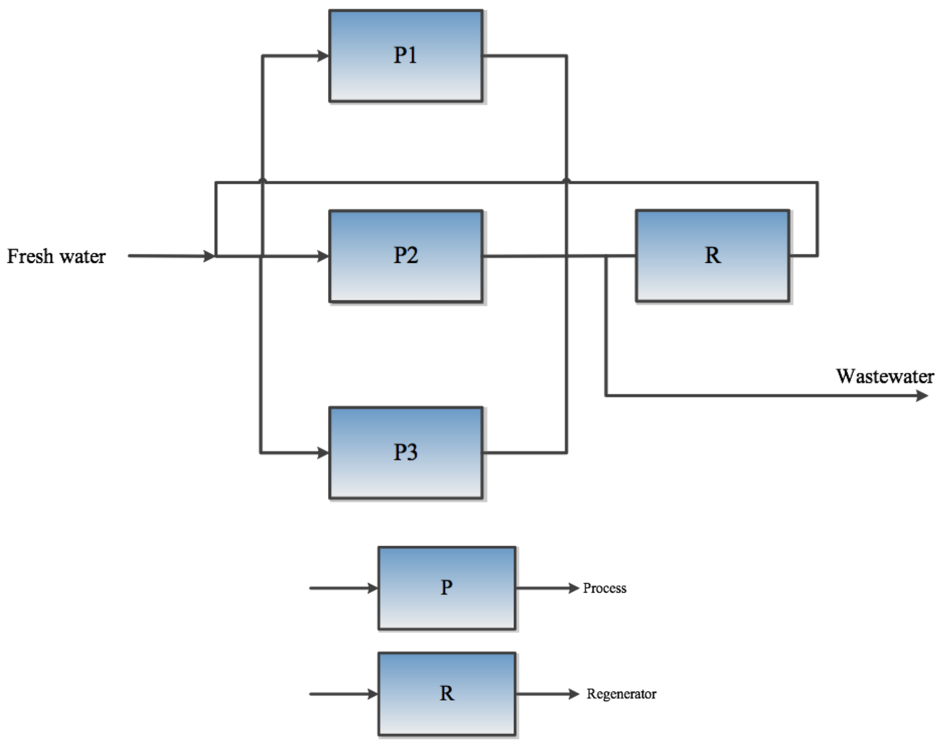


Figure 27 Recycling with regeneration

The application of the techniques described above has the benefit of reduction in the final wastewater flowrate, reduction in cost of wastewater disposal and reduction in freshwater use. All operational practices whose objective is to minimize the generation of effluent require a change in the way in which the process is approached. In industry, the greatest incentives for this change are a reduction in the costs associated with the disposal of effluent discharge, tax incentives associated with gains in the sustainability of the process and an improvement in the image of the company.

5.1.4 *Examples of industrial applications of process integration tools*

Over the past decade, process integration tools have been applied in different processing industries to improve process performance via water conservation and pollution prevention at various industrial sites across the globe. As aforementioned, this technique has been successfully applied in many industries world-wide and particularly in Europe and USA. Table 9 is a snapshot summary of the positive results achieved through some of these projects in USA and South Africa.

Table 9 . Industrial application of process integration tools

Industrial process	Motivation	Results	Country
Kraft pulping process	High usage of water and uildup of non-process elements upon recycle	55% reduction in water usage with a payback period of less than two years	USA
Polymer process	Future expansion wastewater discharge system expected to exceed its maximum capacity during the production process expansion	30% reduction in site wastewater discharge nd with a payback period of less than one year	USA
Pharmaceutical process	Opportunity exist to recover products from wastewater	30% product recovery 20%wastewater reduction	SA
Power station	High usage of water and company strategy to reduce wastewater	13% wastewater reduction, with cost savings of more than US$500k in the first six months	SA

5.1.5 *Case study: Water management through process integration in a coal fired Power Station*

Water is used in coal fired power stations for different kind of processes such as process cooling in the condenser, ash disposal, removal of heat generated in plant auxiliaries, and various other plant consumptive uses. For power plants located on main land, the raw water is generally drawn from freshwater sources such as river, lake, canal, reservoir, and barrage. Treated sewage water may also be used as source of raw water for the power plants located adjacent to the cities. For power plants located in coastal areas, water for cooling of condenser and auxiliaries is drawn from the sea or creek which provides for water requirement of the wet ash handling system also. The requirement of water for other plant consumptive uses is met from an alternative source or by installing desalination plant.

A typical list of plant systems/applications requiring consumptive water is:

a) Cooling water system for condenser & plant auxiliaries

b) Ash handling system

c) Power cycle make-up

d) Equipment cooling system

e) Air conditioning and ventilation system

f) Coal dust suppression system

g) Service water system

h) Potable water system

i) Gardening

j) Evaporation from raw water reservoir

The details on water using and water producing operations are given below. Minimizing plant water requirements needs actions such as rational use of water in each processes, regeneration of deteriorated quality water, directly using wastewater in another process that requires low grade water and recycle and reuse of wastewater streams.

(a) Cooling water system

Cooling water is used to condense the exhaust steam leaving from turbine, secondary cooling in heat exchangers for cooling equipment, and other plant auxiliaries. 60,000 m^3/h of water is circulated in a condenser to cool the exhaust steam in typical 500 MW power generating facility. The temperature rise across the condenser is about 10^0C. A once through type or closed cycle type of cooling system can be employed. Once through types of cooling systems are mostly used in coastal regions with a restriction of the discharge temperature of the hot water not more 7^0C above the temperature of receiving water body. In case of once through systems, the additional evaporation from the surface of the water body to dissipate the imposed heat load by the power station amounts to about 1% of the circulating water flowrate. On the other hand, closed cycle systems involve a cooling tower where 1.5-1.7% of the water circulated in the condenser is lost through evaporation. Drift loss amounts to typically 0.05% of the cooling/circulating water flow. Make-up water is needed in case of closed cycle systems, to compensate for loss of water on account of evaporation, drift and blowdown. The latter is necessary to maintain a desired level of dissolved solids in the circulating water. The requirement of make-up water (M) to be supplied, and blowdown water (B) to be discharged, are dependent on cycles of concentration (C) of the circulating water system as indicated below:

$$B = \frac{E}{C-1} - D \quad \text{and} \tag{1}$$

$$M = E\frac{C}{C-1} \tag{2}$$

where, *E* is evaporation from cooling tower, *D* is drift loss to the atmosphere, and *C* is the cycles of concentration of the circulating water system. The permissible cycles of concentration which can be maintained in the circulating water system is dependent on quality of cooling tower make-up and scheme of cooling water treatment adopted. The blowdown water from the cooling tower can be used for disposal of bottom ash, and unutilized blowdown, if any, is led to central monitoring basin (CMB) of the plant for further utilization/ treatment/ disposal outside the plant boundary. The quantum of blowdown water can be further reduced by increasing the cycles of concentration which can be achieved by suitably improving the chemical regime of circulating water, if feasible.

(b) Ash handling system

For a typical 500 MW power plant with a 40% ash content coal results in generation of about 140 ton/h ash. This ash is made up of fly ash and bottom ash with a ratio of 80:20 respectively. Most of the time water is used to dispose of the ash as a wet slurry and sent to ash ponds. Due to environmental concerns, thermal power plants are looking at options to minimize water requirements in wet ash disposal for bottom ash and dry disposal for fly ash. The reduction of consumptive water requirement includes reducing water to ash ratio for slurry disposal, recirculation of ash pond water and use of high concentration slurry disposal (HCSD) system for fly ash. Currently most power plants are characterized by slurry concentration of 30% for fly ash and 25% for bottom ash. In some power plants the use of recirculated ash pond water has resulted in a reduction of water requirement of ash handling by 30%. The HCSD system for handling fly ash demands positive displacement pumps, since the concentration of solids by weight is more than 60%, as compared to lean slurry transportation which is about 25 – 30% concentration. Currently there are technologies that can be used to transport fly ash without the use of water. However, bottom ash has to be disposed in wet/semi-wet form since proven technology for dry evacuation of bottom ash is not available for large size plants. Cooling tower blowdown can be a good source for transporting and disposal of ash. For power plants that use ash water recirculation system, about 70% of ash water is expected to be recovered and available for reuse. Under these conditions cooling tower blowdown would be sufficient as a make-up water for the ash handling system. Consequently, the use of raw water for the ash handling system is completely avoided. If HCSD system is used instead of wet slurry system for disposal of fly ash, available cooling tower blowdown would suffice to meet water requirements of HCSD system and no additional water would be required from raw water source.

(c) Power cycle make- up

Power cycle make-up refers to demineralized (demin) water added in condenser hotwell to compensate for loss of water due to boiler blowdown and other losses from the system. The quantum of blowdown water depends on boiler steam parameters and quality of make-up demin water. In the past, the demin water make-up requirement of power cycle has been amply considered even up to the order of 8% of boiler maximum continuous rating (BMCR) flow. Over a period of time, this requirement has been reducing, and now a days, design power cycle make-up is generally taken as 3% of boiler maximum continuous rating (BMCR) flow. Accordingly, power cycle make-up requirement for a typical 500 MW unit shall be about 50 m^3/h. In practice, plants are being managed with further reduced make-up, as large size units are provided with condensate polishing units (CPU) and materials of better metallurgy used in feed heating and boiler components. In the present study, power cycle make has been considered as 2% of BMCR flow.

(d) Coal dust suppression

Water is usually sprayed over heaps of crushed coal, belt conveyors, and transfer points and during coal unloading in order to reduce the negative environmental impact of fugitive dust emissions. The amount of water required for coal dust suppression depends upon size of coal stockyard, coal consumption rate, volatility of coal and ambient conditions. Normally, low- grade water such as cooling tower blowdown or plant wastewater is used for coal dust suppression. In order to reduce plant water consumption, water available from drains of coal yard can be recovered and reused for coal dust suppression water system.

(e) Minimizing effluent discharge

Wastewater generated in a thermal power plant typically includes clarifier sludge, filter backwash, cooling tower blowdown, regeneration waste of demin plant and CPU, and boiler blowdown etc. Normally, clarifier sludge is disposed of along with ash slurry and boiler blowdown is led to central monitoring basin (CMB) of the plant. Water required for wet ash disposal is tapped from cooling tower blowdown, and unutilized blowdown water, if any, is led to the CMB.

In the present study, clarifier sludge is considered to be treated for removal of solid waste, and recovered water is recycled to inlet of the clarifier. Filter backwash water from filters of demin plant and potable water system are also considered to be recycled to inlet of the clarifier. The boiler blowdown is considered to be usable in cooling water system to supplement the make-up water as it is expected to have negligible impact on cooling tower inlet temperature. Water from plant drains and filter backwash is treated in effluent treatment plant (ETP), and recovered water is collected in the CMB. Requirement of water for low grade applications such as coal dust suppression and gardening is met from CMB. The wastewater in CMB has high TDS as a result of regeneration waste and cooling tower blowdown water. If water were to be recovered from this wastewater for recycling in the plant, its treatment would require application of membrane separation technology.

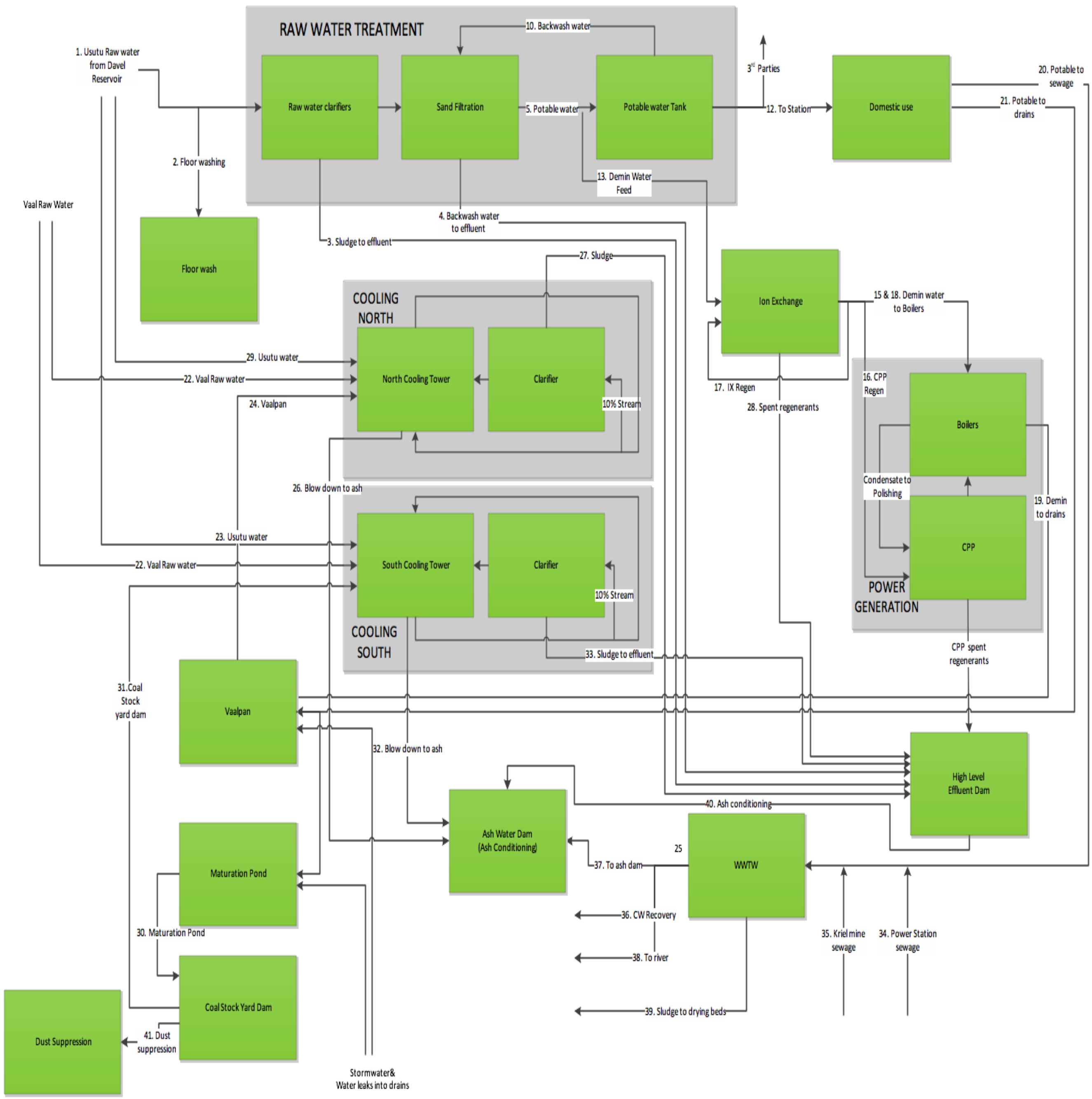
5.2 Methodology

The adopted approach in this study was to build the mathematical model from mass balances and solving it using the General Algebraic Modelling System (GAMS) software. GAMS is a high-level modelling system for mathematical programming and optimization, which can handle complex, large and multicomponent systems. Its main strength lies in the comprehensive suite of solvers that are tailored to various types model structures. The following sections highlight the sequence of steps as applicable to this case study.

5.2.1 *Data gathering and analysis*

(a) Flow sheet

Kriel power station management provided the water balance diagrams, specified process water quality standards for certain units, and Saltman water and salt balance modelling spreadsheet. In an iterative process between ART and Kriel personnel, a process flow diagram of water flow at the power station was developed. Figure 28 shows the developed diagram of water utilization at the power station. Certain operations. Such as floor washing also utilize other sources at times, but this diagram was found to be the norm of the current situation.



Kriel water flow diagram

Figure 28 The diagram developed served as the basis for further development of the GAMS model.

(b) Sources and sinks

Water sources and sinks were identified from the process flow diagram. Table 10 shows the respective processes classified as water sources and sinks. Note that a process unit may serve as both a source and a sink for example a cooling tower has a demand for water and is a source of blowdown water. The raw water sources were labelled variables because that will be the variables that the model will seek to minimize.

Table 10 Identified variables, sources and sinks

Unit Operations	Sources	Sinks	Variables
Usutu Raw Water			X
Vaal raw water supply			X
Floor Washing		X	
3rd parties		X	
Sand filter backwash water		X	
Dirty Sand filter backwash water	X		
Power station potable water use (bathrooms,		X	
Power station potable water leaking into drains	X		
Power Generation: Demin Water		X	
Power Generation: Demin Water to drains-mostly	X		
Power Generation: CPP spent regenerants	X		
Ion Exchange: Spent regenerants	X		
Effluent Dam	X		
North Cooling Tower	X	X	
South Cooling Tower	X	X	
WWTW	X		
Ash Dam/Ash conditioning		X	
Dust suppression		X	
Vaalpan – mostly from leaks from process units	X		

(c) Stream flowrates and quality data

Table 2.3 below shows the flowrates and qualities associated with the respective streams numbered on the flow diagram. With insufficient flow metering currently done on the plant it was decided to use flow data as calculated by the "Saltman" model provided by Eskom management. The model calculates the water balance for the station based on chosen operational parameters and received water qualities. This data corresponds well with the available metered values. The stream qualities are as given by Kriel staff. The values in bold are estimated values.

The model used by ART can incorporate multiple components (such as sulphates, conductivity, Total Dissolved Solids etc), however, it was decided to initially use only Total Dissolved Solids (TDS) as modelling parameter. The main reason for this is a lack of available data for other components. For some streams TDS values had to be correlated from conductivity measurements – an accepted practice at lower ion activities such as found with these stream compositions. Stream compositions for all process streams will be needed if more components are to be incorporated. Importantly, especially the sulphate concentration is of concern as it may often be the limiting parameter in cooling towers (when the allowable sulphate concentration is exceeded before other limits are reached). This is further investigated in the discussion surrounding cooling towers.

Table 11 Stream values and qualities

Stream	Stream description	**Flow rate (m^3/d)**	**Stream quality** TDS	Conductivity (uS/cm)
1	Usutu Raw water from Davel Reservoir	14749	43	68.1
2	Fire-hydrants	2203	43	68.1
3	Sludge to effluent	444	61	**95**
4	Dirty backwash water to drains	444	48	**75**
5	Filtered water	14305	45	70.4
6 - 9, 11	Water 3rd parties		45	70.4
	Water to Kriel town		45	70.4
	Water to Kriel mine and NW Shaft		45	70.4
	Water to contractors		45	70.4
	Water to kwanala centre		45	70.4
	3rd parties	3000	45	70.4
10	Clean filter backwash water	444	45	70.4
12	Potable to Power Station	3000	45	70.4
13	Demin water feed	7862	45	70.4
14	Demineralized water production	7506	0	0.07
15	Demineralized water to Power Station	6824	0	0.07
16	Water to CPP regeneration	682	0	0.07
17	Deminiralized water to regeneration	682	0	0.07
18	HP Demineralized to Power Station by	0	0	0.07
19	Demin water to station drains	3412	0	0.07
20	Potable water to Sewage plant	300	255	400
21	Potable water to Station drains	1890	58	91
22	Vaal raw water supply	92778	130	204
23	Usutu Raw water to north cooling system	0	45	70.4
24	Recovered water from Vaalpan	800	732	1150
25	Recovered sewage effluent	1216	249	**391**
26	North cooling tower blow down	3177	2548	4000
27	North cooling tower clarifier sludge	714	2548	4000
28	Spent regenerants to effluent system	1039	127	**200**
29	Usutu raw water to south cooling system	0	45	70.4
30	Recovered water from the maturation pond	0	567	890
31	Recovered water fron coal stock yard	0	510	800
32	South cooling tower blow down	6467	2548	4000
33	South cooling tower clarifier sludge	627	2548	4000
34	Sewage from the Power Station	300	255	**400**
35	Sewage from the Kriel mine	1350	255	**400**
36	Sewage effluent for use in cooling	0	249	**391**
37	Sewage effluent to ash dams	0	249	**391**
38	Sewage effluent to the environment	0	249	**391**
39	Sewage sludge to drying beds	50	249	**391**
40	Ash conditioning	1400	6369	**10000**
41	Dust suppression	400	2548	**4000**

5.2.2 *Modelling*

GAMS software is used to develop the process integration model. As described on the GAMS website (www.gams.com, March 2014), GAMS is specifically designed for modelling linear, nonlinear and mixed integer optimization problems. The system's inherent solvers allow a user to solve complex problems with a simple and very flexible setup.

The received data in Table 11 is used to develop a model that generates a water use network by calculating optimal distribution of available water sources (at specified qualities) with the goal of minimising the intake of freshwater as well as wastewater generated. It is also worth noting that the regeneration process unit in the superstructure allows for the calculation of optimum placement and capacity of a water treatment facility.

(a) Mathematical model

The mathematical formulation is based on the superstructure shown if Figure 29.

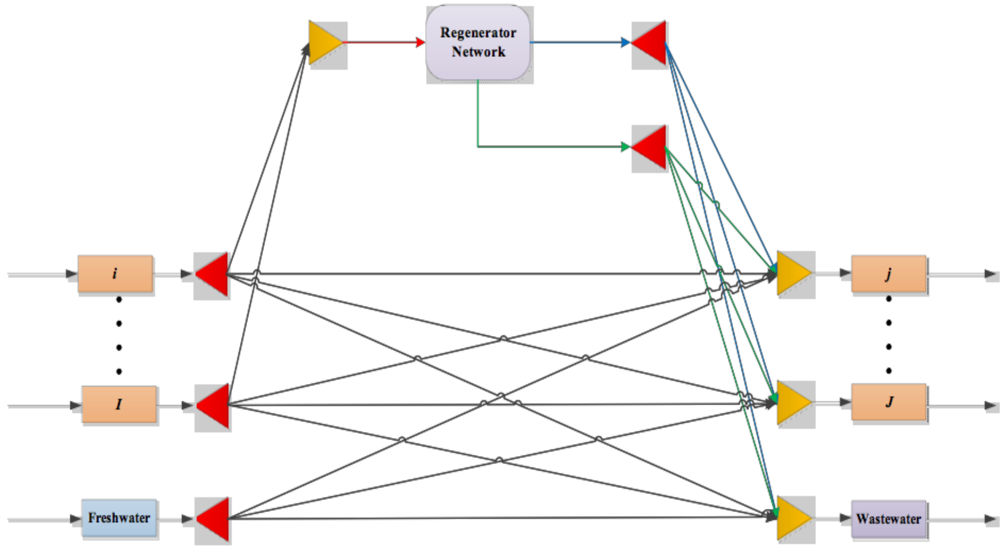


Figure 29 Superstructure for the mathematical model

Sets

$I = \{i \mid i = \text{ water using operation (sink)}\}$

$J = \{j \mid j = \text{ water generating operation (source)}\}$

$C = \{c \mid c = \text{ contaminant}\}$

$R = \{r \mid r = \text{ regenerator}\}$

Continuous variables

FW_i= freshwater into sink i

WW_j= wastewater stream from source j

$F_{j,i}^{out}$= recycle water stream from source j to sink i

F_r^{in}= inlet water stream into regenerator r

F_r^{out}= outlet water stream from regenerator r

$F_{r,i}^{out}$= recycle water stream from regenerator r to sink i

$C_{r,c}^{in}$= inlet concentration of contaminant c into regenerator r

$C_{r,c}^{out}$= outlet concentration of contaminant c from regenerator r

Binary variable

$$y_{i,j} = \begin{cases} 1 \leftarrow \text{if a stream exists between units } i \text{ and } j \\ 0 \leftarrow \text{otherwise} \end{cases}$$

Parameters

$C_{j,c}^{out}$= outlet concentration of contaminant c from source j

$C_{i,c}^{in}$= inlet concentration of contaminant c into sink i

$RR_{r,c}$= removal ratio for contaminant c in regenerator r

F_i^{in}= inlet water stream into sink i

F_j^{out}= outlet water stream from source j

$F_j^{out,U}$= maximum outlet flowrate from source j

δ= minimum allowable flowrate in the final design

Constraints

Regenerator constraints

Constraints are shown below. Constraint (1) states that the total flowrate into a regenerator is made up of individual flows from each source to the regenerator. Constraint (2), on the other hand stipulates that the outlet stream from a regenerator is the sum of all the streams to various sinks from the same regenerator. Constraint (3) gives the inlet concentration of contaminant *c* into the regenerator. Lastly, constraint (4) is the definition of the rejection rate that is specific to contaminant *c* in regenerator *r*.

$$F_r^{in} = \sum_{j \in J} F_{j,r}^{out} \tag{1}$$

$$F_r^{out} = \sum_{i \in I} F_{r,i}^{out} \tag{2}$$

$$C_{r,c}^{in} = \frac{\sum_{j \in J} F_{j,r}^{out} C_{j,c}^{out}}{F_r^{in}} \tag{3}$$

$$F_r^{out} C_{r,c}^{out} = \left(1 - RR_{r,c}\right) F_r^{in} C_{r,c}^{in} \tag{4}$$

Water using operations constraints

Constraint (5) states that the total flowrate into sink *i* comprises the freshwater flowrate plus the total flow from all the relevant sources and the flow from the regenerator. In its current form, this constraint assumes a single regenerator. Constraint (6) states that the outlet stream from source *j* is made up of wastewater that is dispensed with as effluent, the overall reuse stream from source *j* to all the relevant sinks, as well as the water stream into the regenerator. Constraint (7) states that the total load of contaminant *c* into sink *i* cannot exceed the maximum allowed load of the same contaminant in the sink. Lastly, constraint (8) is a feasibility constraint that ensures that all the flowrates in the final design are within allowable limits.

$$F_i^{in} = FW_i + \sum_{j \in J} F_{j,i}^{out} + F_{r,i}^{out}, \forall i \in I = \left\{ i \mid i = \text{sink} \right\} \tag{5}$$

$$F_j^{out} = WW_j + \sum_{i \in I} F_{j,i}^{out} + F_{j,r}^{out}, \forall j \in J = \left\{ j \mid j = source \right\} \tag{6}$$

$$C_{i,c}^{in} \geq \frac{\sum_{j \in J} F_{j,i}^{out} C_{j,c}^{out}}{F_i^{in}} \qquad \forall i \in I = \left\{ i \mid i = \text{sink} \right\}, c \in C = \left\{ c \mid c = \text{contaminant} \right\} \tag{7}$$

$$\delta\, y_{j,i} \leq F_{j,i}^{out} \leq F_j^{out,U} y_{j,i} \qquad \forall i \in I = \left\{ i \mid i = \text{sink} \right\}, j \in J = \left\{ j \mid j = \text{source} \right\} \tag{8}$$

Objective function

The objective function focusing on the minimization of the total freshwater intake into the facility is given in constraint (9a). It may also include the amount of wastewater generated as in (9b) or minimize the costs associated with intake of freshwater and treatment of wastewater as in (9c)

$$Min\ FW = \sum_{i \in I} FW_i \tag{9a}$$

$$Min\ FW, WW = \sum_{i \in I} FW_i + \sum_{j \in J} WW_j \tag{9b}$$

$$Min\ Cost = \sum_{i \in I} FW_i \times CostFW + \sum_{j \in J} WW_j \times TreatmentCostWW \tag{9c}$$

All three objective functions were used by ART to minimize the respective variables. This eventually will enable power station management to make decisions from both a water use target and cost point of view.

Further constraints can be added to prevent unwanted or impractical solutions. However, the idea is not to eliminate all the degrees freedom, hence forcing only one solution, but to leave the model to calculate how distribution of resources could be most efficiently achieved.

5.3 Results and discussion

5.3.1 *Model that optimizes the water utilization network*

As discussed earlier, flow data used in the model was taken from the Saltman model provided by Eskom. The freshwater intake of 109 730 m^3/day predicted by the Saltman model compares well to the current 110 to 115 Ml/d water usage reported by station personnel. Note that this value, which would be the point of reference to compare the findings from this study against, translates into a litres per unit of electricity sent out (l/uso) value of above 2.35. This is significantly more than the reported design spec of 1.8 l/uso or current 2.19 l/uso target for the station. Two separate models were compiled, 1) with a regeneration unit or desalination plant that is able to clean water with a high salt load to produce good quality effluent that can be re-used, and 2) a model that optimizes the water utilization network without a regenerator being used.

With each of the two models, three different objective functions were set (given by equations 9 a - c) to minimize freshwater intake, freshwater and wastewater combined or costs associated with water intake and treatment respectively. Each of this targets provide unique networks and different targets to work towards by station management, whether it is in order to reach the minimum freshwater intake, to minimize waste production or endeavoring to minimize costs associated with water usage and waste management. After formulating the initial model with sources and sinks as listed in Table 2.2, it was apparent that certain modelling outcomes could contribute to more effective water management, but may not necessarily be implemented without further investment or certain commitments by station management. The outcomes are:

A - Re-use of wastewater treatment plant effluent:

Currently the connecting infrastructure between the wastewater treatment plant (WWTP) and the power station is in a state of disrepair. The plant's effluent is also of a poor quality. It will require capital investment to upgrade or replace the treatment plant and refurbish the connecting infrastructure.

B - Allowing interchange of blowdown water between the two cooling towers

With the two cooling towers operating at different cycles of concentration (CoC), the blowdown water of the South cooling tower (operated at lower CoC) is of acceptable quality to feed into the North cooling tower. If recycling of blowdown to the towers is being incorporated, a careful study of possible accumulation of contaminants at steady state conditions will have to be conducted first. Too high salt concentrations may damage infrastructure in the cooling loop.

C – Use of any water for floor washing operation

From preliminary results it seems possible that preventing certain sources that might be harmful to operators from going to floor washing can have a significant influence on the water network. This may be sources such as sewage plant effluent or ion exchange regenerants.

In order to test the impact of each of these possibilities, eight scenarios were created as shown in Table 12, thus allowing each of A, B and C or not. The scenarios were created by adding or removing constraints from the GAMS model.

Table 12 Senarios modeled

Scenarios	***Re-use WWTP water***	***Blowdown interchange allowed***	***Floorwash water from any source***
Currently	NA	NA	NA
Scenario 1	No	Yes	Yes
Scenario 2	Yes	Yes	Yes
Scenario 3	Yes	No	Yes
Scenario 4	No	No	No
Scenario 5	No	No	Yes
Scenario 6	No	Yes	No
Scenario 7	Yes	No	No
Scenario 8	Yes	Yes	No

The reasoning behind investigating different scenarios is that water saving can thus be quantified for each scenario and associated cost be determined for eventual use in a cost benefit analysis.

Ultimately it is important to keep in mind that all of these findings result from very specific inputs to the models and any findings must be evaluated in this light.

The findings for the three discussed objective functions when run on both models, with and without a desalination plant, is presented and evaluated.

Objective function: Minimize freshwater intake

As discussed earlier the current freshwater intake into the station ranges from 110 – 115 ML/d.

Without regenerator/desalination plant

The model was run for each of the scenarios and respective objective function values obtained as shown in Table 13.

Table 13 Minimum Freshwater usage for respective scenario's without a desalination plant

WW - Wastewate; FW- Freshwater; Z- objective function; Fr - Total flow nto Regenerator; STP -Sewage Treatment Plant; Fret - flow out of regenerator	Re-use WWTP water	Blowdown interchange allowed	Floorwash water from any source	Z as **FW** usage **without Regen** in ML/d	
Currently	NA	NA	NA	FW 112	WW 10
Scenario 1	No	Yes	Yes	FW 96.801	WW 0
Scenario 2	Yes	Yes	Yes	Fw 95.591	WW 0
Scenario 3	Yes	No	Yes	Fw 103.581	WW 8.008
Scenario 4	No	No	No	Fw 104.86	WW 8.052
Scenario 5	No	No	Yes	Fw 103.8	WW 6.994
Scenario 6	No	Yes	No	Fw 96.801	WW 0
Scenario 7	Yes	No	No	Fw 104.651	WW 9.06
Scenario 8	Yes	Yes	No	FW 95.591	WW 0

The figures reported in Table 13 translate into freshwater savings of 13% for scenarios 8 and 2, to 4% for scenario 4 or l/uso, respectively. The absolute minimum amount of freshwater intake with the current operational parameters (obtained from Saltman and station personnel) is 95.6 ML/d in scenarios 2 and 8 corresponding to 2.04 l/uso, which is still above both the design target of 1.8 l/uso, but lower than the present station target of 2.19 l/uso. Remember that the l/uso value at the start of this project was about 2.35.

As the current usage figures were used as demands for respective sinks, the above savings are calculated even with prevailing leaks. Hence any savings achieved by fixing leaks etc. can be directly subtracted from these values.

From the results where scenario's 1, 2, 6 and 8 *with* blowdown interchange allowed it is also clear that, with different cycles of concentration and hence different water chemistry in the cooling water of the cooling towers, significant savings may lie in utilizing blowdown water from the two cooling cycles correctly. As mentioned before these values are for very specific input parameters that may show optimistic results, however, even if these results may be exaggerated the trend of water savings with interchange of blowdowns remains. The re-use of WWTP effluent contributes close to 3% savings in freshwater intake and a further 2 – 3% savings can be added if the model has the freedom to allocate any source's water to floor washing. It is also interesting to note that scenario 4 where none of A, B or C is allowed still manages a 3% reduction in freshwater intake through optimizing the water use network.

Appendix I shows the water networks suggested by the model to achieve the minimum objective function for each scenario. These networks can be used as a starting point to identify the so called low hanging fruit. Practical infeasibilities appearing on these networks can be corrected by collaborating with station personnel to identify them during the implementation stage and investigating the effect of altering the model to eliminate the infeasibility. Water networks for the subsequent runs with other objective functions are not shown as these are to a large extent representative of those networks. However, it is recommended that each is individually evaluated during the implementation phase of the project.

5.3.2 *With regeneration/desalination plant*

Table 2.6 shows the minimum freshwater intake achieved by the model with a regeneration plant for the respective scenarios as defined before. Note that scenarios 1, 2, 6 and 8 are for all intents and purposes the same as the values achieved by the model without a desalination plant, while the values for the other scenarios are in the order of 5 - 8% lower than findings in Table 14.

Table 14 Minimum freshwater usage for respective scenarios with a desalination plant

WW - Wastewater; FW- Freshwater; Z- objective function; Fr - Total flow into Regenerator; STP -Sewage Treatment Plant; Fret - flow out of regenerator	Re-use WWTP water	Blowdown interchange allowed	Floorwash water from any source	Z as **FW** usage **with Regen** in ML/d	
Currently	NA	NA	NA	FW 112	WW 10
Scenario 1	No	Yes	Yes	FW 96.81	WW 0
Scenario 2	Yes	Yes	Yes	Fw 95.591	WW 0
Scenario 3	Yes	No	Yes	Fw 95.92	WW 0
Scenario 4	No	No	No	Fw 97.62	WW 0
Scenario 5	No	No	Yes	Fw 97.51	WW 0
Scenario 6	No	Yes	No	Fw 96.801	WW 0
Scenario 7	Yes	No	No	Fw 96.14	WW 0
Scenario 8	Yes	Yes	No	FW 95.591	WW 0

When evaluating the networks (not shown) suggested by the models it can be concluded that the reason why scenarios 1, 2, 6, and 8 have the same values is that they already have no liquid waste stream even when there is no regeneration unit. These are also the scenarios that allowed an interchange of blowdown streams, thereby eliminating the waste. Scenarios 3, 4, 5 and 7 however, had waste streams in 3.1.1 which are treated by the desalination plant to be reintroduced in the cooling cycle, thus lowering the required freshwater intake.

Most significant of these observations are that *no desalination plant is necessary* if the water networks suggested for the scenario’s with equal objective function values are found to be valid and feasible.

Objective Function: Minimize freshwater intake and wastewater

5.3.3 *Without regenerator/desalination plant*

Table 1 shows exactly the same freshwater and generated wastewater volumes as the findings from 3.1.1, even when the waste is added as part of the objective function to be minimized. Optimum utilization of water sources therefore also translates into minimization of waste as previous waste streams are re-used by re-structuring the water use network.

Table 15. Minimum combined freshwater usage and waste without a desalination plant

WW - Wastewater; FW- Freshwater; Z- objective function; Fr - Total flow into Regenerator; STP -Sewage Treatment Plant; Fret - flow out of regenerator	Re-use WWTP water	Blowdown interchange allowed	Floorwash water from any source	Z as **FW+WW without Regen** in ML/d	
Currently	NA	NA	NA	FW 112	WW 10
Scenario 1	No	Yes	Yes	FW 96.801	WW 0
Scenario 2	Yes	Yes	Yes	Fw 95.591	WW 0
Scenario 3	Yes	No	Yes	Fw 103.581	WW 8.008
Scenario 4	No	No	No	Fw 104.86	WW 8.052
Scenario 5	No	No	Yes	Fw 103.8	WW 6.994
Scenario 6	No	Yes	No	Fw 96.801	WW 0
Scenario 7	Yes	No	No	Fw 104.651	WW 9.06
Scenario 8	Yes	Yes	No	FW 95.591	WW 0

As in 3.1 scenarios utilizing the blowdown, or a portion of the blowdown water, from one cooling tower as feed water in another show the most promising figures. This also leads to a zero liquid effluent discharge as the purge of accumulated salts is achieved by using the remaining blowdown water for ash conditioning. Once again this emphasizes the importance of managing the decision making regarding the frequency of blowdown as well as the utilization of blowdown water.

5.3.4 *With regeneration/desalination plant*

Adding a regenerator to the equation enables the model to send any residual waste for treatment and so minimizing the waste while having more fresh (regenerated) water as a source. It can be seen in Table 2.8 that the scenarios that did not have any waste streams before still have the same objective function values when compared to findings from 3.2.1., while the scenario's that previously had waste streams now have significantly lower objective functions.

Table 16 Minimum combined freshwater usage and waste with a desalination plant

WW - Wastewater; FW-Freshwater; Z- objective function; Fr - Total flow into Regenerator; STP - Sewage Treatment Plant; Fret - flow out of regenerator	Re-use WWTP water	Blowdown interchange allowed	Floorwash water from any source	Z as **FW+WW with Regen** in ML/d	
Currently	NA	NA	NA	FW 112	WW 10
Scenario 1	No	Yes	Yes	FW 96.81	WW 0
Scenario 2	Yes	Yes	Yes	Fw 95.591	WW 0
Scenario 3	Yes	No	Yes	Fw 95.92	WW 0
Scenario 4	No	No	No	Fw 97.62	WW 0
Scenario 5	No	No	Yes	Fw 97.51	WW 0
Scenario 6	No	Yes	No	Fw 96.801	WW 0
Scenario 7	Yes	No	No	Fw 96.1	WW 0
Scenario 8	Yes	Yes	No	FW 95.591	WW 0

From these findings one can conclude that a desalination plant does make a difference in reducing wastewater as well as the freshwater intake when effluent management enters the equation.

Objective Function: Minimizing cost of freshwater intake and waste treatment

Costs associated with water utilization and waste management at Kriel Power Station can be calculated in several ways as discussed in the following three sub-sections.

Without regenerator/desalination plant and waste disposed on ash dams

According to internal Eskom information, Kriel power station currently pays R6 068/ML for freshwater obtained from the Vaal scheme and R8 045/ML for water obtained from the Usuthu scheme. Cost of treatment of sewage water is estimated to be R4 000/ML (Sezani and Marlene, 2012). No costs are currently paid for waste disposal as cooling water purge streams are disposed of on the ash dams. As seen in Table 17, with no regeneration plant, costs are minimized as freshwater intake is minimized. Even if this is the current situation at the power station, attributing no cost to waste management reduces this table's value for future decision making as waste management threatens to take on significant costs in the future.

Table 17. Minimum cost while waste can be disposed of on ash dams.

WW - Wastewater; FW-Freshwater; Z function; Fr Regenerator Treatment Plant; Fret out of regenerator

	Re-use	Blowdown	Floorwash	Z as cost of **FW+STP without**
Currently	NA water	NA allowed	NA any source	R 712 000.00 FW 112 WW 10
Scenario 1	No	Yes	Yes	R 601 613.64 FW WW 0
Scenario 2	Yes	Yes	Yes	R 598 662.29 FW 95.59 WW 0
Scenario 3	Yes	No	Yes	R 653 783.55 FW WW
Scenario 4	No	No	No	R 653 783.55 Fw WW
Scenario 5	No	No	Yes	R650 522.06 FW WW
Scenario 6	No	Yes	No	R606 724.32 FW WW 0
Scenario 7	Yes	No	No	R659 005.30 FW WW
Scenario 8	Yes	Yes	No	R 604 237.60 FW WW 0

With regeneration/desalination plant and disposal of brine to landfill

DWA intends to prohibit the disposal of saline streams on ash dams in the near future. This means blowdown water will have to be treated via a desalination plant. Costs to do that will be in the order of R5 000 to R10 000 (with the R10 000 figure being used in the model) per ML treated plus R1 970 000 for disposal of brine. This treatment costs includes attenuation of capital costs and were conservatively deducted from previous ART studies for desalination plants, while the disposal costs for brine are from a quote supplied by a waste management company late in 2013. Figure 30 illustrates the cost allocation used in the model for this section.

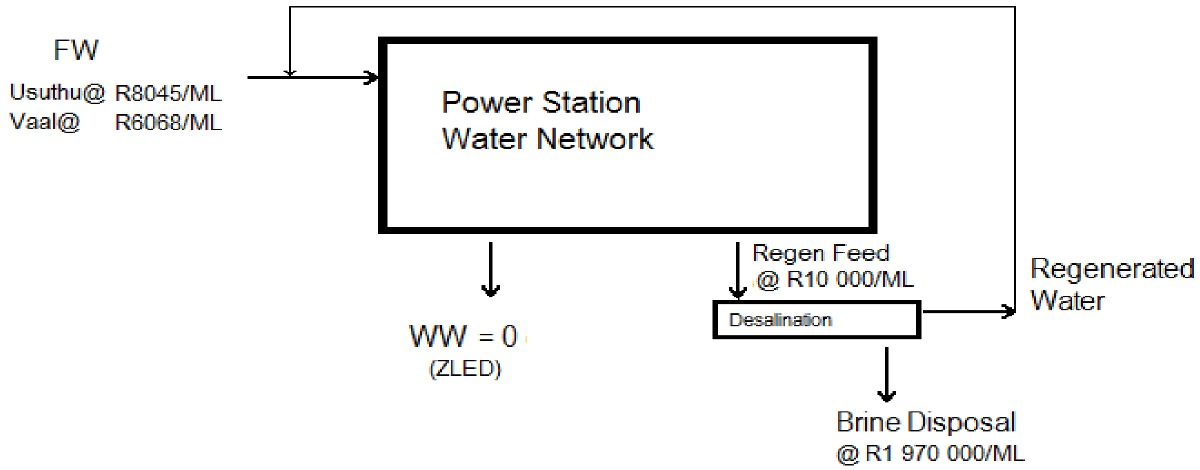


Figure 30 Cost allocation when brine is being disposed of in a landfill

Complimentary to Eskom's zero liquid effluent discharge (ZLED) policy a desalination plant provides an option for dealing with saline waste streams – at a price. While salt rejection from the feed stream may be as high as 99%, the recovery for modern plants is generally around 90% (actual percentage of feed water ending up as product water) with a 10% concentrate stream or waste stream to be managed.

Table 18 presents the findings. Note that all wastewater was sent to the regenerator as there is no alternative means of dealing with it and complying with ZLED when DWA disallows disposal of salt streams on ash dams. The cost associated with current situation in the first row of Table 18 was approximated by assuming the 10 ML of wastewater is sent to the regeneration plant at 90% recovery to provide 9ML of the required 112ML while 1ML needs to be disposed of.

Table 18. Minimum cost when disallowing any wastewater

WW - Wastewater; FW- Freshwater; Z- objective function; Fr - Flow into Regenerator; STP -Sewage Treatment Plant; Fret - flow out of regenerator	Re-use WWTP water	Blowdown interchange allowed	Floorwash water from any source	Z as cost of **Fw+Fr+Fret+STP with Regen** in ZAR
Currently	NA	NA	NA	R2600 000.00 FW 112 WW 10
Scenario 1	No	Yes	Yes	R601 806.30 FW 96.81 WW 0
Scenario 2	Yes	Yes	Yes	R596 807.89 FW 95.195 WW 0
Scenario 3	Yes	No	Yes	R2 099 949.78 FW 95.92 WW 0
Scenario 4	No	No	No	R2 287 548.83 Fw 97.62 WW 0
Scenario 5	No	No	Yes	R2 071 249.33 FW 97.51 WW 0
Scenario 6	No	Yes	No	R607 707.10 FW 96.81 WW 0
Scenario 7	Yes	No	No	R2 560 558.52 FW 96.14 WW 0
Scenario 8	Yes	Yes	No	R602 789.35 FW 95.7 WW 0

With Regeneration/Desalination Plant and Brine management on site

The findings above show how the wastewater treatment costs render the cooling tower blowdown management critical, even when it can simply be sent to the treatment plant to re-produce freshwater.

Furthermore the model's suggested water networks for scenarios that previously produced no wastewater (Scenarios 1, 2, 6 and 8) still prevents any water from being treated by the desalination and this translates into costs that amount to a fraction of that for the other scenarios.

An alternative to the cost structure different from the above scenario is to include brine management facilities with the desalination plant at a cost of R40 000/ML (also estimated from previous ART studies) of wastewater treated by the plant. These costs include the capital costs attenuated and may be less for a more energy efficient technology such as eutectic freeze or much more if energy costs are high. Figure 31 illustrates the cost allocation in the model for this section.

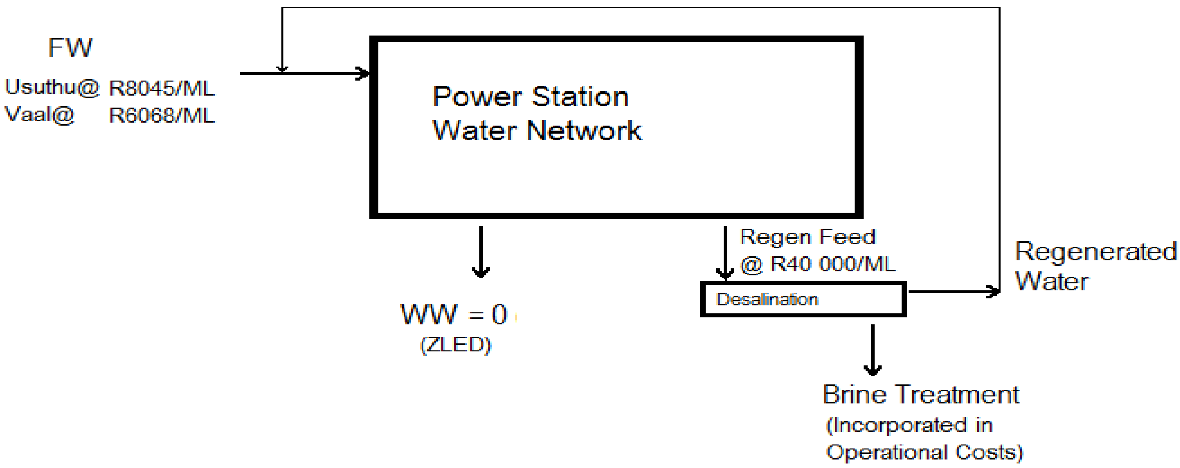


Figure 31. Alternative treatment cost allocation for Desalination plant

As before the cost associated with current situation in the first row was estimated by assuming the 10 ML of wastewater is sent to the regeneration plant at 90% recovery to provide 9ML of the required 112ML of freshwater. The results in Table 19 indicate at least 50% cost reduction with on-site waste management compared to landfilling costs of brine. The results in Table 19 indicate at least 50% cost reduction with on-site waste management compared to landfilling costs of brine.

Table 19. Minimum cost with brine treatment incorporated in treatment costs

WW - Wastewater; FW-Freshwater; Z- objective function; Fr - Flow into Regenerator; STP -Sewage Treatment Plant; Fret - flow out of regenerator	Re-use WWTP water	Blowdown interchange allowed	Floorwash water from any source	Z as cost of **Fw+Fr+STP with Regen** in ZAR
Currently	NA	NA	NA	R1 200 000.00 FW 112 WW 10
Scenario 1	No	Yes	Yes	R601 806.30 FW 96.81 WW 0
Scenario 2	Yes	Yes	Yes	R596 807.89 FW 95.195 WW 0
Scenario 3	Yes	No	Yes	R890 340.12 FW 95.92 WW 0
Scenario 4	No	No	No	R931 176.32 Fw 97.62 WW 0
Scenario 5	No	No	Yes	R891 594.88 FW 97.51 WW 0
Scenario 6	No	Yes	No	R607 707.10 FW 96.81 WW 0
Scenario 7	Yes	No	No	R982 706.13 FW 96.14 WW 0
Scenario 8	Yes	Yes	No	R602 789.35 FW 95.7 WW 0

5.3.5 *Further discussion*

(a) Cooling Tower Blowdown Management

As shown throughout the minimization models in this section, feeding blowdown from a cooling tower operated at a lower cycles of concentration into one operated at a higher CoC (like the South and North cooling towers respectively), can save a lot of water. Doing this in effect changes the salt balance around the cooling tower operated at lower CoC and thus the operating conditions must be carefully evaluated. The developed GAMS model assumes steady state and therefore the accumulation of salts as blown down is continuously recycled is not automatically calculated. Appendix II contains an example of the mass balance to be conducted around the cooling towers before a change to the water network is to be implemented. This is a critical part of the implementation phase.

The following aspects of cooling tower operation must be taken into consideration at Kriel:

- The "Chemistry standard for Cooling Water" at Kriel sets maximum TDS and Sulphate concentrations in cooling water at the same level for both cooling towers. This however contradicts the reported different CoC for the two towers unless operational staff manages blowdown on different levels. It would be strongly advised to appoint a task team to revisit the way it is being managed.

- General operational “habits” and philosophies regarding the use of cooling water also compromise the conservation of water. This goes hand in hand with the abovementioned bullet.

- With the cooling cycles’ proportionately large water usage, maintenance of any leaking equipment (such as ejector weirs) in the cycle may contribute significant water savings and must be managed and executed diligently.

(b) Freshwater consumption target

The original (design spec.) water consumption target for Kriel Power Station is reported to bel 1.8 l/uso. It is important to note that this target was set for better quality coal, thus increasing the efficiency of the generation cycle and possibly also better freshwater quality which would allow higher cycles of concentration and therefore less make-up water needed. If the findings from the model can be incorporated a water consumption of 2.04l/uso may be achieved at the reduced 95ML of freshwater per day and this value may be improved on by eliminating current losses.

It is important to also note that improving the power factor of the plant through optimizing the cooling towers (refurbishment, better water quality etc.) or improving boiler performance (better coal quality or optimization of boiler/cooling cycle interaction) the water consumption rate is also improved as the unit sent out improves. The relationship between cooling tower efficiency and power generation also contributes significantly to this. A PhD student has recently completed a study of the interdependent optimization of the cooling tower and boiler as part of his doctorate degree (Ndlovu, 2013).

5.3.6 *Selected cost benefit analysis*

The following findings from section 3 were chosen to do a high level cost benefit analysis in order to get a provisional estimation of the value that may be contributed by each option.

(a) Sewage Treatment Plant

A current heuristic rule for costing of activated sludge sewage treatment plants is a cost of R1 million per Ml/d plant capacity. For package treatment plants this cost is in the region of 20% lower. For a plant capacity of 1.6Ml/d needed this translates into cost of +- R1.3 Million for a new package treatment plant at Kriel.

If it is assumed that treated sewage is at the required quality to replace 1ML of freshwater per day, this amount to a saving of R6064*30 = R182 000/month or R2.2 Milllion per year. This figure justifies the upgrade or replacement of the sewage treatment plant and also prioritising the refurbishment/replacement of the current piping infrastructure from the sewage treatment plant to the power station that is in a dilapidated state.

(b) Blowdown management

Given the points discussed, the cost of an appointed task team to investigate findings from this study and investigate cooling tower operations at Kriel in general must be weighed up against expected savings from the work they perform. For a scope entailing a desktop investigation and interviews with internal specialists, it is being assumed for this evaluation's purposes that a team of 2 specialists will spend 360 man hours at approximately R1000/h on such a study. Translating to a cost of R360 000. If 50% of the 13% freshwater savings from the findings in 3.1 of this project associated with blowdown management can be achieved, it translates into at least R50 000 of savings daily or R1.5 Million per month. That is discounting associated wastewater treatment costs.

(c) Regeneration/Desalination plant

With capital costs attenuated into treatment costs freshwater produced from wastewater sent to a desalination plant will cost an estimated R30 to R50/m^3 compared to the R6/m^3 currently paid for Vaal freshwater. In terms of the freshwater consumption targets a desalination plant also only shows an improvement in the scenarios evaluated earlier that do not allow blowdown from one cooling tower to be re-used in the other. This is largely due to total elimination of blowdown waste when these streams are carefully managed.

As the abovementioned waste elimination is only achieved by using a portion of the blowdown water on ash dumps, the one situation where there would be no other option but some form of wastewater treatment or regeneration is when DWA disallows this practice and therefore forces another form of wastewater treatment.

5.4 Conclusions and recommendations

The following conclusions can be made from the findings in this document:

- Savings of between 4% and 13% may be possible by changing the way water is currently utilized and re-used at the station. These figures translate into l/uso figures of 2.23 to 2.04 respectively with February 2014 consumption values (the current station target being 2.19 l/uso according to station personnel). These savings still do not achieve the design water consumption target of 1.8 l/uso. The same objective function values are achieved by minimizing freshwater consumption or the sum of freshwater consumption and wastewater produced.

- Reuse of the wastewater treatment plant effluent has a direct impact on water consumption and investment in infrastructure to enable the introduction of good quality sewage effluent into the cooling towers shows savings in the order of R2.2 million per year.

- Optimization of the stations water network still brings 3% savings without implementation of any of the three preliminary findings mentioned.

- Observations on site showed a significant amount of water ends up in the station drains. With the bulk of water use at the station going to the cooling towers it is expected that regardless if any other of the findings of this study is implemented, effective maintenance on cooling cycle equipment (such as valves, ejector weirs etc.) may reduce water consumption by as much as 5% or R1 million/month. Findings in this report are based on input water demands (for respective unit process) that include prevailing leaks at the station. Any savings through maintenance is additional to the results already shown in this report.

- Management of the cooling cycle and especially blowdown water with related procedures have a significant impact on the amount of freshwater intake. A thorough understanding of the intricacies of cooling tower operation and performance is critical to optimise this. The appointment of a task team to perform this work approximates savings of R1.5 Million per month after initial investment of an estimated R360 000 and it is highly recommended.

- As the water use target is measured in relation to the amount of power generated, the measurement can be improved by optimizing the cooling cycle/boiler relationship. It is recommended that a task team using process optimization tools is implemented to investigate this.

- If saline waste streams cannot be prevented (where blowdown interchange is infeasible) a desalination plant improves on freshwater consumption figures and serves to aid Eskom's ZLED policy. In instances where no waste is produced the desalination plant adds no value in terms of freshwater consumption or otherwise.

- With the incorporation of a desalination plant the daily costs associated with water will rise from around R700 000 per day to R1 million – R2.5 million per day depending on the waste management option chosen.

- It was found that optimization of the power stations water utilization has a direct impact on the amount of waste produced which translates into a 50% (or more) reduction in waste management costs (apart from savings in freshwater consumption).

- Implementation of any of the water networks or portions of it should be foregone by a well executed HAZOP study with risk management. Neglecting to identify instances where the loss of a necessary good quality stream is not introduced to a unit process may lead to equipment damage.

- *Ultimately it is important to keep in mind that all of these findings result from quite specific inputs to the models and any findings must be evaluated in this light.*

- This work has showed the clear water energy nexus that exist in the power plant. Flows of energy and water are basically interweaved each other. Optimizing the freshwater efficiency in electricity generation will play a great role to tackle freshwater scarcity the world is facing. The reason being approximately 40% of freshwater withdrawal in developed nations is used for power generation.

5.5 Action plan

ART recommend the appointment of a task team based at Kriel, with input from experts from head office and other supporting Eskom structures. The team will draft an action plan from findings of this project that may include the following tasks:

- The water networks recommended by the optimization model are shown in Appendix I. These networks can be used as a starting point to identify the so called low hanging fruit. Practical infeasibilities appearing on these networks can be corrected by identifying them with station personnel and investigating the effect of altering the model to eliminate the infeasibility as part of the implementation of the project.

- Look at current listed projects. Prioritise according to the GAMS models' suggested water networks

- Appoint and manage a task team optimizing cooling tower operations (with specific attention to water quality management).

- Involve specialist to optimise Boiler/Cooling Tower interaction. Any improvement here translates into a multiple improvement in the l/uso target achieved.

- With several leaks and losses due to infrastructure in a poor condition it is suggested that the action plan include a directive to the engineering team to focus attention on updating maintenance plans and schedules for equipment in the cooling cycle.

- Conduct a HAZOP study before implementation of findings.

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CHAPTER 4

6 Skill gap

Water management is very broad and hence requires varied specs of skills. A number of studies conductive in many provinces in South Africa have shown a worrying situation amongst personnel responsible with managing our small water treatment plants (SWTPs). In terms of administrative issues, some plant operators were found not to have adequate knowledge of the functioning of the SWTPs and most were unable to calculate chlorine dosage, determine flow rates or undertake repairs of basic equipment. Poor working conditions, frequent stock depletion of chemicals, lack of maintenance culture, lack of emergency preparedness and poor communication were also cited. To improve performance of SWTPs local governments must audit the skills they have and require to sustainably manage water resources. Broadly they should ensure qualified staff in the following knowledge domains are available: process engineering, microbiology, chemistry and management. In addition as part of continuous professional development the local government should offer periodic training especially to plant operators and develop retention strategies by ensuring that highly skilled personnel have clear career growth path and are their rewards are commensurate with their qualification and skills.

6.1 Water engineers

Crucial to water management, though, is the role of engineers. In South African for every 3,166 people one is one engineer. During the RTD, the expert from Namibia, Prof Samuel John, reported that in Namibia, for every 1639 people one is an engineer. Compared to South Africa, one may tend to justify the numbers on the basis of population difference; approximately 2.5 million in Namibian compared to 54 million in South Africa currently. The other side of the story is a comparison between South Africa and a fellow BRICS country, like India, with a very huge population (approx. 1.27 billion). For every 136 people in India one is an engineer. This compels us to look elsewhere to explain the disparity. One may blame this on history, which is true to some extent. However, more importantly, the disparity could be more to do with our mind set than history. If history created the mind-set then it is not too late to develop a curriculum that will create a paradigm shift. This we must done collectively and now. A study conducted by Hosking and Jacoby (2013) show that of the 13 local municipalities sampled in the whole country, one engineer serves 90,925 people.

6.2 Water technicians

Over the years the number of competent technicians working in the local government has been decreasing due to retirement and migration. The replace of those leaving has been slow due to a lack of mentoring programme in place. The emphasis here in on those who are both qualified and competent. There are many jobless technicians in the market with paper qualifications but at the same time there exist many unfilled vacancies for the same category of people. Of the 13 municipalities there were 243 unfilled posts for technicians in 2009/2010, out of which, 155 were in Ethekwini municipality.

6.3 Water management inspectors

Water management inspectors are in a special category of experts that must be distinguished from engineers and technicians. The inspectors need to have technical, managerial and legal knowledge on water and environmental issues. The role of an inspector should be more preventive than corrective.

6.4 Process integration practitioners and skills gap in South Africa

NRF/DST Chair in Sustainable Process Engineering at the University of the Witwatersrand is the only research group that develops and applies process integration tools for wastewater minimization in process industries. Promoting education and training professionals in this area will be required for sustainable development. Therefore, this research group is critical and has to grow in the country for providing young and experienced engineers with the required skills and competences which help to cope with the labour market demands and rapid development, particularly in the water and wastewater industry.

6.5 Conclusion and way forward

6.5.1 *Conclusions*

While wastewater is perceived as burden with regard to the financial implication of managing and treating it, there are opportunities to harness benefits from wastewater to point of turning some costs into profit. For instance, energy cost can be significantly reduced by adopting biogas technology. There is seem to a link between biodiversity, food production and wastewater that needs to be investigated further to get the full benefit of the nutrients removed from the sewage.

The process integration technique described above has a potential to reduce the energy and water requirements of process industries. This technique has successful applied in many industries in Europe and US. The gross water is the amount of water that would have to be used if there was no reuse and recycle. This project will investigate where South Africa process industries stand when it comes to reuse and recycle and propose potential solutions for best practice of water and wastewater management.

In this work, it is proposed that the solution to the challenges facing both the anaerobic degradation and photocatalytic degradation of organic pollutants lies in the integration of the two processes.

This is based on the possibility that photocatalytic pre-treatment of toxic pollutants can increase their biodegradability before conducting the anaerobic process. Moreover, the cost of energy required by the photodegradation process can be offset by the energy generated by the anaerobic process.

6.5.2 *Way forward*

Proposed interventions based on early warning indicators

It was reported that an estimated 63% of South Africans dwell in urban areas, with 40% in metropolitan municipalities. The population estimates project that in 15 years, 7.8 million more people will move from rural areas to cities in South Africa and that in 2050, another 20 years from then, a further 6 million. Given the figures, some of the recommendations that came from the discussion are that there is need to:

(a) Coordinate advisory functions and apply differentiated regulations;

(b) Inculcate in the public a sense of deep reverence for water as is the case in Middle East;

(c) Generate ideas that can be converted into content, which result in development of relevant curriculum to equip people with skills relevant our situation;

(d) Develop more skills in science and engineering;

(e) Collect and exchange data identify, priorities, pollution sources and hotspots;

(f) Generate region specific data and extrapolate, to other regions, only where applicable and

(g) Implement low-cost but efficient technologies and management strategies such as intelligent pressure regulation.

6.5.2.1 Priority issues

There was a detailed discussion on the challenges and possible interventions, all of which cannot be included here. However, as a way of example the question about obtaining clean water from sea water came up several times. In response to the question, Dr Beason Mwaka (Water and Sanitation Department) explained that it costs R12 to produce 1000 L clean water from sea water. The same volume can be produced at a cost of R8 and R1 of from sewage and river water, respectively. For sea water or sewage to be used as a source of clean water engineers would work hard to reduce the treatment cost. The critical issues were identified as.

a) Water leaks and other un-accounted water losses

b) Skill development

c) Maintenance of the infrastructure

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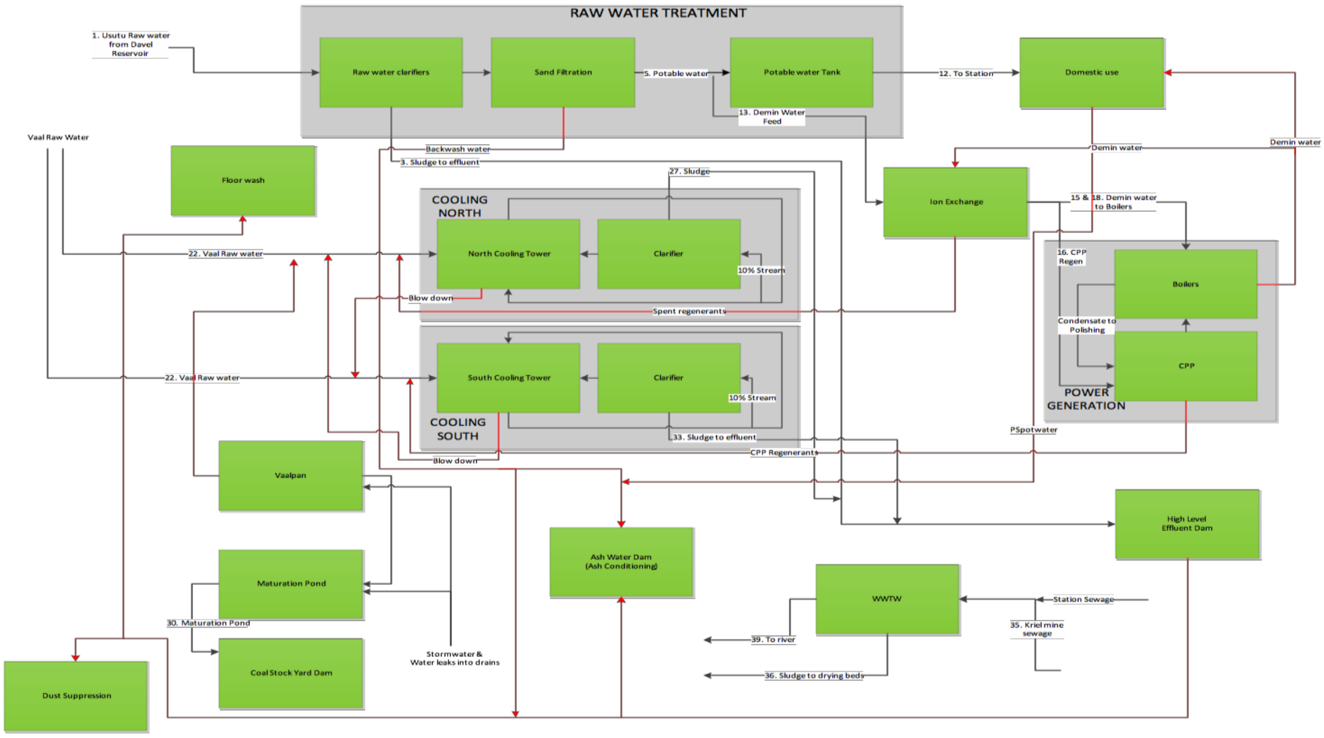
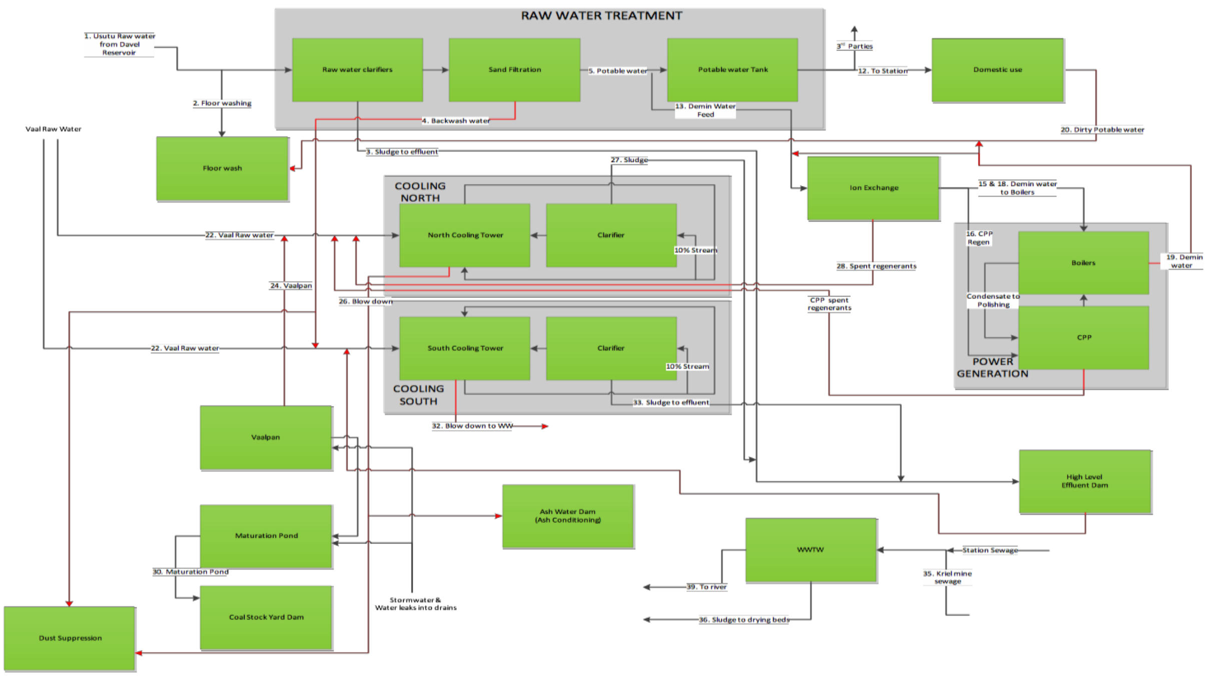
APPENDIX I: Flow Sheets for Freshwater Minimization Scenarios

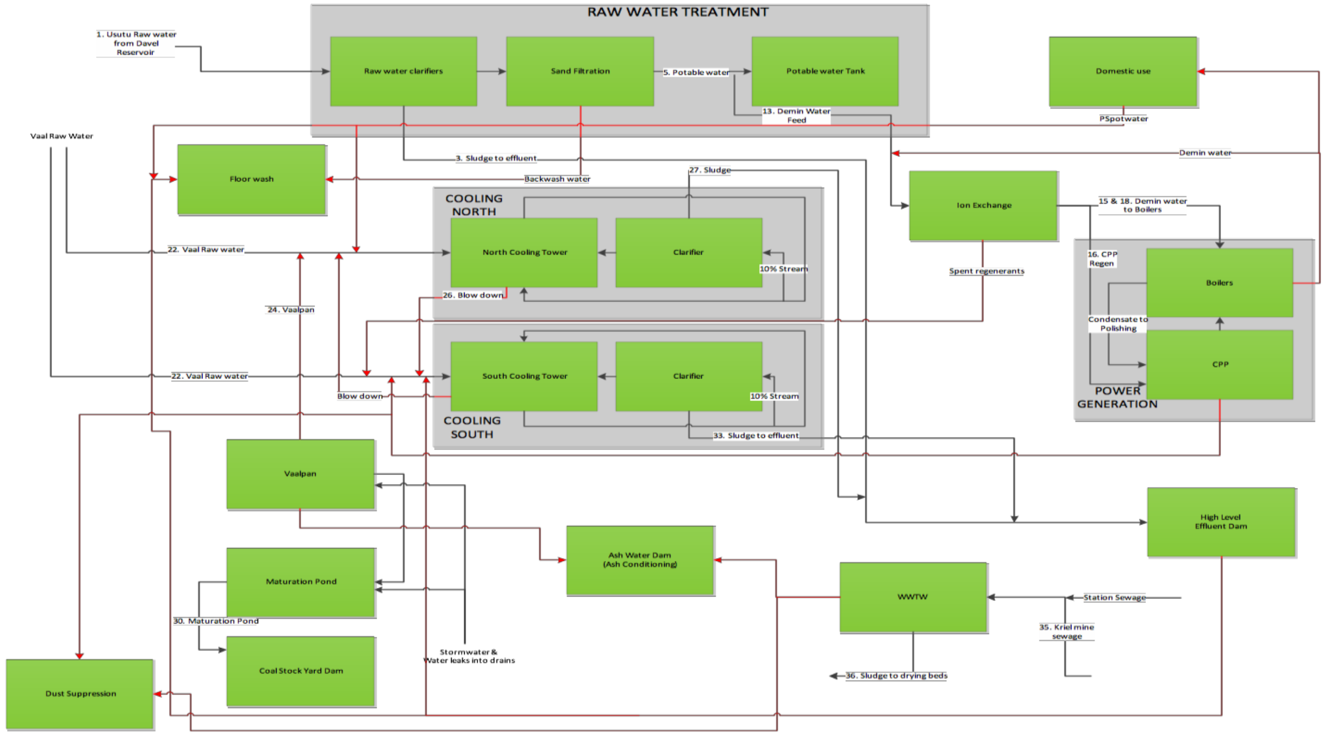
Scenario 1: Freshwater intake (96 801m^3/d)



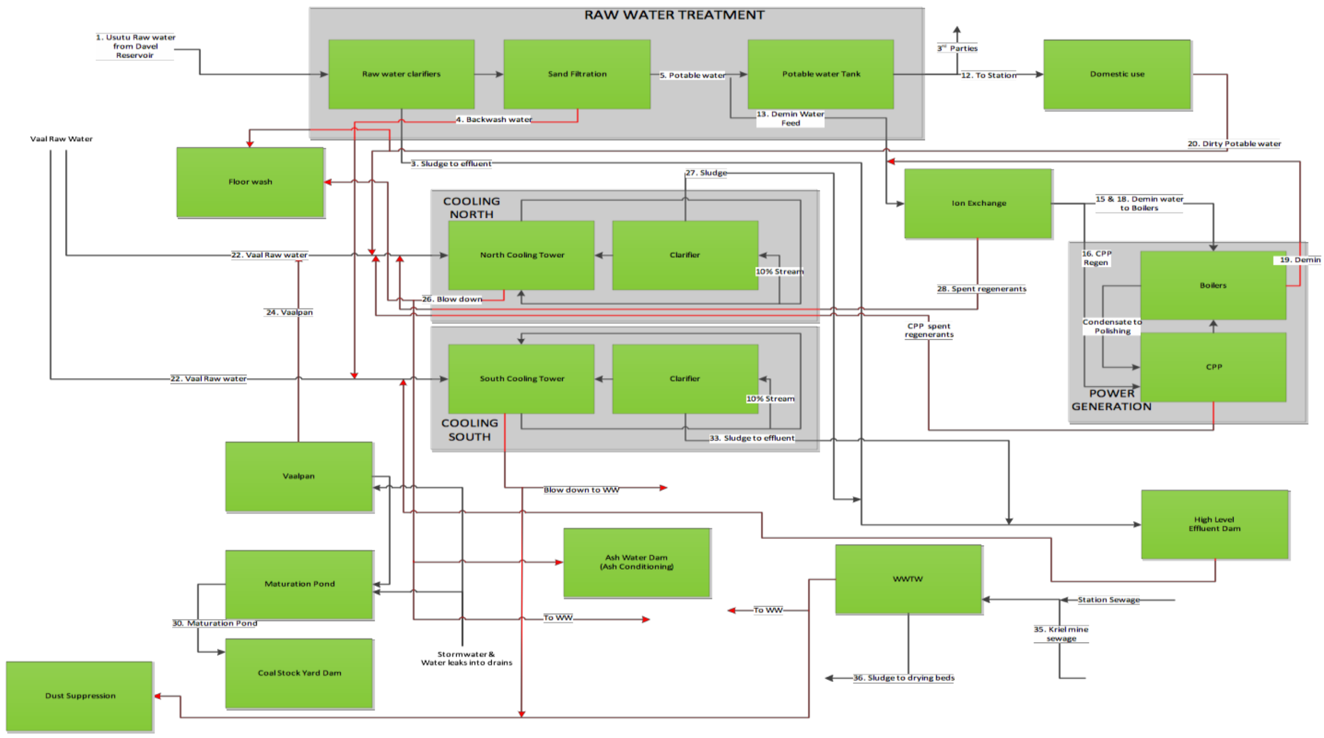
Scenario 2: Freshwater intake (95 591 m^3/d)



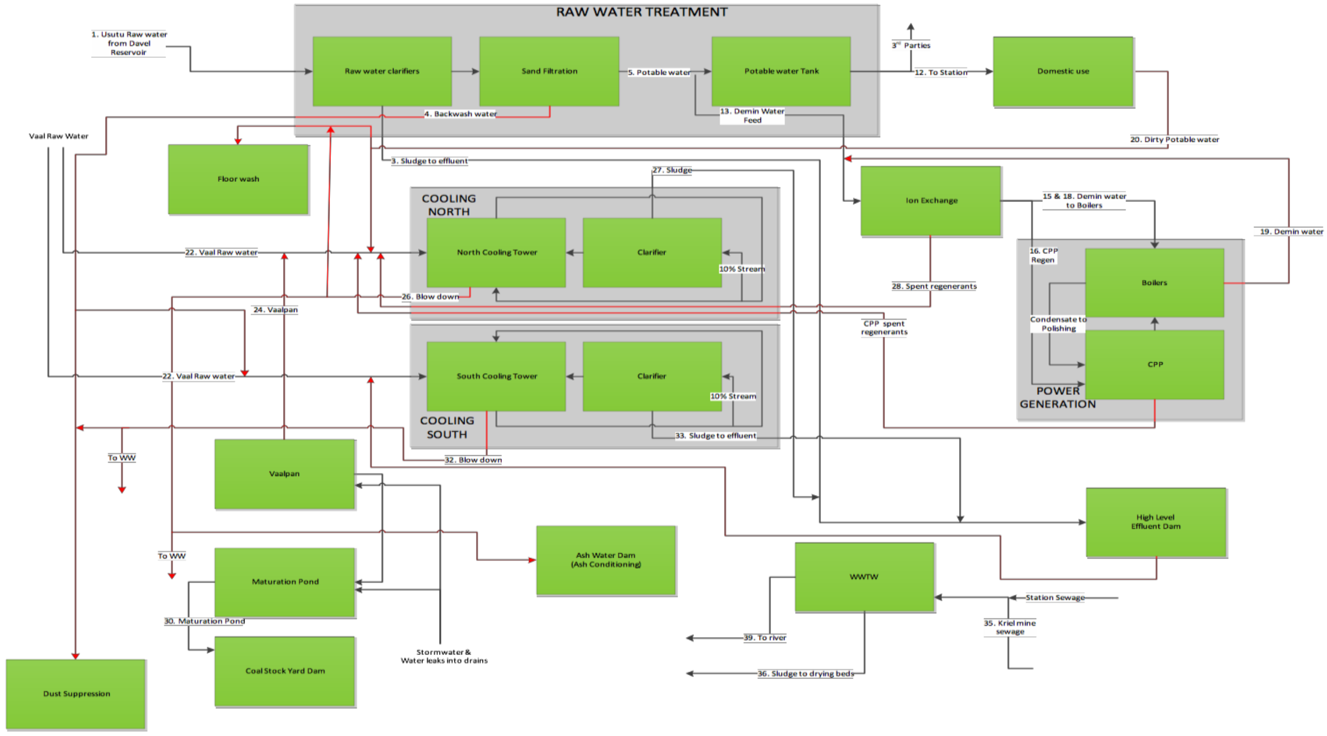
Scenario 3: Freshwater intake (103 581 m^3/d)



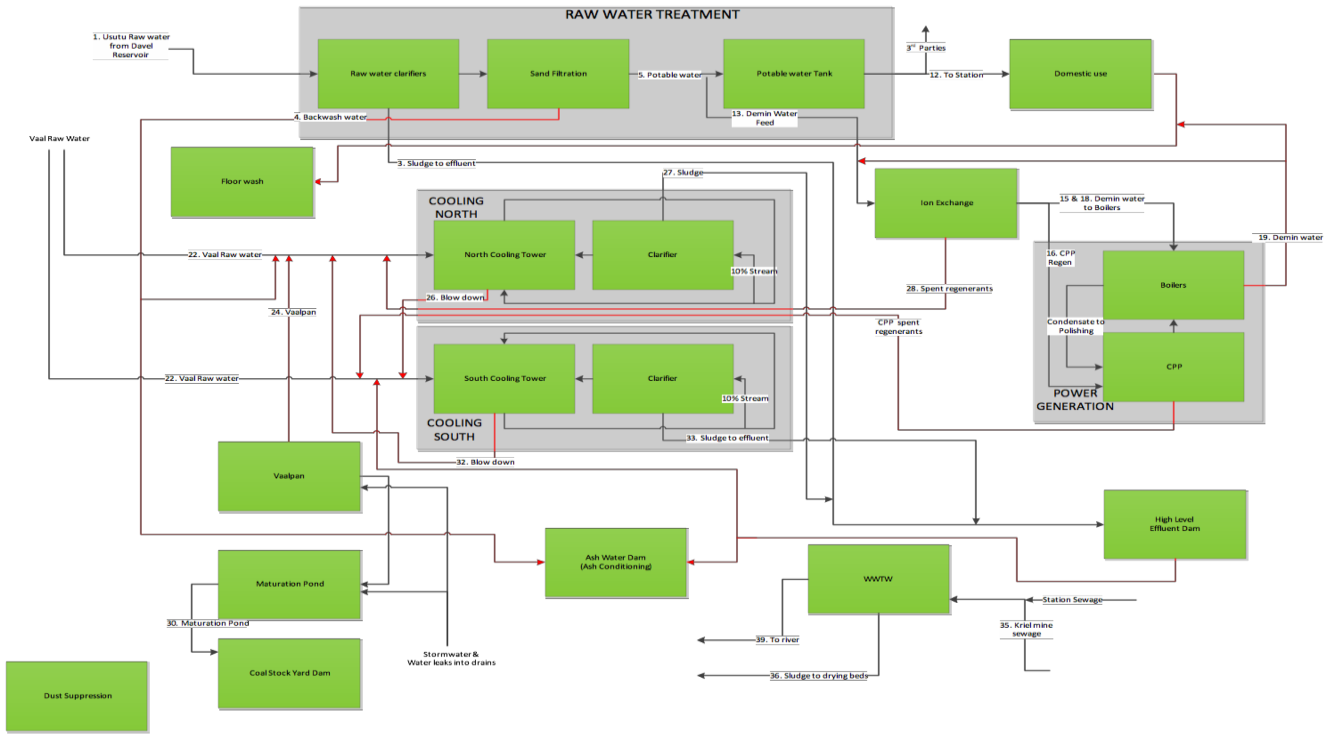
Scenario 4: Freshwater intake (104 860 m^3/d)



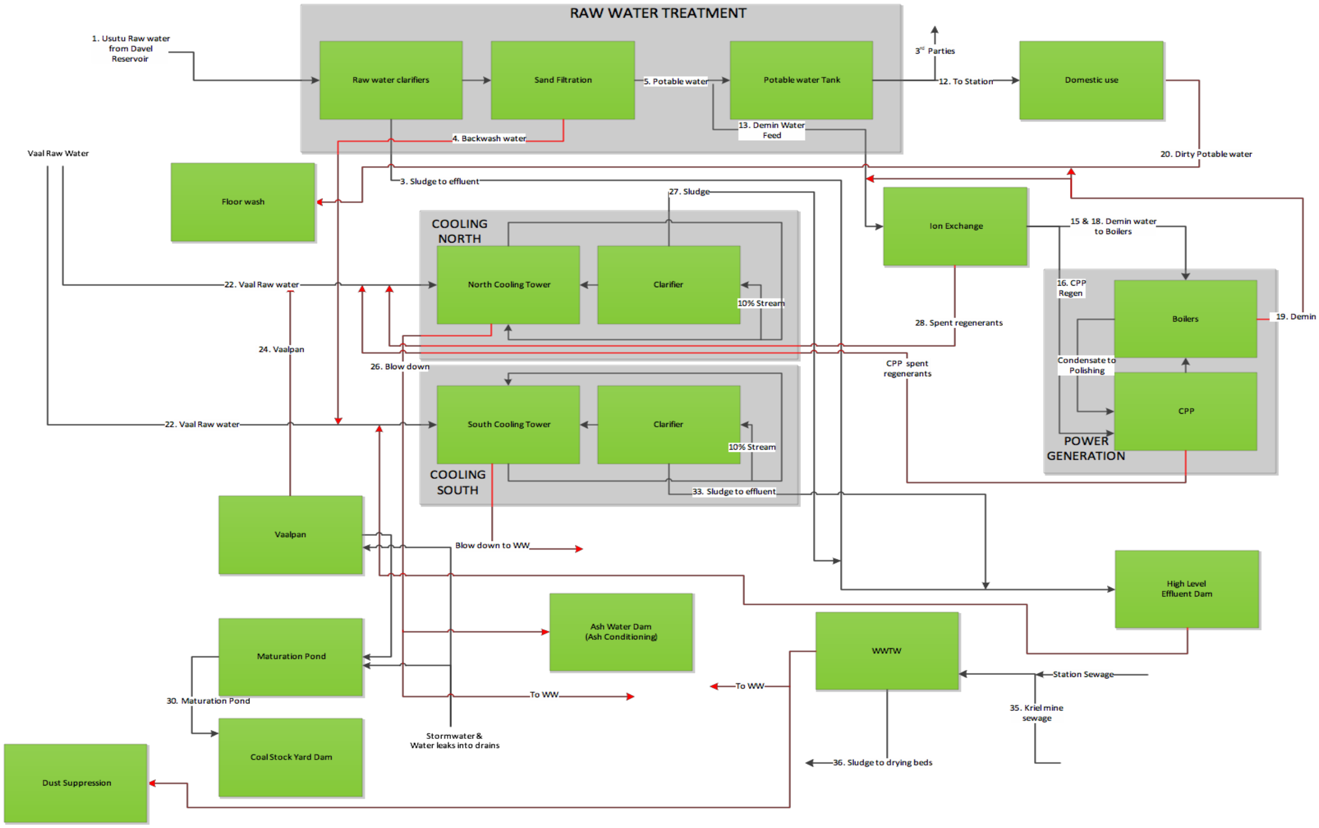
Scenario 5: Freshwater intake (103 800 m^3/d)



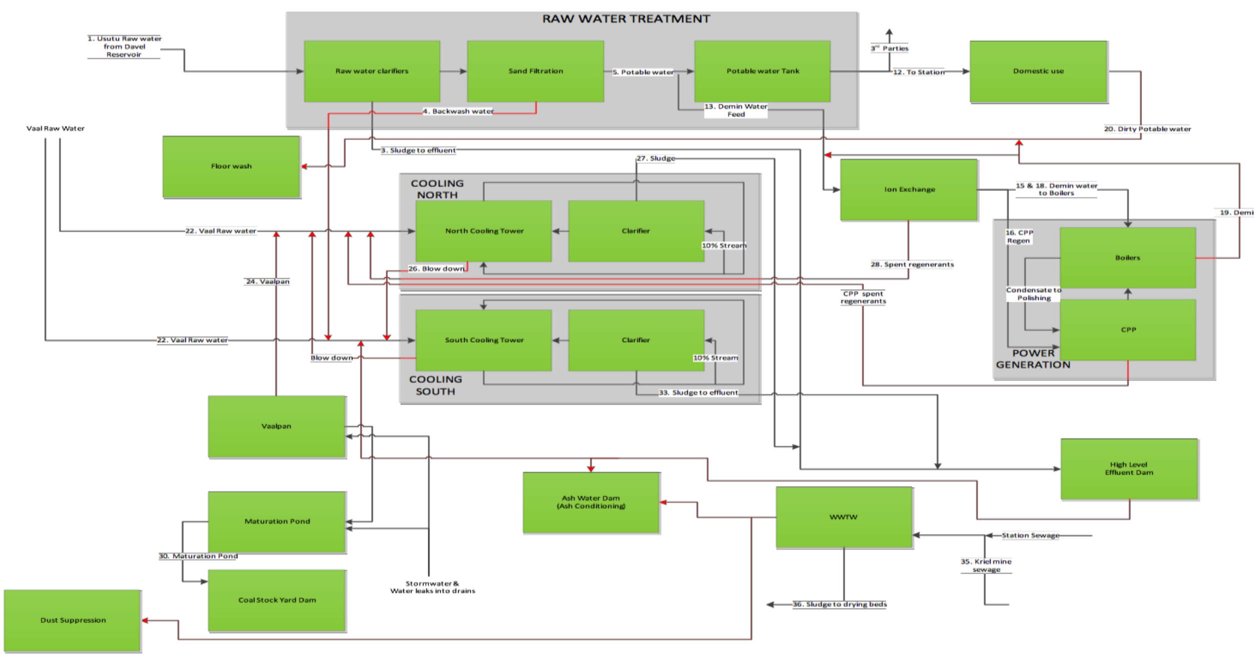
Scenario 6: Freshwater intake (96 801m^3/d)



Scenario 7: Freshwater intake (104 651 m^3/d)



Scenario 8: Freshwater intake (95 591 m^3/d)



APPENDIX II: Testing a New Water Network With a Cooling Tower Mass Balance.

This example illustrates how the mass balances and operational conditions for the cooling towers have to be evaluated carefully for each suggested water network before implementing changes.

Figure 23 contains data from one of the water networks suggested by the model for a scenario incorporating blowdown interchange. The total freshwater intake for this scenario was 95Ml/d and no wastewater was produces. The quality data of the streams is taken from the model for TDS and estimated values for sulphates.

Table 20. Example Stream flows and qualities

Streams into CTN					
	Flow (m3/d)	SO4 Content(mg/kg)	Fractional TDS		Fractional TDS
Effluent dam	833.3	331	5.78473	1965	34.34137
SF1	181.1	100	0.379815	70	0.265871
CPP	208.22	15	0.065504	128	0.558967
Boilers	0	1	0	3.2	0
Ps potable	588.285	100	1.233791	58	0.715599
IX	518.9	15	0.163241	128	1.392988
Vaal	351.3	435	3.204949	1150	8.472853
CTS blowdn	6000	750	94.37701	2600	327.1736
Fw vaal	39000	15	12.26901	130	106.3314
TOTAL	47681.105				
AVG (mg/kg)		117.4780471		479.3	

Streams into CTS					
	Flow (m3/d)	SO4 Content(mg/kg)	Fractional TDS		Fractional TDS
Effluent dam	847.1	331	5.511581	1965	34.91009
SF1	181.3	100	0.356456	70	0.266164
CPP	208.6	15	0.06152	128	0.559987
Boilers	0	1	0	3.2	0
Ps potable	589.6	100	1.159219	58	0.717198
IX	520	15	0.153357	128	1.395941
Vaal	357.3	435	3.055838	1150	8.617565
CTN blowdn	3066.7	750	45.22105	2600	167.2239
Fwvaal	45102.3	15	13.30142	130	122.969
TOTAL	50872.9				
AVG		68.82044393		336.7	

Of interest for our discussion are the average sulphate and TDS contents of the streams going into each cooling tower. Per definition the cycles of concentration is the concentration of the cooling water divided by the concentration of the make-up water. The station’s upper limits for the concentration of TDS in the cooling water are 2600mg/l and 750mg/l for sulphates (if the most conservative standard is used).

When the maximum CoC that can be allowed for the South cooling tower is calculated for instance we find it to be 750/68.8 = 10.9 for sulphates and 2600/336.7 = 7.7 for TDS. For the North cooling towers the values are 6.4 and 5.4 respectively. This water network can therefore not be blindly employed and the cooling towers operated at CoC's higher than these values without violating set