Developing methods to access sensitive industrial wastewater information in South Africa (with treatment in mind)

G E Harding
BSc (Chem) Eng (UCT)

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Executive summary

South Africa is a water stressed country, therefore it is important to understand water use and wastewater generation. Previous research and workshops have identified gaps in the characterisation and remediation of wastewaters in South Africa. Wastewater management can take advantage of wastewater as a valuable resource. However, treatment is required to recover this value, while characterisation is required to develop treatments. Yet wastewater characterisation information is often poorly reported. The nature of industrial wastewaters (in terms of volume, location and composition), and the norms of wastewater characterisation reporting (in terms of quality and accessibility) formed the basis for two research questions.

A major component of this research was developing methods to access sensitive wastewater information. Relational approaches were based on building relationships through phone calls, emails, meetings and site visits. Formal, legal requests for were made with application in terms if the Promotion of Access to Information Act (PAIA).

Even though wastewater information is not confidential, it is not readily accessible. 87 people from 42 companies or institutions were contacted; 14% of interactions lead to shared data or a meeting, and 12% shared resources.

Key industries of interest were: pulp and paper, fish processing, power generation, mining and petroleum. Previous estimates of South African industrial wastewater volumes ranged from 70 – 350 Mm^3/annum. The pulp and paper industry contributed between 28 and 43% of this volume; petroleum contributed 9 to 26%. Both industries were located inland and in coastal regions of South Africa. These industries were most concerned with COD. Mining and power generation contributed 10 – 15% and 7 – 14% respectively. These industries were located inland, and were concerned with total dissolved solids, and specifically sulphate, sodium and chlorides. The fish processing industry contributed between 0 and 23% of volumes, depending whether wastewaters released to a marine environment were included.

Seven parameters were reported for over half of the streams considered (65 in total). These parameters were: pH, volume, electrical conductivity, nitrogen, sulphate, sodium and COD. Sulphate and sodium were dominant ions. Calcium was not measured, even though discharge limits were listed in environmental licenses.

Characterisation information was reported for compliance and not for treatability. The parameters measured should be expanded to include important parameters for treatability. Industry, research institution and governmental bodies can work together to identify such parameters and develop locally relevant treatments.

It is recommended that possible synergies between these groupings be enhanced to improve wastewater management. But an atmosphere of trust and transparency is required to facilitate synergistic relationships. The legal framework in South Africa can be used to motivate for transparency with respect to wastewaters.

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List of Abbreviations

AAS	Atomic absorption spectroscopy
AMD	Acid mine drainage
AOX	Adsorbable organic halides
APHA	American Public Health Association
AS	Absorption spectroscopy
AWWA	American Water Works Association
BFD	Block flow diagram
BOD	Biological oxygen demand
CSIR	Council for Scientific and Industrial Research
CWDP	Coastal Water Discharge Permit
DEA	Department of Environmental Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ECA	Environmental Conservation Act
EDR	Electrodialysis reversal
EDTA	Ethylenediaminetetraacetic acid
EIA	Environmental Impact Assessment
EIAMS	Environmental Impact Assessment and Management Strategy
FOG	Fat, oil and grease
GDP	Gross domestic product
ICMA	Integrated Coastal Management Act
KSA	Key strategic areas
KZN	KwaZulu Natal
NATSURV	National Industrial Water & Waste-Water Survey
NEMA	National Environmental Management Act
NWA	National Water Act
PAIA	Promotion of Access to Information Act
RO	Reverse osmosis
RQO	Resource quality objective
RWQO	Resource water quality objective
SAR	Sodium adsorption ratio

SDG	Sustainable development goals
SEV	Specific effluent volume
SWI	Specific water intake
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
UF	Ultrafiltration
UNICEF	United Nations Children’s Fund
UV	Ultaviolet
WA	Waste Act
WAA	Waste Amendment Act
WEF	Water Environment Federation
WHO	World Health Organization
WMA	Water management area
WRC	Water Research Commission
WUL	Water Use Licenses
ZLD	Zero liquid discharge

Some definitions

Brine	A solution with high salt concentration; > 35 000 mg/l (USGS, 2016b)
Characterisation	The act of describing the quantitative nature of a liquid stream
Effluent	See “Wastewater”
Saline stream	A solution with slight, moderate or high salt concentration; between 1 000 mg/l and 35 000 mg/l (USGS, 2016b)
Wastewater	A liquid waste from industrial or other human processes

CHAPTER 1: Introduction

1.1. Background

South Africa is a water stressed country, with Kirk (2015) predicting that South Africa will face high to very high water stress by the year 2040. In light of this, it is necessary to consider how water is used and how water is wasted. Industrial water users recognise this and have responded by implementing water recycling schemes (Claassen and Masangane, 2015). Reuse and recycling schemes require suitable treatment technologies to ensure the reused/recycled water is of an appropriate water quality. To develop treatment technologies research endeavours need to be informed by wastewater characterisation data. Institutions of research and technology development should be able to access wastewater characterisations information to enable research is contextually suitable.

Given the context of water scarcity and water recycling schemes in South Africa, various bodies interested in water research pooled together to determine priority research areas. The Water Research Commission (WRC), Eskom and the Council for Scientific and Industrial Research (CSIR) co-hosted a brine workshop focusing on the current state and future priorities of brine research in South Africa in January 2014. This workshop highlighted the gaps in knowledge and where knowledge did not lead to implementation. Several research priority areas were identified (Claassen and Masangane, 2015).

One of the priority areas included a necessity to understand the wastewaters currently generated in South Africa as an initial step towards designing treatment processes. The physical and chemical characteristics of wastewaters are important in this regard, in addition to quantity (mass or volume). A final priority was to develop treatment methods and/or schemes for complex, multicomponent wastewaters.

These priority areas are in line with the WRC's key strategic areas (KSA). The first KSA, Water Resource Management, broadly relates to this research because it focuses on new ideas and new solutions for a stable and secure water supplies (WRC, 2017a). The third KSA focuses on water use and waste management in domestic, industrial and mining sectors. It seeks to advance policy, technology, science, and management of water supply and wastewater management. Furthermore, it considers reuse of wastewaters to improve productivity, support economic growth, and minimise negative effects on human and environmental health (WRC, 2017b). This is aligned with the sustainable development goals, specifically goal 6.3, which strives to achieve safe water reuse and recycling.

Globally over 80% of wastewater is released into the environment untreated (WWAP, 2017). In high-income countries 70% of municipal and industrial wastewater is treated; 38% in upper-middle income countries; 28% in lower-middle income countries; and only 8% is treated in low-income countries (Sato et al., 2013). Water quality is projected to continue worsening in the next decade (WWAP, 2017). But wastewater management and water availability are linked. In countries that are facing water stress, there is a tendency to approach the problem (and solution) as a challenge of water supply, rather than as a challenge of wastewater management, even though these are intimately connected (WWAP, 2017: pp17).

Wastewater management and treatment can alleviate water supply challenges and provide a sustainable resource. Treatment of wastewaters allows for the recovery of water contained in these waste streams. Wastewaters contain dissolved salts and metals. Therefore treatment allows for the possible recovery of valuable salts, metals and minerals. If the stream contains organic components, this could be bio-digested into gas and fuel. Water, salt and energy recovery provide important economic motivation for water treatment. Finally, wastewaters need to be appropriately treated to reduce potential environmental and social threat posed by these streams.

1.2. Problem statement

Water users endeavour to reduce their water footprint and comply with the hierarchy of waste management (Figure 1). This means that water users need to consider and practice waste minimisation techniques. In this context zero liquid discharge (ZLD) is an ideal in wastewater management. This means that wastewater is treated to recover all water and dispose of only solid waste. Several treatment technologies exist for treating water that can be used in treatment schemes. Primary treatment technologies often generate secondary wastewaters with reduced volume, but more complex, multicomponent chemistry. New technologies are required to address secondary wastewaters with increasing complexity.

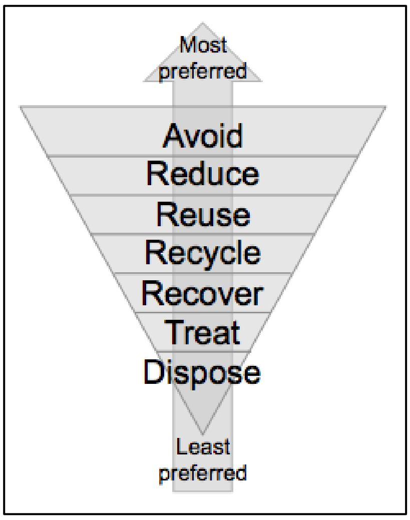

Figure 1: Hierarchy of waste management (DEA, 2011)

Figure 2 illustrates a simplified interpretation of industries' interaction with water. Generally, water is abstracted from an appropriate source and pre-treated to the required quality for use. The feed water can become polluted as it interacts with materials in industrial processes. The primary wastewater stream is often dilute in composition and large in volume. Most industries treat this wastewater, using various primary treatment technologies depending on the industry and the wastewater. Treated water can be recycled back for reuse. Primary treatment technologies can generate a secondary wastewater. These can be treated in secondary, tertiary and more treatments schemes toward ZLD.

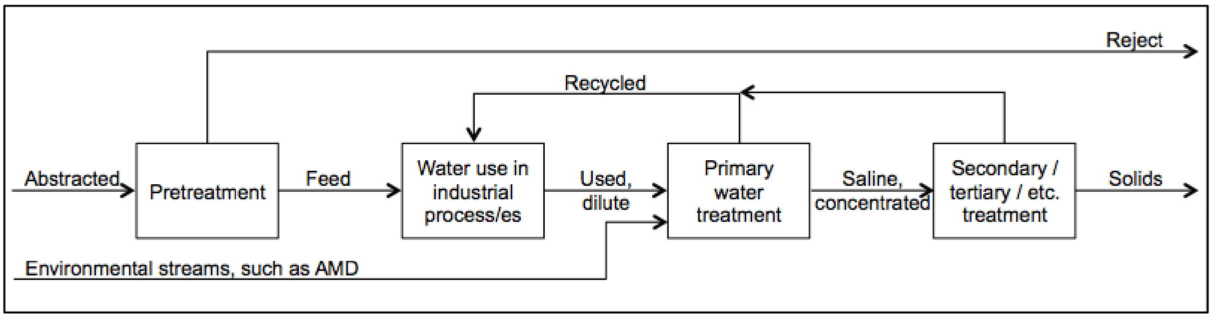

Figure 2: An ideal but simplified interpretation of industries' interaction with water

Wastewater characterisation lays the foundations for responsible and sustainable water use. This is because wastewater characterisation is first step in developing appropriate methods for treatment and handling of wastewater, which in turn translates to implementation in industry, including water reuse and recycling, and therefore less wastewater.

Simultaneously, wastewater characterisation information is sensitive and not readily assessable in the public domain. Companies disclose this information, in confidence, when they require additional treatment. This information is not available for concerned citizens and researchers interested in treatment schemes and technologies for industrial wastewaters. The absence of accessible comprehensive characterisation information limits the ability of research endeavours to address the needs of local industry.

Furthermore, wastewater characterisation data quality and reporting is variable (Cloete et al., 2010). Meaningful wastewater characterisation data needs to consider a comprehensive list of parameters that are relevant to technology development.

This project assumes that characterisation data for industrial wastewaters exists, but in private or inaccessible records. Records held by governmental departments, although publically accessible, often require legal processes to gain access. Private companies are often reluctant to release wastewater information, citing concerns about confidentiality, reputation and possible prosecution (Cloete et a., 2010).

1.3. Research question

Water users generally generate wastewater. While wastewaters are often considered as a waste stream, they are also a potential resource. The value in wastewater may be in the form of recoverable water, salts, minerals, metals or energy. Appropriate treatment technologies are required to recover these resources. Treatment of wastewater has the additional benefit of reducing environmental and/or social threat posed by wastewaters. New treatment technologies are required to handle waste streams with increasing complexity. The development of such technologies requires comprehensive characterisations information for local industrial wastewater. Additionally, access to wastewater characterisation information can promote the relevance of research endeavours.

In light of the above, the following research questions are driving this research. First, **what is the nature of South African industrial wastewaters?** What are the physical, chemical and biological components in industrial wastewaters; in what volume; and where? The second research question is: **What are the norms of South African industrial wastewater characterisation and reporting?** This question is asking how comprehensive, consistent, correct and accessible characterisation information and reporting is across a number of industries.

1.4. Aim and objectives

The main aim of this project is to determine the nature and norms of industrial wastewaters from major industries in South Africa, and the reporting thereof.

Therefore, the objectives are to:

1. Identify major industrial generators of wastewater in South Africa;
2. Assess the nature of these wastewaters, in terms of volume, location and composition;
3. Assess the norms of wastewater characterisation reporting, in terms of quality and accessibility.

The first objective sets the scope for this research. This objective will be addressed through a literature review.

The second objective addresses the first research question, by assessing the nature of industrial wastewaters. Appropriate sources of information are identified, and then methodologies to access this information are developed.

The third objective is to evaluate the norms of wastewater characterisation reporting in South Africa, both in terms of quality of reporting of characterisation data and regarding the accessibility of wastewater characterisation information.

1.5. Scope and limitations

Five industries generating wastewater in South Africa were considered in this research. These were the pulp and paper, fish processing, power generation, mining (limited to gold and coal), and petroleum industries.

Wastewater samples were not collected and tested directly; no primary data was collected. Secondary data was sourced to answer the aims and objectives. The secondary data illuminated wastewater characterisation in terms of key components and species to each industry and showed the reporting norms for wastewater characterisation data. Analysis was limited by what information was available in open access sources and what could be unlocked from the government and private sector.

Wastewater details are sensitive and often considered confidential. Therefore the data presented was dependent on the data that could be accessed. Private companies were reluctant to release their sensitive information, and governmental bodies were equally unwilling to release environmental permits and licenses.

1.6. Plan of development

1.6.1. Introduction

This chapter introduces the project, its background, problem statement and research questions. The scope and limitations have been discussed above.

1.6.2. Theory and literature review

The research questions ask about the nature and norms of wastewater characterisation and reporting in South Africa. Chapter Two will consider water characterisation parameters; a global and South African look at wastewater, including existing research regarding wastewaters in South Africa; and the legal framework in which industry operate. This provides the necessary foundation to begin answering the research questions, and also sets the scope of the research by address the first objective. The chapter concludes by highlighting the gaps in knowledge, and the key questions of the research.

1.6.3. Research approach and methodology

The research approach details how each of the key questions is answered. First, the industries of interest are determined through a literature review (presented in Chapter 2, Section 2.3), and this is used to guide the remainder of the research. Data is found in published, public and private sources; and relational and formal approaches are used to access information. Levels of analysis were completed through literature reviews, synthesising literature and case studies.

1.6.4. Results and discussion – Wastewater location, volume and composition

This is the first of two results chapters. This chapter covers preliminary results and explores the locations, volumes, and basic compositions of wastewaters. The data has been collected from local and global published literature and has been reanalysed and synthesised.

1.6.5. Results and discussion – Wastewater characterisation and reporting norms

The second results chapter considers the information accessed from industry and government departments. This chapter considers the accessibility of wastewater information; considering the outcomes of relational and formal approaches to accessing information. The reporting norms of characterisation are considered by the level of detail and number of parameters listed in various source documents. Case studies of wastewater streams characterised and reported in each industry are presented to answer the nature of industrial wastewaters in South Africa.

1.6.6. Conclusions and recommendations

This section looks back to the objectives and key questions and in doing so draws conclusions from the research. Based on this, recommendations are made.

CHAPTER 2: Theory and literature review

This chapter will address theory relating to water characterisation and wastewater generation globally and in South Africa. It will provide insights into the legal framework around discharging wastewaters and access to information in South Africa. The chapter will conclude with by motivating the need for this project, including the gaps in current knowledge that this project aims to fill.

2.1. Water characterisation parameters

Water quality is characterised by a number of different parameters. Characterisation parameters can range from partial and broad, to comprehensive and specific. Private companies monitor wastewater quality in terms of major parameters and components that are specified in operating or discharge licenses. Detailed water quality characterisation would be performed when considering treatment or possible reuse of a wastewater stream. Treatment requirements depend on water quality and therefore wastewater characterisation.

Comprehensive characterisation of wastewater can inform research endeavours and technology development for the treatment of wastewaters with increasing complexity (complex, multicomponent). The following section will discuss a range of parameters that can be used to characterise wastewaters.

Cloete et al. (2010) refer to water quality in terms of physical, chemical and biological parameters. Physical parameters include temperature and sediment loading; chemical parameters indicate the salinity of the water; biological parameters refer to organic nutrients in the water. They also note that metals are increasingly important, as well as manufactured organic components (herbicides, pesticides) and microbial contamination (from untreated sewage).

Zibi (2016) proposed a brine characterisation protocol that considered water analysis in two broad categories: general measurements and major and trace element analysis. Major and trace element analysis was considered in four sub-categories, including (i) anions and cations; (ii) ammonia and phosphates; (iii) trace elements, and (iv) other.

2.1.1. General parameters

General parameters include pH and solids. Solids can be suspended or dissolved, which in turn impact other measurements such as turbidity, salinity and conductivity. One might consider in-situ temperature measurements in this grouping.

2.1.1.1. pH, acidity and alkalinity

pH is a measure of acidity or basicity/alkalinity. It is related to the concentration of hydrogen ions (H^+), by Equation 1.

$pH = -\log_{10}[H^+]$ **Equation 1**

The neutral pH of water (at 24 ℃) is 7. A pH below 7 is acidic, with lower values representing stronger acids. The acidity of a sample is its capacity to react with a strong base (APHA et al., 1999: 2-24). A pH above 7 is basic, with higher values representing stronger bases. Alkalinity is the neutralising capacity of a sample (APHA et al., 1999:2-26).

pH can be measured with a pH meter. This has electrodes that measure the voltage of the sample and compares it to a standard solution to calculate the pH. A laboratory pH meter can be accurate to ± 0.02 pH units (Golterman et al., 1978: 53) / ± 0.05 pH units (APHA et al., 1998: 2-25). Calibration with known buffer solutions maintains the accuracy of a pH meter.

The pH of a solution can contribute to metal solubility (and therefore toxicity); corrosiveness, chemical reaction rates, chemical speciation, and biological processes (APHA et al., 1998: 2-24).

2.1.1.2. Solids

Solids are either suspended or dissolved in water. Total suspended solids (TSS) is a measure of material that is retained by a filter, while total dissolved solids (TDS) is the material that passes through a filter (APHA et al., 1998: 2-54).

TSS is measured by passing a sample through filter paper with a pore size of 2.0μm. The retained material can be weighed. Total solids and/or TDS can be determined gravimetrically, by drying a sample of known volume in an oven at a specific temperature. The remaining solids can then be weighed. To determine total solids one would use a sample directly; while to determine TDS one would first filter a sample to remove suspended solids (eg. South African National Standard, 2013).

Solids in water can be unpalatable and an eyesore when present in high amounts. Solids may adversely affect treatment processes.

The TDS content of wastewater is a commonly reported parameter. However, it is insufficient information to design certain treatment systems. For example, reverse osmosis (RO) units depend on the molar concentration of dissolved species and the dissociation of the species. Scaling in a eutectic freeze crystallisation unit is related to the solute concentration of dissolved species present (Pronk et al., 2006). Therefore greater detail of what species contribute to the TDS is required for treatment of wastewater streams.

2.1.1.3. Turbidity

TSS are associated with turbidity. Turbidity is an optical property, measuring the amount by which suspended solids and colloidal material cause light to be scattered and absorbed (APHA et al., 1999).

Turbidity can be measured with a nephelometer. The device has a light source and light detector. The intensity of light scattered through a sample is compared to the intensity of light scattered through a standard reference. Light scattering is related to the turbidity (APHA et al., 1998: 2-9). Water clarity is important for potable water, or where water is used in products for human consumption (food and beverages).

2.1.1.4. Salinity

Salinity is an indication of the amount of dissolved solids in a water sample (APHA et al., 1999). Originally it was conceived as a unitless measure, of mass of dissolved salts per mass of solution. The United States Geological Survey defines water quality, in terms of salinity, as follows (USGS, 2016b):

Fresh water:	< 1 000 mg/l
Slightly saline:	1 000 – 3 000 mg/l
Moderately saline:	3 000 – 10 000 mg/l
Very saline:	10 000 – 35 000 mg/l
Briny water:	> 35 000 mg/l

Salinity is often measured indirectly, via conductivity, density, speed of sound, or refractive index (APHA et al., 1998: 2-48). Conductivity and density methods are preferred for their sensitivity and precision.

The salinity of a water body is dependant on its source (for example sea water has a high salinity, of approximately 35 000 mg/l, while fresh or river water will have a low salinity). Industrial discharges can change the salinity of a receiving water body for a period of time or in a ‘sacrificial’ area (DWAF, 1995).

Much like TDS, greater detail around the particular species contributing to salinity is required for the treatment of wastewater streams with appreciable salinity.

2.1.1.5. Conductivity

Conductivity is a measure of a samples ability to carry an electric current (APHA et al., 1998: 2-44). Conductivity is a function of ion identity, concentration, mobility, and valence. Inorganic aqueous solutions are generally good conductors. Poorly dissociating organic compounds in solution have poor to no conductivity (APHA et al., 1998: 2-44).

Conductivity can be measured with a conductivity meter, which operates similarly to a pH meter. It consists of a probe with electrodes that measures the potential difference between the solution and a standard solution. Calibrating buffer solutions should be used to maintain accurate measurement.

A conductivity measurement can be used to indicate salinity and TDS. This is because the conductivity of a sample is owing to the presence of dissolved ions. A linear relationship can be used reasonably well to predict dissolved solids from a known electrical conductivity, using a conversion factor, f, as in Equation 2:

$$Total\ dissolved\ solids = f \times Conductivity$$ **Equation 2**

The conversion factor varies depending on the dominant ions (van Niekerk et al., 2014). Higher conversion factors, greater than 0.70 were associated with high alkalinity and magnesium. Lower conversion factors, in the range of 0.50 to 0.55, were associated with dominant sodium chloride ions. Conversion factors in the range of 0.63 to 0.65 were associated with dominant chloride and sulphate ions (van Niekerk et al., 2014).

In a study of 45 South African mine water samples in Gauteng and Mpumalanga, Hubert and Wolkersdorfer (2015) determined appropriate conversion factors between electrical conductivity and TDS. They recommended that for waters with electrical conductivities of less than 5 000 µS/cm a conversion factor of 0.97 could be used to approximate dissolved solids in mg/l.

2.1.2. Anions, cations and trace elements

2.1.2.1. Anions

Anions are negatively charged ions. Anions can be determined using ion chromatography (APHA et al., 1998: 4-2). Anions of the carbonate system, such as carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), as well as hydroxyl ions (OH^-), contribute to the total alkalinity of a wastewater.

2.1.2.2. Cations

Cations are positively charged ions. Major cations are sodium, calcium, magnesium and potassium. Sodium can negatively impact soil quality (Ayers and Westcot, 1994). Calcium and magnesium cations are associated with hardness.

2.1.2.3. Hardness

Total hardness is expressed as calcium carbonate in mg/l (APHA et al., 1998: 2-36). Hardness can be calculated by titration with ethylenediaminetetraacetic acid (EDTA); or as a sum of calcium and magnesium concentrations. A high measure of hardness is associated with scaling problems (IPIECA, 2010), which can damage equipment. Calcium is therefore an important parameter to assess the treatability of a stream.

2.1.2.4. Trace elements

Trace elements can be ecologically beneficial, troublesome or toxic. The effect that trace elements can have on a receiving environment depends on the species' identity and the concentration in which they are present (APHA et al., 1998: 3-1). Many elements can be measured by atomic absorption spectroscopy (AAS) or inductively coupled plasma mass spectrometry (ICP-MS), amongst other techniques.

2.1.3. TOC, COD and BOD

Total organic carbon (TOC), chemical oxygen demand (COD) and biological oxygen demand (BOD) are all measures of the organic content in wastewater. TOC, COD and BOD measure the amount of oxygen required to break down and decompose organic material. COD is a measure of all oxidisable chemicals; BOD is a measure of organic carbon oxidisable by bacteria (Fuller, 2016). These parameters are related, where TOC is an umbrella that can be categorised into non-oxidisable and oxidisable carbon. Oxidisable carbon (measured in COD) can be further categorised into biologically degradable (measured in BOD) and non-biologically degradable material. High TOC, COD and BOD deoxygenate water and can lead to algal blooms and death of aquatic life.

2.1.4. Nitrogen systems

Nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3) and organic nitrogen are different forms of nitrogen. Nitrate and nitrite are oxidised forms of nitrogen. Organic and ammonia nitrogen can be determined using Kjeldahl nitrogen method. Total nitrogen can be determined by complete oxidation all the various nitrogen compounds, followed by a measurement for nitrate (APHA et al., 1998: 4-99). Nitrogen is a nutrient necessary for plant and animal life. However excess quantities decrease the dissolved oxygen content in water and result in the eutrophication of a body of water (USGS, 2017a).

2.1.5. Phosphate systems

Phosphate measurements include total and orthophosphate. Orthophosphate can be measured using colourimetric methods. Total phosphate (including orth-, organic- and poly-phosphates) are hydrolysed with sulphuric acid to orthophosphate and then measured colourimetrically (Golterman et al., 1978). Phosphorous is a nutrient, which can decrease available oxygen and increases eutrophication (USGS, 2017b).

2.1.6. Other parameters

Other parameters that can be considered in comprehensive wastewater characterisation include detailing metals, inorganic non-metals, other organic components (phenols, volatile organics, surfactants, tannins, lignins, amongst other specific organic compounds), radioactive species, toxic species, biological and microbiological components. Biological parameters are usually of low relevance with respect to industrial wastewaters.

2.2. A global look at wastewater

The right to access clean water and sanitation is a globally recognised human right. Sustainable development goal (SDG) 6 is to “ensure availability and sustainable management of water and sanitation for all” (UN, 2017). SDG 6.3 relates to wastewater. It is to improve water quality by 2030, through reduction of pollution and dumping, by increasing the amount of wastewater treated, and by increasing safe water recycling and reuse (UN, 2017). These global goals ask local people to take actions that protect water resources from pollution (UNGA, 2014 in WWAP, 2017).

2.2.1. Water use and wastewater generation

Agriculture is a major user of freshwater resources (70%), but water demands of industry and energy are growing (WWAP, 2017). Globally 3 928 km^3 of freshwater is abstracted per annum. Figure 3 shows the portion of this water that is consumed and discharged (WWAP, 2017). Agricultural, municipal and industrial consumption accounts for 44%. The remaining 56% is wastewater; with 16% arising from industry.

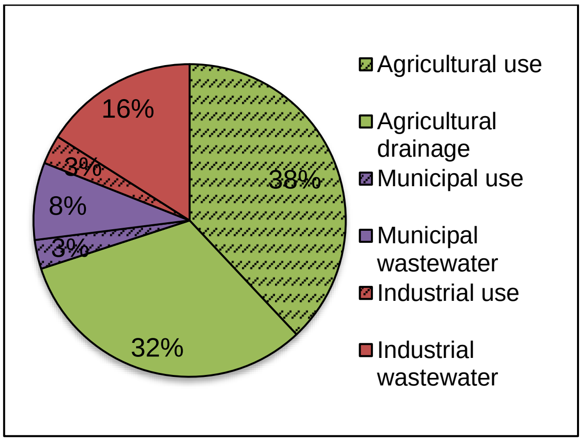

Figure 3: Global consumption and wastewater production by major sectors in 2010 (WWAP, 2017)

Major industrial sectors are: mining and quarrying; manufacturing; production and distribution of electricity; and construction. Other industries include: pulp and paper; iron and steel; food industries; brewing; dairies; organic chemicals; and textiles.

Wastewater quality is as critical, if not more important, than wastewater volumes arising from different industries. This is because "the toxicity, mobility and loading of industrial pollutants have potentially more significant impacts on water resources, human health and the environment than actual volumes of water" (WWAP, 2017). Furthermore, there is a paradigm shift from wastewaters as waste to viewing wastewater as a resource, resulting in a growing market for industrial water treatment. This market is projected to grow by 50% between 2015 and 2020 (GWI, 2015 in WWAP, 2015).

2.2.2. Benefits and co-benefits of wastewater treatment

Wastewater use and by-product recovery present new business opportunities in a world that is moving toward circular economies. Considering the business case for wastewater, recovered resources contribute to covering the cost of new or retrofitted infrastructure (Irina Bokova in WWAP, 2017). Still, wastewater is perceived to be a burden and is underexploited as a potential resource (WWAP, 2017).

In addition to recoverable resources, a number of co-benefits of wastewater treatment exist. These include (WWAP, 2017):

- Improvements to human health;
- Greater gender equity (because women and girls are mainly responsible for collecting water (UNICEF/WHO, 2011), and are disproportionately exposed to health risks associated with poor quality water (Moriarty et al., 2004));
- Improved environmental health;
- Increased water security;
- Increased food security (if appropriately treated wastewater can be used to supplement and/or replace water for agriculture);

- Increased energy security (if appropriately treated wastewater can be used to supplement and/or replace water for power generation);
- Improved climate change mitigation capabilities (wastewater management can help bridge the gap between water supply and demand in a future where climate change projections predict increasing discrepancies); and
- Improved livelihoods.

The above suggests that considering the intersection of global challenges, wastewater management will need to be part of an integrated solution. For example, Hutton and Haller (2004) (in WWAP, 2017) suggest that a US$1 investment in sanitation can return US$5.5 worth of benefits. These benefits include saving time (with better access to water and sanitation facilities), gain in productive time and less time ill, saving in health treatment costs of serving sick patients, and value through prevented deaths (Hutton and Haller, 2004).

2.2.3. Data and governance

While wastewater can be considered as a valuable resource, it is necessary to support this with appropriate and necessary data. For example, SDG 6.3 relies on two indicators; the first is the proportion of wastewater safely treated, and the second is the proportion of water bodies with good ambient water quality (WWAP, 2017 pp25). However, data on water quality and wastewater management is deficient, with particular deficiency in developing countries (WWAP, 2017). This makes monitoring progress of this particular SDG a challenge. UN-Water (2016a in WWAP, 2017) explain that "reliable data generate social, economic and environmental benefits in both public and private sectors as they can underpin advocacy, stimulate political commitment and investments, and inform decision-making on all levels". In other words, technology development, governance, activism, regulations and monitoring all depend on appropriate data to inform action.

Data on volume of wastewater, quality of wastewater, wastewater collection, and wastewater treatment is inadequate globally, but with particular concern in developing countries. Sato et al. (2013) studied data from 181 countries, on three aspects of wastewater: generation, treatment and use. Figure 4 shows the percentage of countries with data available for one, two or three of these aspects; and Figure 5 shows the age of the data.

They found 55 countries (30%) had reliable data on all three aspects; 69 countries (38%) had information on one or two aspects, while the other 57 countries had no information (32%). Also, only 37% of data was considered recent (reported within the five years preceding the publication, i.e. between 2008 and 2012).

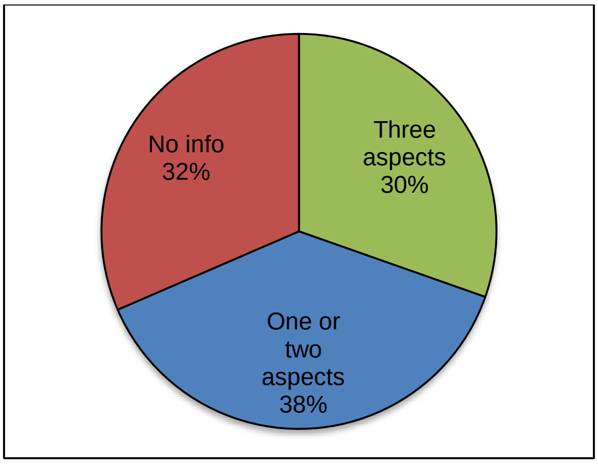

Figure 4: Countries with all, some or no information of wastewater generation, treatment and/or use (Sato et al., 2013)

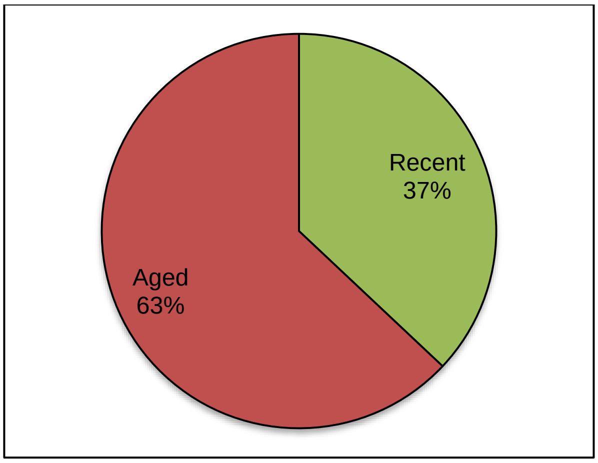

Figure 5: Age of wastewater information (Sato et al., 2013). "Recent" data is from five years before the publication. "Aged" data older than 5 years.

Collecting, collating and comparing data nationally and globally is a challenge because of gaps in data, insufficient or variable detail, and inconsistencies within and between countries. In order to coordinate water use, consumption, wastewater generation and discharge these gaps will need to be addressed (WWAP, 2017).

For regulation to be effective, and where no or little regulation is currently in place, Helmer and Hespanhol (1997) suggest that initially limiting that number of variables in water quality objectives is more effective than measuring a broad range of parameters poorly. They add that this focuses attention on crucial water quality variables, which can significantly improve water quality at a limited cost. However, a few critical parameters may be insufficient to comprehensively understand the state of wastewater, what resources it may hold, and what treatment it may require.

2.2.4. Looking at Africa

It is already noted there are challenges with data, particularly in the global south. In sub-Saharan Africa, 32 of 48 countries had no data available on wastewater treatment and generation (Sato et al., 2013). Notable exceptions are Senegal, Seychelles and South Africa, where "complete information on wastewater generation, treatment, and use" are available. However, the information for Seychelles and South Africa dated to 2000 and 2003 respectively (Sato et al., 2013). While knowing the volumes of wastewater is valuable, information describing wastewater quality is not reported.

Many factors contribute to an increasing gap between water availability and demand in Africa. These include political, financial, infrastructural and human resource challenges (WWAP, 2017). This is projected to worsen as urban populations grow (World Bank, 2012). Competing water users, as well as ongoing wastewater quality issues, compound struggles of water availability. In addition to domestic wastewater, major industries in Africa are mining, oil and gas, logging, and manufacturing.

2.2.5. Summary of the global position

Water and wastewater management are fundamentally linked with the human right to water and dignified sanitation. Wastewater management also can contribute to major global challenges (health; gender equality; water, food and energy security; climate change). However, this requires data at an appropriate resolution as well as good governance. These challenges are felt strongly in Africa. The final words of the WWAP's (2017) report on wastewater are as follows:

> *"In a world where demands for freshwater are continuously growing, and where limited water resources are increasingly stressed by over-abstraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable in the context of a circular economy."*

2.3. Generation and distribution of wastewater in South Africa

The main aim of this section of the literature review is to address the first objective, by determining which industries are of interest in terms of wastewater generation. Volumes of wastewater generated from South African industry previously studied will be examined in Section 2.3.1. Previous studies also reported crude wastewater quality characterisations by industry, which is considered in Section 2.3.2. Section 2.3.3 will provide a literature review of water use, wastewater generation and qualitative nature of wastewaters in the key industries identified.

2.3.1. Volumes of wastewater streams by industry

Previous research projects have examined water use and wastewater generation in South Africa. Two of these include the reports and databases developed by van der Merwe et al. (2009) and Cloete et al. (2010), regarding wastewater generation by sector in South Africa. A distribution of wastewater generation by sector is shown in Figure 6 and Figure 7. Van der Merwe et al. (2009) report a total wastewater volume of 962 000 kL/day, which is approximately 350 Mm^3/annum, while Cloete et al. (2010) report 69 Mm^3/annum. This is 20% of the total van der Merwe suggest.

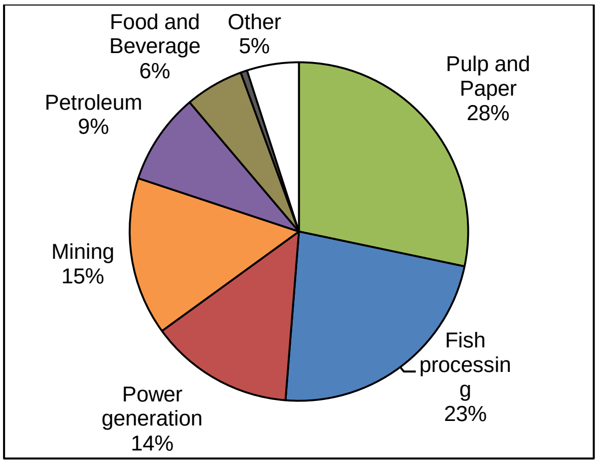

Figure 6: Wastewater generation in South Africa, as understood from van der Merwe et al., 2009.

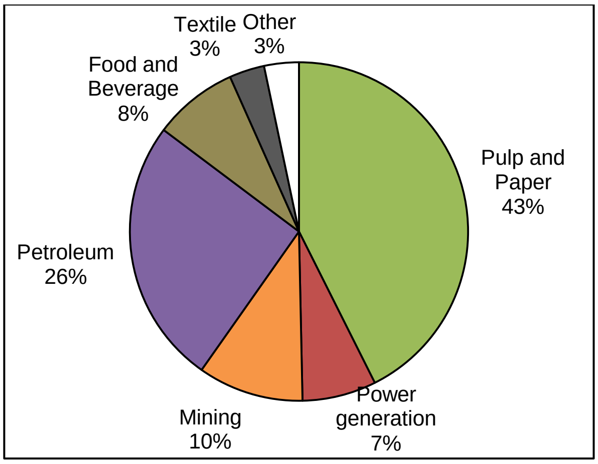

Figure 7: Wastewater generation in South Africa, as understood from Cloete et al., 2010.

Van der Merwe et al. (2009) surveyed 268 companies, with 185 positive responses (69%), from a range of industries. They found that some organisations lacked data or were unwilling to release data for commercial sensitivities.

Cloete et al. (2010) approached metropolitan councils and regional offices of the Department of Water Affairs and Forestry to identify major water users. Thereafter specific organisations were contacted and additional information requested. The information differed from source to source, which they attributed to limited monitoring and reluctance from both public and private bodies to release sensitive information. They noted, “Data for effluent production was often not available or incomplete”.

Nonetheless, in both cases, the pulp and paper industry (green) is the biggest contributor to wastewater generation. Power generation (red), mining (orange), and petroleum (purple) industries are also major contributors. The food and beverage (brown) industry contribute greater than 5% in each case. The textile industry (grey) contributes a small portion in each case. “Other” includes chemicals, pharmaceuticals, cement, metals processing, paint, plastics, tanneries, and waste management.

Van der Merwe et al. (2009) also identified the fish processing (blue) industry as a major contributor. Cloete et al. (2010) included fisheries in their “food and beverage” category, but it was not a significant contributor. This could be because they did not include wastewater discharged to a marine environment in their study. However, that is speculation and not confirmed in their research report.

Van der Merwe et al. (2009) differentiated between wastewaters discharge to marine and inland environments. They reported a total saline volume of 962 000 kL is released per day. Of this, 56% is released to inland environments, and the remaining 44% is discharged to a marine environment. The industries discharging to inland and marine environments are shown in Figure 8 and Figure 9 respectively.

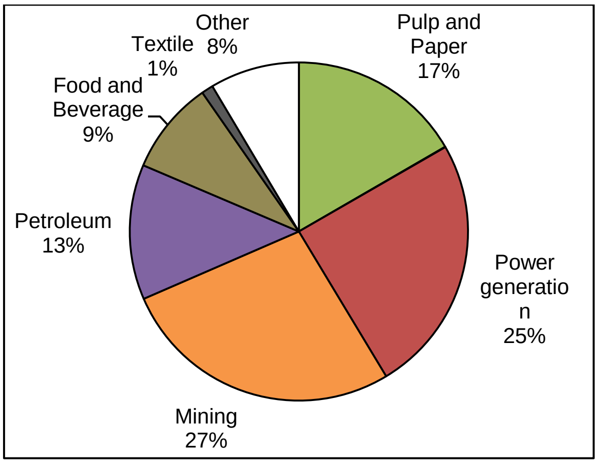

Figure 8: Wastewater discharged inland (56%), adapted from van der Merwe et al., 2009.

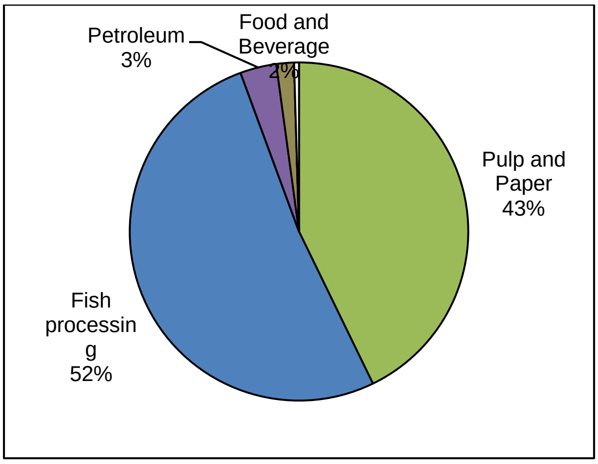

Figure 9: Wastewater discharge to marine environment (44%), adapted from van der Merwe et al., 2009.

Van der Merwe et al. (2009) noted the disposal method for wastewaters at the time of their research. The volumes and discharge locations by industry are plotted in Figure 10. Food, beverage and textiles are grouped into other.

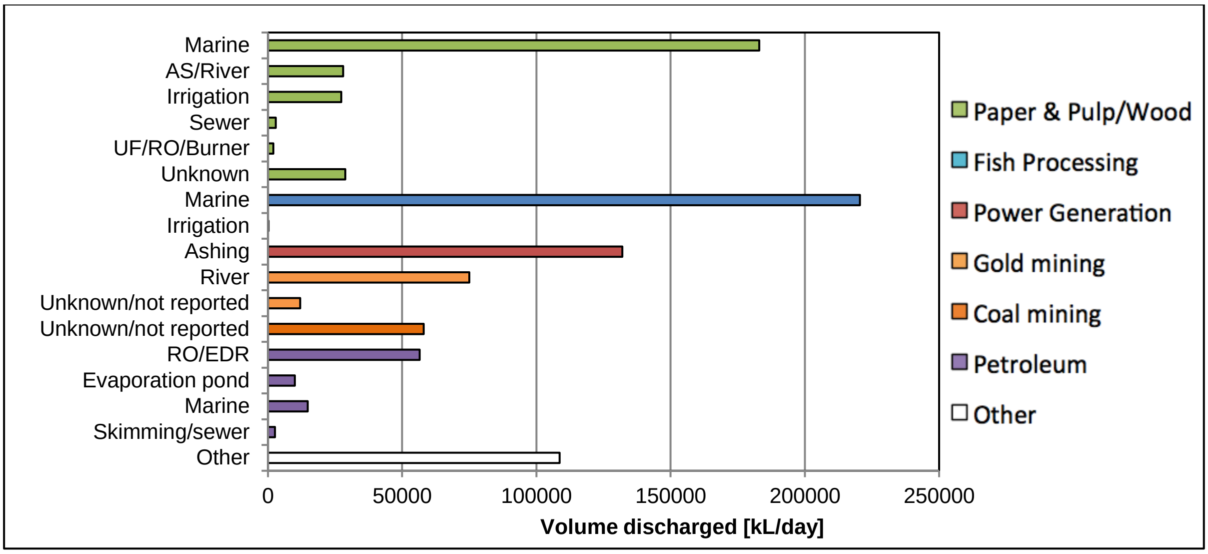

Figure 10: Disposal locations of industrial wastewaters, adapted from van der Merwe et al., 2009.

The Cloete et al. (2010) database considered both water use and wastewater generation. Their results indicated that significant water users might not necessarily be major wastewater generators. Water consumption and wastewater generation by sector are shown alongside each other in Figure 11 and Figure 12. They report water consumption of 326 Mm^3/annum and wastewater generation of 69 Mm^3/annum.

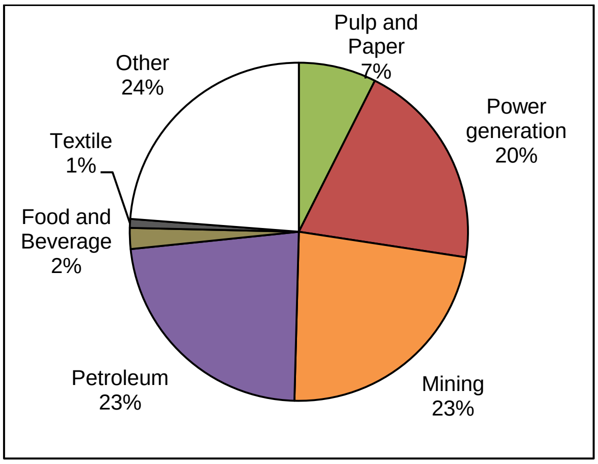

Figure 11: Water consumption by sector (326 Mm^3/annum), adapted from Cloete et al., 2010.

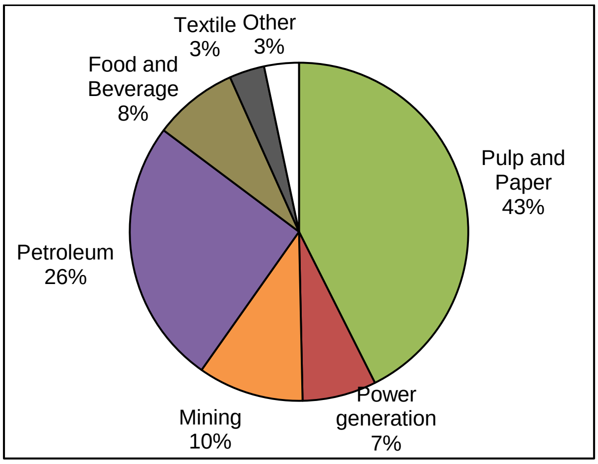

Figure 12: Wastewater generation by sector (69 Mm^3/annum), adapted from Cloete et al., 2010.

2.3.2. Crude wastewater quality characterisation by industry

The volume of wastewater originating from any particular industry does not necessarily correlate with the potential hazard associated with that wastewater. In order to access the potential hazard, and/or the potential value contained in wastewater, comprehensive wastewater quality characterisation is required. The database developed by van der Merwe et al. (2009) captured basic composition information of salinity and COD, given in Table 1.

Table 1: Summary of salinity and COD for different sectors [mg/l] (van der Merwe et al., 2009).

	Pulp and Paper	Fish processing	Power generation	Mining	Petroleum	Food and beverage	Textile
Salinity	118 – 15 000	4 000 – 36 000	1 200	2 000 – 2 800	3 000 – 6 500	280 – 3 000	150 – 4500
$Salinity_{ave}$	4 110	30 570	1 200	2 130	3 270	1 760	850
COD	120 – 32 000	2 000 – 7 800			0 – 1 200	800 – 3 800	430 – 23 000
COD_{ave}	5 580	4 860			620	2 130	5 520

Salinity indicates the total dissolves salts in the sample. However, it does not indicate which species contribute to the salinity, or other dissolved metals/solids that might be present. Knowing the species distribution provides critical insight to determine if and what treatment schemes are necessary and worthwhile. An analysis of ions and metals present provides insight into the potential value in the wastewater and is required to assess treatability.

COD partially indicates the organic content of the stream. Biological treatments can be used to address such contaminants. However certain inorganic components, or other species, may adversely affect the functioning of such biological treatments.

Cloete et al. (2010) used data from a number of different sources, including private companies and metropolitan councils. They found the quality of wastewater data to differ considerably. The quality of wastewater information received ranged from no composition information; through qualitative, vague information (e.g. “mainly organic”, “heavy metals”, “organic/inorganic” or “mixture”); to basic characterisation, (e.g. reporting values for COD, pH, EC, and others). In addition to the range of available information, they experienced difficulties accessing information for fears around confidentiality, fear of prosecution, and/or fear of increased treatment costs.

2.3.3. Water use and wastewater generation by industry

Van der Merwe et al. (2009) and Cloete et al. (2010) identified pulp and paper, fish processing, power generation, mining and petroleum industries as major wastewater generators by volume in South Africa. The following section will report a process overview for each industry of interest, including water use and wastewater sources, and give a qualitative indication of the nature of wastewaters.

2.3.3.1. Pulp and paper

The pulp and paper industry manufactures virgin or recycled wood/paper into one of several products: newsprint, household paper, printing and writing paper, paperboard, corrugated paper (Wen et al., 2016), packaging materials, coffee filters, paper cups and plates, and facial tissues (Ali and Sreekrishnan, 2001).

There are 29 pulp and paper mills operating in South Africa, with five major contributors (Kimberly-Clark, Mondi, Mpact, Sappi and Twinsaver Group). There are eight integrated pulp and paper mills, five paper mills, eleven tissue manufacturers, and five packaging material manufacturers (van der Merwe-Botha, 2017).

The majority of pulp and paper mills are along the coastlines of South Africa. Van der Merwe et al. (2009) reported that the pulp and paper industry was responsible for 28% of saline stream generation; of which 68% (19% of total) is released to marine environments. Cloete et al. (2009) report the pulp and paper industry contributes 43% to wastewater generation.

The unit operations in the pulp and paper can be thought of in three major groups: pulp making, pulp processing and papermaking. A simplified block flow diagram with inputs and outputs is illustrated in Figure 13.

The pulp and paper industry accepts wood (hard or soft), non-wood (straw, reed, bagasse or bamboo) or waste paper as inputs (Wen et al., 2016). Assuming a traditional wood input, the logs are debarked to remove bark, sand and dirt (Kamali and Khodaparast, 2015). Debarking also breaks the wood into smaller wood chips. The wood chips are forwarded to the pulping stage of the process (also called digestion) where a cellulose-rich pulp is produced. Majority of the lignins and hemicellulose are removed here (Ali and Sreekrishnan, 2001). These processes are subsections of the “pulp making” stage. There are a variety of methods to produce pulp, including chemical, mechanical, chemical-mechanical (Wen et al., 2016), thermo-mechanical (Ashrafi et al., 2015) or using a waste pulp. Each method uses a different process and process chemicals, as well as operating conditions.

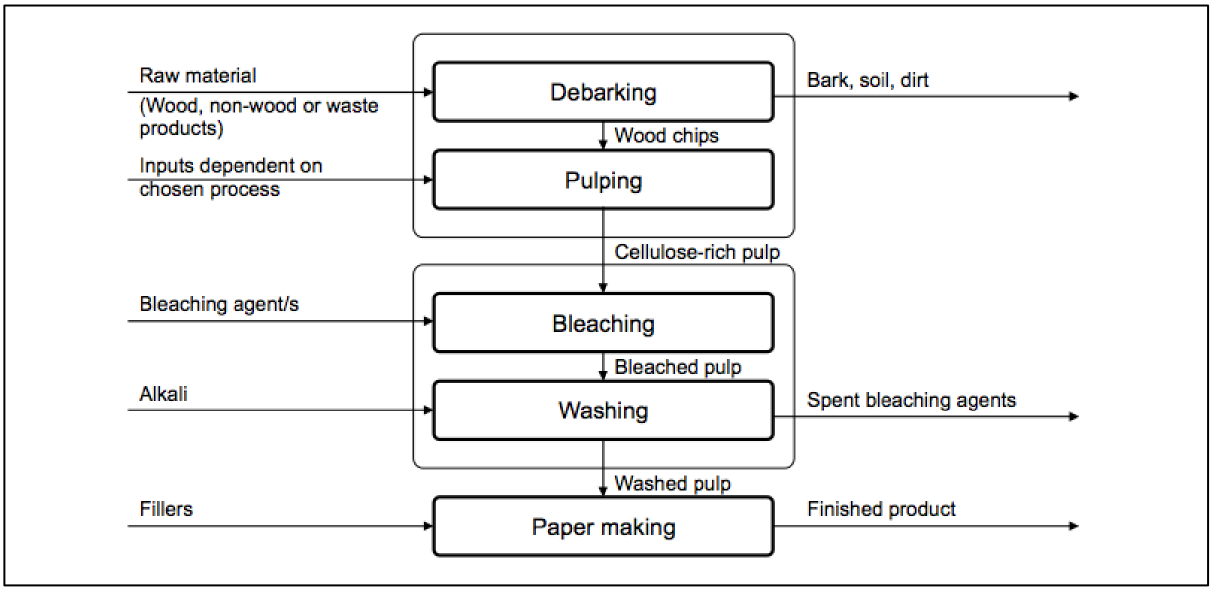

Figure 13: Simplified BFD of unit operations within the pulp and paper industry, adapted from Ali & Sreekrishnan, 2001; Kamali & Khodaparast, 2015.

The pulp is forwarded to the pulp processing stage where bleaching and washing take place. Here pulp may also be screened and thickened (Teschke, 1997; Steffen et al., 1990). The cellulose-rich pulp is brown. Bleaching agents such as chlorine, chlorine dioxide, hydrogen peroxide, oxygen, or ozone may be used individually or in combination with one another. The bleached pulp is sent for washing, in which an alkali is added, to remove the bleaching agent from the pulp.

Finally, the washed pulp can be made into paper (or the desired product). Fillers such as clay, titanium oxide, calcium carbonate and sizing agents may be added (Ali and Sreekrishnan, 2001). The mixture is processed through a paper machine, which presses the pulp into sheets and dries the sheets. The product may be finished with coating chemicals if necessary (Steffen et al., 1990).

Water is used in almost all of the unit operations, including: debarking and wood preparation; pulping; bleaching; and washing. In general wastewater from the pulp and paper industry can contain: chlorinated compounds (lignosulphonic acids, resin acids, phenols, and hydrocarbons); coloured compounds; absorbable organic halogens (AOX); high BOD, COD, suspended solids and toxicity (WWAP, 2017).

In the debarking and wood preparation step, water is used to remove undesired solids. The wastewater generated here contains suspended solids, including soil, dirt and grit, and BOD (Pokhrel and Viraraghavan, 2004).

Pulping requires water, whether to carry pulping chemicals or to modify the consistency of pulp streams (Macdonald, 2004). Each pulping method requires different volume and quality water, and will generate a unique wastewater. Chemical pulping generates particularly high-strength wastewaters (Pokhrel and Viraraghavan, 2004). The Kraft pulping process (which is largely a chemical process) may generate a wastewater high in COD, BOD, resin acids, AOX, compounds containing nitrogen and phosphorus, suspended solids, metals, salts and colour (van der Merwe-Botha et al., 2017). In general, pulping wastewater may contain: resins, fatty acids, BOD, COD and volatile organic compounds such as terpenes, alcohols, phenols, acetone and chloroform (Pokhrel and Viraraghavan, 2004).

Water is used to carry bleaching agents in the bleaching unit operation. Bleaching agents and waste streams from the bleaching plant are often reported as the most toxic liquid waste stream (Savant et al., 2006; Pokhrel and Viraraghavan, 2004). The chlorine chemicals added to bleach the paper react with organic compounds (such as lignins, phenols and resin) transforming them into xenobiotics (Savant et al., 2006; Ali and Sreekrishnan, 2001). Xenobiotic chemicals are chemicals that are not naturally occurring in the ecosystem. Approximately 500 chlorinated chemicals have been identified in the waste streams from pulp and paper mills, including: chloroform, chlorate, resin acids, chlorinated hydrocarbons, phenols, catechols, guaiacols, furans, dioxins, syringols, vanillins and more (Suntio et al., 1988 and Freire et al., 2003 in Savant et al., 2006). These compounds are estimated in waste streams collectively as AOX. It should be noted that chlorine based bleaching process are not used in South African mills today because of the associated environmental impact (van der Merwe-Botha, 2017).

In the washing stage, water is used to remove bleaching agents from the pulp. This wastewater contains BOD, COD, suspended solids and a high pH (Pokhrel and Viraraghavan, 2004). Finally, wastewater from the paper making stage contains COD and inorganic dyes (Pokhrel and Viraraghavan, 2004).

Water pinch technology (matching wastewaters from one unit operation with feed water to another unit operation) can be applied in pulp and paper mills to optimise water use, and minimise wastewater generation (Macdonald, 2004).

2.3.3.2. Fish processing

The fish processing industry processes fish and aquatic invertebrates into food for human consumption, fishmeal for animal feed and value-added products such as leather from the skins of sharks or rays (Islam et al., 2004). Fish is a perishable substance and therefore typically requires significant processing (Islam et al., 2004). Here the word 'fish' is used to refer to more than strictly fish and is inclusive of any aquatic species commercially harvested and processed.

In South Africa the majority of fish processing sites are in the Western Cape. Van der Merwe et al. (2009) reported that the fish processing industry was responsible for 23% of wastewater generation, all of which is released to the marine environment.

The unit operations in the fish processing industry include fish receiving and storage, processing and cooking, as well as canning and packaging. Hygiene and cleanliness standards must be maintained in processing factories because some of the product is intended for human consumption. Therefore, washing of fish, cans and process equipment is also a major operation within these plants. A simplified block flow diagram is illustrated in Figure 14. Other operations within the fish processing industry produce fishmeal and fish oil, via a different set of unit operations.

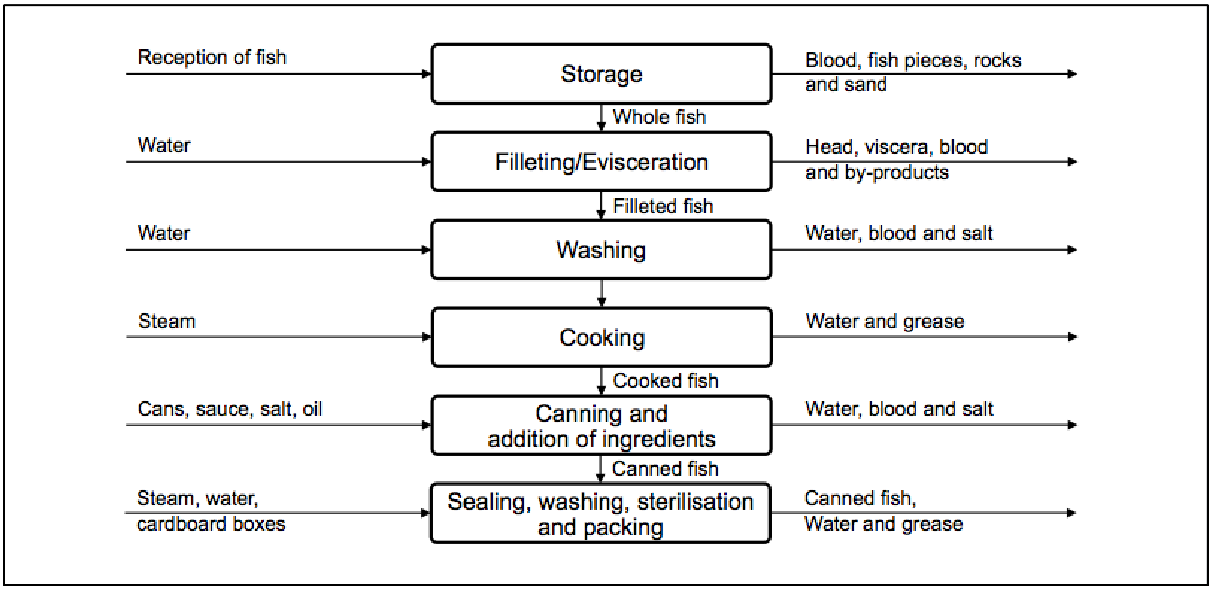

Figure 14: Simplified BFD for fish processing in the fish processing industry, adapted from Cristóväo et al., 2015; Cristóväo et al., 2016; Palenzuela-Rollon, 1999 in Chowdhury et al., 2010.

Fish is received on site and stored. Storage may be in brine or in cold storage. In canning operations, the initial processing of fresh, stored or thawed fish removes unwanted parts such as the head (or beak of abalone) and viscera. This process is called filleting or evisceration. The rejected parts may be processed into fishmeal. Filleted fish is washed and forwarded to cooking operations. Cooking may be with steam, or via smoking or fermenting (Chowdhury et al., 2010). After the fish is cooked, it is packed into cans and sauces or other ingredients are added. Thereafter the cans are sealed, washed and sterilised before being packaged for transport.

In general, wastewater from the food industry may be expected to contain high levels of BOD and suspended solids. The volume and composition of wastewaters from the fish processing industry are highly variable. Variations are a function of the production season (WWAP, 2017), species of fish processed, additives used, unit processes, and process water source (Cristóväo et al., 2015; Cristóväo et al., 2016; Chowdhury et al., 2010).

Wastewater is generated during storage. Water is used in filleting and washing processes. The related wastewater generated can contain blood. Steam is used in the cooking processes, with an associated wastewater of water that may contain fish oil. Water is used to maintain hygiene standards in canning and sterilisation processes.

The organic content of the wastewater from the fish processing industry can be high, containing: high BOD; COD (Islam et al., 2004; Chowdhury et al., 2010); fat, oil and grease (FOG); and pathogenic microflora (Islam et al., 2004).

Receiving and storing fish requires water for transportation and preservation. Wastewater contains blood, small pieces of fish and scales, rocks and sand (Cristóväo et al., 2015). In cases where fish is stored in a brine solution, the wastewater will be rich in salt, blood and scales (Cristóväo et al., 2015).

Wastewaters from filleting and evisceration are rich in blood, salt and fish waste not suitable for food. Wastewater from washing the fish contains blood, oil, salt, scales and fish tissue (Cristóväo et al., 2015). Cooking of fish releases fats, oils and grease (organic material) into the wastewater. The canning, washing and sterilisation processes generate wastewater with fish oils.

Water used for utilities and cleaning is often drawn from a marine environment; and wastewaters are returned to the marine environment (van der Merwe et al., 2009). An adverse impact on marine ecology is possible because of pollutants that can be picked up during processing, as well as waste heat in the returned water. Organic material can promote microbial activity and therefore deoxygenate receiving waters, or contaminants may be toxic to life in receiving water bodies (Achour et al., 2000). Wastewater could also resemble seawater (as in abalone farming facilities) and therefore pose minimal environmental risk.

2.3.3.3. Power generation

Coal-based energy sources and the national energy producer, Eskom, dominate the South African power generation industry. Eskom generates approximately 95% of electricity used in South Africa (Eskom, 2017), of which 89% is from coal-fired power stations (Pather, 2004). Municipal power stations and independent power producers provide the remaining portion (van Zyl and Premlall, 2005).

The majority of the coal-fired power stations are located near coal mining operations. The power stations are largely built in the Mpumalanga province, with one located in the Free State, and two stations in Limpopo. Ten base-load stations contribute 34 130 MW of electricity (green triangles in Figure 15). Three return-to-service power stations contribute 3 650 MW (grey squares), and two new-build stations provide 9 588 MW (blue circles).

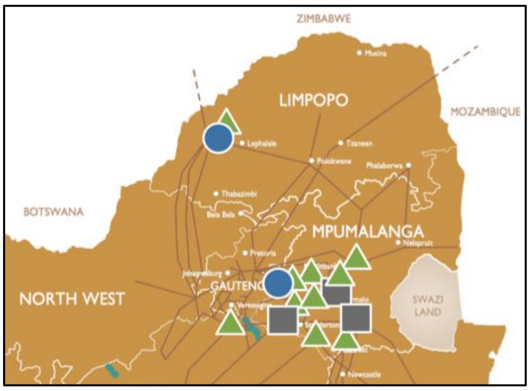

Figure 15: Location of base-load (green), return-to-service (grey) and new-build (blue) power stations (Eskom, 2016)

The power stations abstract water from rivers and dams in the surrounding catchments, in the north-eastern parts of South Africa. Duvha uses water from the Komati and Upper Vaal systems, as well as the Witbank dam in the Olifants water management area (WMA). Majuba uses water from the Zaaihoek dam in the Thukela WMA. Matimba uses water from the Mogol/Mokolo river in the Limpopo WMA (Gericke, personal communication, 25-29 April 2016).

Power stations convert one form of energy into another (more useful) form. Coal-fired power stations convert chemical energy, stored in coal, into thermal energy, via burning. Thermal energy is absorbed by water, which boils into steam. The steam drives turbines. Finally, generators coupled to the turbines transform mechanical energy to electrical energy (Eskom, 2016).

Water is used in two water circuits. The primary loop includes a steam generator; high, medium and low-pressure steam turbines; and a condenser. This loop uses demineralised water, required by the steam generator. The secondary loop contains the condenser and cooling tower, with water of lower quality. The primary and secondary loop exchange only heat, where the cooling water in the secondary loop is used to condense the spent stream in the primary loop. No material is exchanged. The interaction of the primary and secondary loops is illustrated in Figure 16.

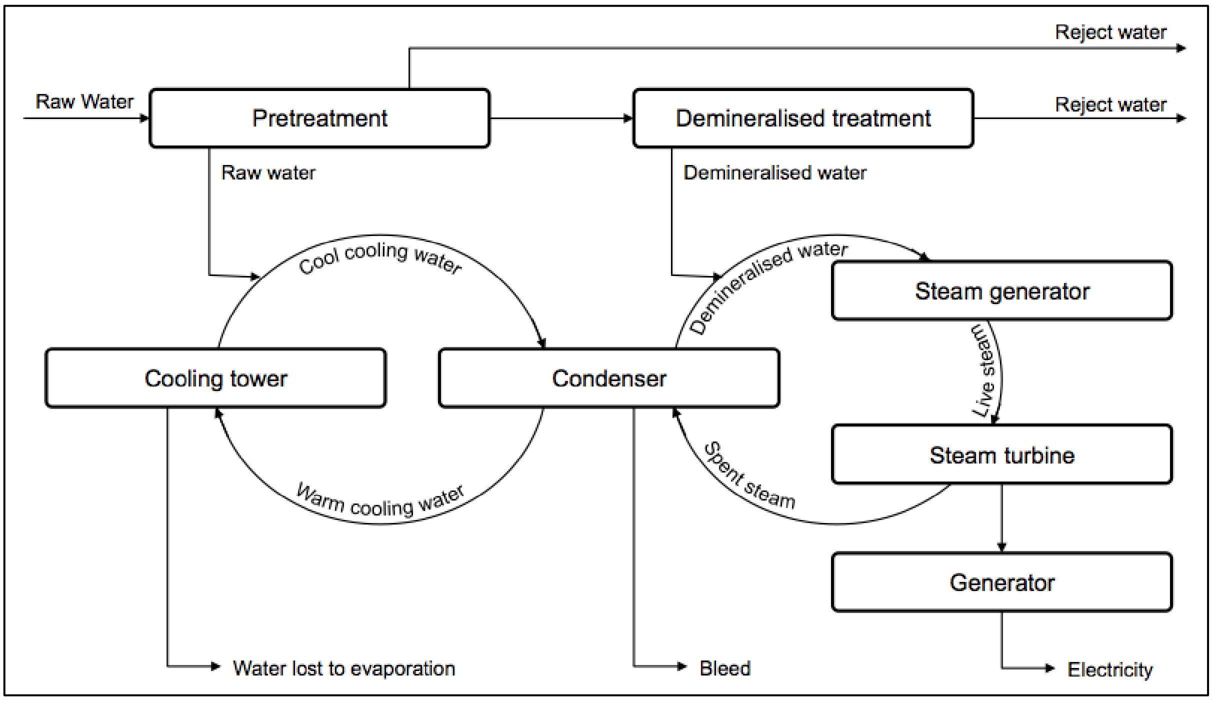

Figure 16: Simplified BFD of unit operations for a coal-fired power station

Wastewater is generated when treating feed water to the required qualities. Raw water contains organics, inorganics, and dissolved gasses that must be removed before the plant or people can use it.

Raw water is first clarified, removing solid material such as mud and clay. Clarified water is filtered through sand filters. The sand filters remove suspended solids. These are backwashed with clean water and compressed air, which generates a wastewater stream (Eskom, 2014).

The filtered water is either treated to potable water or is sent to the desalination plant. The desalination plant consists of one or both of reverse osmosis (RO) units and/or ion exchange units. The RO permeate is either used in the cooling water loop or is feed water into ion exchange units. Ion exchange removes dissolved, dissociated salts from the water by adsorption onto zeolite-resins (Eskom, 2014). Cationic and anionic resins are recharged with sulphuric acid and caustic soda respectively, creating a regeneration wastewater.

2.3.3.4. Mining

The mining industry process minerals in the earth into value-added mineral products. Van der Merwe et al. (2009) and Cloete et al. (2010) report that mining wastewaters contribute between 10% and 15% to the total of wastewater generation in South Africa. South Africa has a number of commodities that are mined, including: gold, coal, platinum group metals (PGMs), diamond, and silver (Figure 17). The Witwatersrand basin is the world's most abundant remaining gold resource (CoM, 2017a); and Limpopo and Mpumalanga hold 3.5% of the world's coal resources (CoM, 2017b).

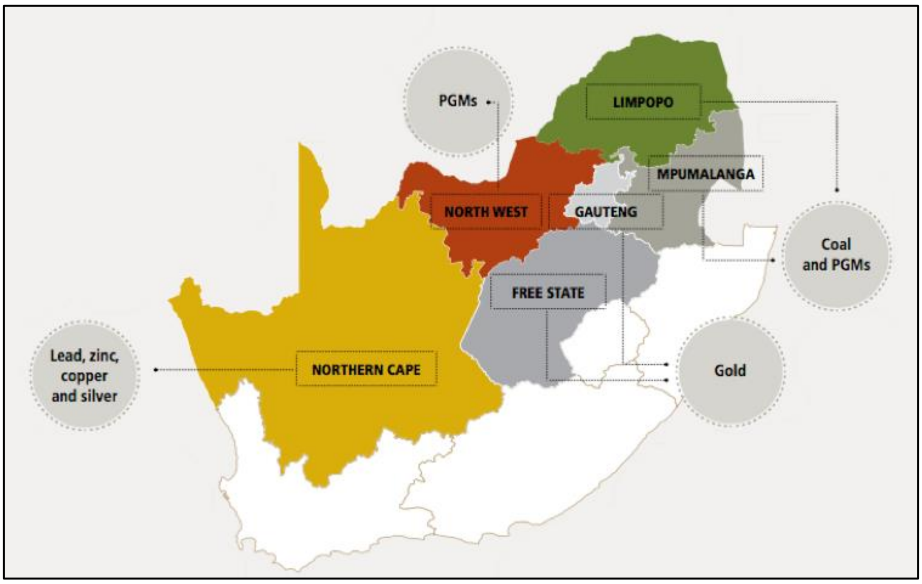

Figure 17: Mining commodities across South African provinces (Chamber of Mines, 2017c).

There are many different types of mining (opencast or underground and many other categories and sub-categories). If a mineral is present in economically favourable conditions, it is extracted. In essence, extraction involves removing mineral-bearing rock from the earth, and this is done in several ways. Simply put, the process involves breaking up rock in the earth into moveable, removable pieces.

After the rock has been extracted, it is generally crushed and/or milled into smaller fractions, which are separated into value and gangue. The ore (value-rich fraction) is forwarded to a series of processes to recover and upgrade the value of the mineral, metal or coal. These processes depend on the mineral being processed.

Although the above requires water, in South Africa there is greater concern about mine decants and mining impacted water. The nature of this water depends on the mineralogy of surrounding rock, and to what degree the area has been rehabilitated.

Wastewaters from tailings may be expected to contain suspended solids, alkalinity or acidity, dissolved salts and heavy metals (WWAP, 2017).

The nature of mining impacted water depends on its location. The nature and composition of rock differs across mining regions in South Africa. The rock compositions determine the dissolved salts, ions and pH of the water. Waters from coal mining in the northern parts of Mpumalanga are characterised by a presence of divalent ions such as Mg^{2+}. Monovalent ions like Na^{+} are more prevalent in waters from the southern parts of Mpumalanga (Günther & Naidu, 2008). Furthermore, if mining impacted water arise in dolomite-bearing rock, the acidity is buffered by dolomite, and the resulting water may not be acidic in nature. Generally, this water has significant concentrations of sulphates and iron. Other metals are also present.

2.3.3.5. Petroleum

The petroleum industry in South Africa produces liquid fuels from crude oil or synthetic fuels such as coal or natural gas. South Africa has no oil reserves and therefore imports crude oil to be refined (SAPIA, 2016). The major liquid fuels used in South Africa are petrol and diesel. Other products of the industry include jet fuel, illuminating paraffin, fuel oil, bitumen and liquefied petroleum gas (SAPIA, 2016).

There are four crude oil refineries and two synthetic fuel processing and refining facilities in South Africa. Chevref, Enref, Natref and Sapref are crude oil refineries. The Sasol complex in Secunda processes coal-to-liquid and gas-to-liquid fuels; and PetroSA processes natural gas into liquid fuels.

Four of the refineries are located in coastal areas, and the remaining two are inland (Figure 18). Sasol Secunda and Natref are inland, located in Mpumalanga and Free State. Chevref and PetroSA are in the Western Cape. Enref and Sapref are in KwaZulu-Natal. The chemical industry contributes approximately 5% to the GDP in South Africa. The petrochemical industry is responsible for 55% of that (Oliveira, 2014).

Figure 18: Location of refineries in South Africa (SAPIA, 2016).

The refining of crude oil accounts for over 70% of the liquid fuel in South Africa; hence this will be the focus of a broad process overview. The refining of crude oil is a complicated process, which varies from plant to plant. Variations arise based on the size of the plant, nature of the crude processed, products made as well as the complexity of the operation (IPIECA, 2010).

In general, crude oil arrives at the refinery and is desalted. Desalting removes the inorganic aqueous salts present in the crude oil. These salts originate from the well in which the crude oil was extracted from. The desalted crude is sent to a fractional distillation column, which separates it into its fractions. Further downstream processing transforms the fractions into more valuable products.

Water is used in various units on a refinery. The quality of water required is dependent on the intended use (IPIECA, 2010). It is standard practice in refineries, especially in water-scarce environments, to cascade water for a variety of purposes before treatment. Process water is closely contacted with hydrocarbons and requires demineralised water. Cooling water is used for heat exchangers and product coolers. These are frequently required to condense vapour fractions from the crude distillation unit. Boiler feed water needs to be of a very high quality. Some water is used as potable water for personnel on the plant, safety showers, eye baths, fire hydrant systems and as utility water for cleaning and maintenance (IPIECA, 2010).

The nature of wastewaters are a function of the complexity of the refining operation (Al Zarooni and Elshorbagy, 2006). Liquid wastewaters from the petroleum industry are polluted with organic species, COD and oil. Sulphur containing and nitrogen containing compounds are present in the wastewater as hydrogen sulphide and ammonia (Altaş and Büyükgüngoör, 2008). Hydrogen sulphide is toxic to humans and aquatic systems alike, even in very low concentrations (> 0.5 ppm for receiving water bodies) (Altaş and Büyükgüngoör, 2008). Additionally, it can be responsible for unpleasant odours. Oil and grease in the wastewater can clog and corrode pipes and sewer lines, also generating unpleasant odours (Diya'uddeen et al., 2011). Phenolic compounds are harmful at low concentrations to organisms in receiving water bodies and are potentially dangerous to human health (Abdelwahab et al., 2009).

When crude oil arrives on site, it is stored in crude tanks. Mud and sediment in the crude settle out, and is periodically removed, generating a wastewater stream containing COD, hydrocarbons, suspended solids and sulphides.

Wastewater from the desalter is expected to contain COD, hydrocarbons (including phenols and benzene), suspended solids, sulphides and ammonia (IPIECA, 2010).

Steam is commonly used as the stripping medium to remove hydrogen sulphide and ammonia from the desired product. This wastewater is called sour water. Typically sour water is treated in a dedicated process. This removes hydrogen sulphide and ammonia, and regenerates a water stream (IPIECA, 2010).

A caustic reagent is used to remove acidic compounds from the crude and desired fractions. Spent caustic contains organic acids, hydrogen cyanide, carbon dioxide and any remaining hydrogen sulphide (IPIECA, 2010).

Blowdown streams for cooling water, boiler feed water and steam generators are another wastewater. These streams contain fewer contaminants than process streams.

Treatment methods for refinery wastewaters include coagulation, adsorption, chemical oxidation, biological methods and use of membranes (Diya'uddeen et al., 2011). Biological treatments may require pre-treatment (Demırcı et al., 1998). Treatment methods for the reduction of COD include filtration, coagulation/flocculation, ion exchange, RO, electrodialysis, and adsorption (El-Naas et al., 2010). Treatment methods to remove phenolic compounds include biological treatment, activated carbon adsorption, solvent extraction, chemical oxidation and electrochemical methods (Abdelwahab et al., 2009).

2.4. Legal framework

Detailed wastewater characterisation information is valuable to organisations concerned with research and development of water treatment technologies as it enables the design of contextually appropriate solutions. To enable this, these institutions need to be able to access comprehensive wastewater characterisation information from industries of interest. Cloete et al. (2010) and van der Merwe et al. (2009) both note a reluctance of public and private organisations to release sensitive information.

Various Acts are written and approved by South African parliament and the president in order to give effect to various rights enshrined in our constitution. Two rights of interest here are Section 28 and the environment, and Section 32 and access to information. The following section will look at the legal framework around these.

2.4.1. Constitution and Bill of Rights

The constitution of the republic of South Africa, Act No. 108 of 1996, is a founding document of South Africa's democracy. The South African constitutions set ideals for a deeply divided nation post Apartheid. The second chapter of the constitution is the Bill of Rights. These are the rights due to every person in South Africa. This chapter *"enshrines the rights of all people in our country and affirms the democratic values of human dignity, equality and freedom"*. It also requires the state to *"respect, protect, promote and fulfill the rights in the Bill of Rights"*. This sentiment is echoed in many pieces of South African legislation, including Acts. The objective of an Act is by-and-large to give effect to rights enshrined in the constitution.

Section 24, in chapter 2 of the constitution, explains one's right to the environment. Every person, now and in the future, has the right "*to an environment that is not harmful to their health or well-being*", which is protected such that pollution is limited, conservation is promoted, and development is sustainable.

Section 32, in chapter 2 of the constitution, explains one's right to access information. Every person has the right to access information held by private or public (state) bodies if that information is required to protect any other right, and legislation is required to make this administratively and financially realisable for both the applicant and the state.

2.4.2. Right to the Environment (and related legislation)

The South African constitution considers people at the centre of environmental management, as opposed to environmental conservation for conservation sake (DEA, 2017). The Environmental Conservation Act (ECA), Act 73 of 1989, defines the environment as "*the aggregate of surrounding objects, conditions and influences that influence the life and habits of man or any other organism or collection of organisms*". The ECA is a piece of legislation pertaining to "*the effective protection and controlled utilization of the environment*". This legislation has been updated in the National Environmental Management Act (NEMA), Act No. 107 of 1998. NEMA defines the environment as:

"*The surroundings within which humans exist and that are made up of –*

(i) the land, water and atmosphere of the earth;

(ii) *microorganisms, plants and animal life;*
(iii) *any part or combination of (i) and (ii) and the interrelationship among and between them; and*
(iv) *the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being*".

To summarise: The term "environment" encompasses all surroundings (including land, water and the atmosphere) and all life within the vicinity (including microorganisms, plants and animals) that influence human health and well-being (as described in s24 of the constitution). "Well-being" is a sufficiently vague enough term to expand beyond simply health, but also speak to aesthetics and cultural values. This sentiment is carried into the definition of pollution. NEMA defines pollution as:

"Any change in the environment caused by–
(i) substances;
(ii) radioactive or other waves; or
(iii) noise, odours, dust or heat.
emitted from any activity, including the storage or treatment of waste or substance, construction and the provision of services, whether engaged in by any person or organ of state, where that change has an adverse effect on human health or well-being or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future"

NEMA has been extended in several related Acts, including NEM: Integrated Coastal Management Act (ICMA), Act No. 24 of 2008; and NEM: Waste Act (WA), Act No. 59 of 2008. The amended WA, the National Environmental Management: Waste Amendment Act (NEM:WAA, 2014) defines waste, not in terms of solid/liquid/gaseous state, but rather as follows:

"*Waste means–*
(a) any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, material or object, whether or not such substance, material or object can be re-used, recycled or recovered and includes all wastes as defined in Schedule 3 to this Act; or
(b) any other substance, material or object that is not included in Schedule 3 that may be defined as a waste by the Minister by notice in the Gazette,
but any waste or portion of waste, referred to in paragraphs (a) and (b), cease to be a waste–
(iv) once an application for its re-use, recycling or recovery has been approved or, after such approval, once it is, or has been re-used, recycled or recovered;
(v) where approval is not required, once a waste is, or has bee re-used, recycled or recovered;
(vi) where the Minister has, in terms of section 74, exempted a waste or a portion of waste generated by a particular process from the definition of waste; or
(vii) where the Minister has, in the prescribed manner, excluded a waste stream or a portion of a waste stream from the definition of waste."

Relevant to this project is that waste is a substance that is unwanted, rejected, abandoned, discarded or disposed of.

Schedule 3 in the amended Waste Act (NEM:WAA, 2014) defines different types of waste. Category A is hazardous waste, which includes: Business waste *("waste the emanates from premises that are used wholly or mainly for commercial, retail, wholesale, entertainment or government administration purspose")*; Residue deposits ("*residue stockpile remaining at the termination, cancellation or expiry of a prospecting right, mining right, mining permit, exploration right or production right"*); Residue Stockpile (*"any debirs, tailings, slimes, screening, slurry, waste, rock, foundry sand, mieral processing plant waste, ash or any other product derived from or incidental to a mining operation …"*). Category B is general waste, which includes: Business waste; Building and demolition waste; Domestic waste; and Inert waste. Each of these subcategories is detailed further in Schedule 3 in NEM:WAA.

Furthermore the National Water Act (NWA), Act 36 of 1998, defines waste as it relates to water as follows:

"Waste includes an solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled ir deposited on land ir into a water resource in such volume, compoisiton or manner as to cause, or to be reasonably likely to cause the water resource to be polluted."

Section 28 of NEMA outlines the responsibility linked with the constitutional right to the environment:

"*Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorised by law or cannot reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment.*"

In other words, if an operation has, is, or could in the future, impact on the environment, then said operation has a responsibility to obtain authorisation and to avoid or minimise degradation to the environment.

Such authorisation could come in the form of an Environmental Impact Assessment (EIA) or Environmental Impact Assessment and Management Strategy (EIAMS). EIA regulations of 1997, as under the ECA, were replaced with new regulation under NEMA in 2006. These have since been amended and updated in 2010 (DEA, 2017).

Authorisation for discharges to a coastal environment is given under NEM: ICMA. Authorisation comes in the form of a Coastal Water Discharge Permit (CWDP). Authorisation for water use, storage and discharge inland is regulated in Water Use Licenses (WULs). These are issued in accordance with the National Water Act (NWA), Act 36 of 1998.

2.4.3. Water use and resource quality objectives

In Section 21 of the NWA, water use is defined as including, amongst others:

"*… water use includes*

(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall of other conduit;
(g) disposing of waste in a manner which may detrimentally impact on a water resources;
(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people"

Section 22 (2) (c) describes that a person who uses water in the sections quoted above "*must comply with any applicable waste standards or management practises prescribed under section 26(1) (h) and (i)*". Section 26 goes on to detail regulations on use of water, stating that the "*Minister may make regulations* –

(h) prescribing waste standards which specify the quantity, quality and temperature of waste which may be discharged or deposited into or allowed to enter a water resource;
(i) prescribing the outcome or effect which must be achieved through management practises for the treatment of waste, or any class of waste before it is discharged or deposited into or allowed to enter a water resource;
(j) requiring that waste discharges or deposited into or allowed to enter a water resources be monitored and analysed, and prescribing methods for such monitoring and analysis"

Section 29 goes on to contemplate the conditions for issue of general authorisation and licenses for water use. Section 29 (1) (b) (ii) requires "*monitoring and analyse of and reporting on on every water use*". Section 29 (1) (c) relates to discharge or disposal of waste; stating that conditions in general authorisation and licenses can specify –

(ii) … permissible levels for some or all of its chemical and physical components;
(iii) … treatment to which it must be subjected, before it is discharged; and
(iv) … the volume which may be returned".

Such wastewater can be discharged into a water resource, on the conditions above, and on conditions relating to the resource quality objectives (RQO). Resource quality is defined in the NWA as:

"*the quality of all the aspects of a water resource including* –

(a) the quantity, pattern, timing, water level and assurance of instream flow;
(b) the water quality, including the physical, chemical and biological characteristics of the water;
(c) the character and condition of the insteam and riparian habitat; and
(d) the characteristics, condition and distribution of the aquatic biota".

RQO were developed as unambiguous goals for the quality of relevant water resources, and to balance "*the need to protect and sustain water resources*" and "*the need to develop and use [water resources*]".

The objectives for a particular resource, given in Section 13 (3) may relate to –

(a) the Reserve;
(b) the instream flow;;
(c) the water level;
(d) the presence and concentration of particular substances in the water;
(e) the characteristics and quality of the water resource and the instream and riparian habitat;
(f) the characteristics and distribution of aquatic biota;
(g) the regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of the water resources; and
(h) any other characteristics".

The RQOs are both quantitative and qualitative descriptors of "quality, quantity, habitat and biotic conditions" required for the specific management of a particular area.

RQOs form an umbrella, under which resource water quality objectives (RWQOs) are also defined. The RWQO are the water quality components of the RQO. Unlike the RQOs, the RWQO only apply to water quality and constituent loading, and not the other aspects of habitat, biota and quantity (DWAF, 2007). The RWQO provide objectives at a higher spatial or temporal resolution than the RQOs (DWAF, 2007).

The RWQOs are determined while considering both the ecological requirements and water user/s requirements of the resource. The RWQOs are a function of (DWAF, 2007):

- The catchment, including: topography, land use, geology, ecology;
- Ecological similarity to neighbouring catchments;
- Ecological importance and sensitivity of habitat, species and community, including: biodiversity, rarity, uniqueness, fragility;
- Strategic importance of the resource, with respect to social and economic development;
- Water users, including: domestic, agriculture, industry, and recreation.

Furthermore, the RWQO may be variably determined based on (DWAF. 2007):

- Period (e.g. annual, seasonal or monthly)
- Location and area
- Management class (e.g. minimally used, minimally impacted, moderately used, moderately impacted, heavily used, heavily impacted)

Therefore the RWQO are variable and different from station to station, river-to-river, catchment to catchment and WMA to WMA. The guidelines are adaptive, and compliance must meet different requirements depending on location.

The Department of Water and Sanitation (DWS) publish information on the National Integrated Water Information System platform (DWS, 2018). They map compliance with the RWQO at aggregated (Figure 19) and individual (Figure 20) monitoring stations. Figure 20 zooms in on the red block outlined in Figure 19.

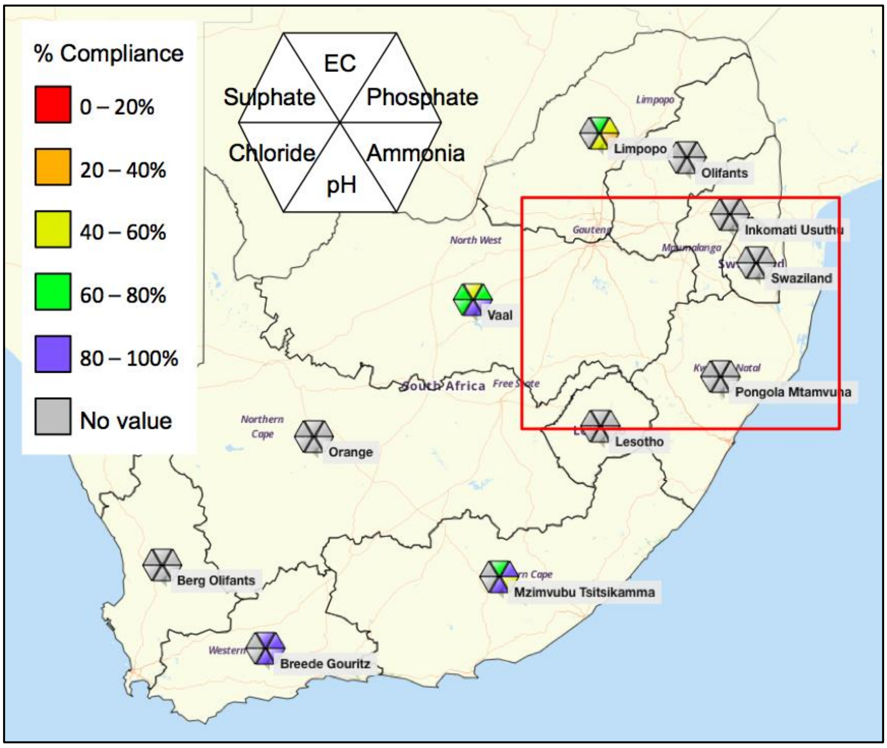

Figure 19: Compliance with RWQO at aggregated monitoring stations

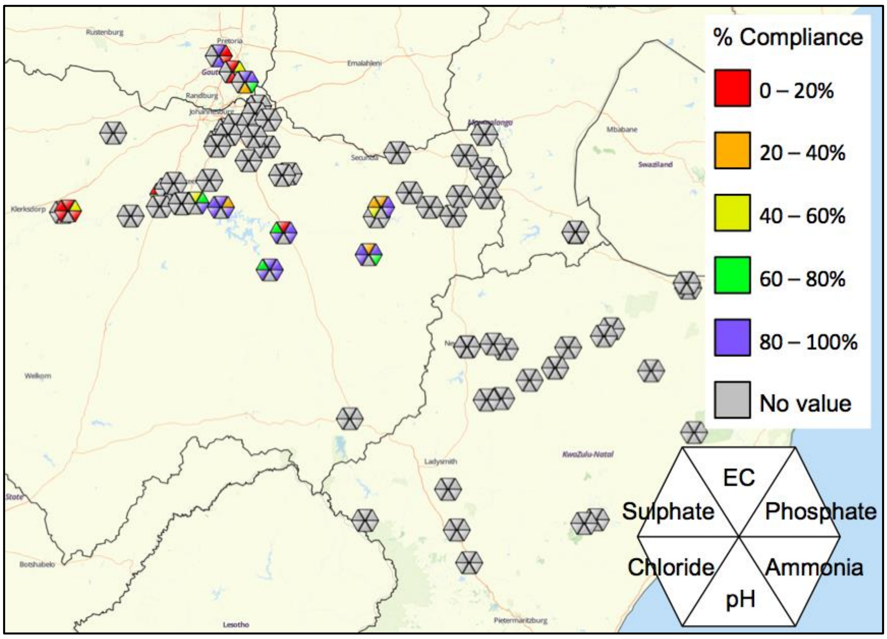

Figure 20: Compliance with RWQO at individual monitoring stations, within the red block on Figure 19

There are no values of compliance for many of the individual and aggregated stations.

RWQO can be converted to end-of-pipe discharge standards by the following equation (DWAF, 2007):

$$C_W = \frac{C_R(M_R + 1) - C_S}{M_R}$$ **Equation 3**

Where:
- C_W is the discharge concentration
- C_R is the receiving instream concentration
- M_R is the mixing ratio, defined at the rate of discharge to rate of stream flow.
- C_s is the desired maximum instream concentration

The receiving instream concentrations are based on the reference condition of the resource. Where information is not available, standard values may be applied as a basis; noting that for toxic substances that basis is zero (DWAF, 2007). Recommended standards are given in Table 2.

Table 2: Recommended standards to be applied when insufficient data is available (DWAF, 2007)

Constituent	Unit	Recommended standard		Constituent	Unit	Recommended standard	
		Short term	Long term			Short term	Long term
Aluminium	mg/l	0.28	0.28	Selenium	mg/l	0.05	0.05
Arsenic	mg/l	0.24	0.24	Zinc	mg/l	0.076	0.068
Cadmium	mg/l	0.01	0.01	Iron	mg/l	0.3	0.3
Chlorine	mg/l	0.063	0.056	Boron	mg/l	1.0	1.0
Chrome III	mg/l	0.5	0.5	Sulphides	mg/l	1.0	1.0
Chrome IV	mg/l	0.05	0.05	COD	mg/l	75	75
Copper	mg/l	0.01	0.01	Susp. solids	mg/l	25	25
Cyanide	mg/l	0.21	0.2	pH	-	6.0 – 9.0	6.0 – 9.0
Fluoride	mg/l	1.0	1.0	Temperature	^{o}C	35	35
Lead	mg/l	0.015	0.013	Orthophosph ates	mg/l	0.8	0.6
Manganese	mg/l	0.4	0.4	TDS	mS/m above intake	75	75
Mercury	mg/l	0.004	0.003	Nitrate/Nitrite	mg/l	15	20
Phenol	mg/l	0.1	0.1	Ammonia	mg/l	10	10

With reference to the discussion in Section 2.1.1.5 and Equation 2, around conductivity and TDS, it is interesting to note that the standard values for TDS have units of mS/m. It is not said what conversion factor is being applied.

2.4.4. Right of Access to Information (and related legislation)

The Promotion of Access to Information Act (PAIA), Act No. 2 of 2000, gives effect to the constitutional right in s32 of the constitution. This is the first objective listed under s9 (a) in PAIA. Section 9 (b) (i) notes that access to information is subject to limitations including "*the reasonable protection of privacy, commercial confidentiality and effective, efficient and good governance".*

A further objective is "*to establish voluntary and mandatory mechanisms or procedures to give effect to that right in a manner which enables persons to obtain access to records of public and private bodies as swiftly, inexpensively and effortlessly as reasonable possible"*, in s9 (d).

Section 31 (a) in NEMA (Access to environmental information and protection of whistle-blowers) describes what environmental information should be available:

"Every person is entitled to have access to information held by the State and organs of state … including any emissions to water, air or soil and the production, handling, transportation, treatment, storage and disposal of hazardous waste and substances".

Section 31 (c) describes under what conditions a request may be refused:

"A request for information contemplated in paragraph (a) can be refused only:

- *(i) if the request is manifestly unreasonable or formulated in too general a manner;*
- *(ii) if the public order or national security would be negatively affected by the supply of information; or*
- *(iii) for the reasonable protection of commercially confidential information;*
- *(iv) if the granting of information endangers or further endangers the protection of the environment; and*
- *(v) for the reasonable protection of personal privacy".*

To understand s31 (c) (iii) in NEMA, and s9 (b) (i) in PAIA, it is necessary to understand what is meant by "commercially confidential information". The definition in NEMA s1 (iv) says "commercially confidential information" is:

"Commercial information. the disclosure of which would prejudice to an unreasonable degree the commercial interests of the holder: Provided that details of emission levels and waste products must not be considered to be commercially confidential notwithstanding any provision of this Act or any other law".

Using this definition, emission levels and waste products are not considered commercially confidential and therefore are not protected by s31 (c) (iii) in NEMA, and s9 (b) (i) in PAIA, or s36 of PAIA, which requires mandatory protection of commercial information.

2.5. Summary and Gap analysis

The following section will conclude Chapter 2 with a overview of each section above, the gaps in current knowledge, and how this project aims to fill these deficiencies.

2.5.1. Water characterisation parameters

Characterising water provides insight into the physical, chemical and microbial make-up of water. Chemical characterisation includes organic and inorganic species found in the water. The more comprehensive wastewater characterisation information is, the more useful it is for treatment purposes, but it is also more expensive. Comprehensive wastewater characterisation information can be used to design and develop appropriate, contextually relevant treatment systems.

Cloete et al. (2010) and van der Merwe et al. (2009) found there is a wide variation in the quality of wastewater characterisation information, as well as a reluctance or fear around releasing this information. Characterisation information in terms of broad parameters provides a partial insight into the wastewater composition.

The development of technologies that can be used to achieve zero liquid discharge requires the characterisation of wastewater streams. Characterisation information is currently inconsistent between organisations in both the public and private sectors.

2.5.2. Wastewater globally and in South Africa

Currently, only approximately 80% of wastewater is treated across the world. This represents an underexploited, but affordable and sustainable, resource (WWAP, 2017). In addition to its value as a resource stream, wastewater treatment creates a number of co-benefits for global challenges.

In Africa, major industries of interest, concerning wastewater, are mining, oil and gas, logging, and manufacturing. This research has identified five industries of interest in South Africa regarding wastewater generation: pulp and paper, fish processing, power generation, mining (specifically gold and coal), and petroleum.

Volumes of wastewaters are captured in both databases mentioned above; however, wastewater characterisation data is partial in both cases. Van der Merwe et al. (2009) database captures salinity and COD, to measure inorganic and organic contributions to wastewater. This research was focused on brines (defined as "concentrated water solution, typically containing 1-6% of dissolved low-value salts, emanating from the RO process") and innovative approaches to handling them.

Salinity is insufficient to describe what specific species are in wastewater, in a similar way that COD indicates the organic material, but no information on the identity of organic species present. Some treatment technologies, such as RO, require more detailed information of the dissolved salts. The design of RO units includes calculating the osmotic pressure, which depends on the dissociation of dissolved salts. Hence total salinity provides insufficient information.

2.5.3. Legalese

The constitution of South Africa enshrines the right to an environment that is not harmful to one's health or well-being. This means that wastewaters must be discharged in a way that does not negatively impact on the receiving environment, now and in the future. This condition and responsibility provide legal motivation for management and treatment of wastewater streams. Treatment requires comprehensive characterisation information because only after the hurdle of characterising a wastewater has been overcome can it be assessed for treatability.

Resource water quality objectives (RWQO) differ from water body to water body. Therefore, similarly end of pipe discharge standards are different everywhere.

Research institutions need to be able to access wastewater characterisation information. NEMA defines ‘confidential information’ as explicitly excluding wastewater and waste information. This gives affect to the PAIA, which requires that some information, including information regarding wastewaters and waste, be made available to a requester. This forms part of the methodology in terms of gaining access to sensitive information that is held by both state and private bodies.

2.6. Key questions

The overarching aim of this research is to determine the nature and norms of wastewater characterisation and reporting in South African industry. Two research questions are guiding this work. The first is: What is the nature of South African industrial wastewaters? The second is: What are the norms of South African industrial wastewater characterisation and reporting?

The first objective was to determine significant industries of interest, with respect to industrial wastewater generation. Therefore the first key question was:

1. What are the major industries of interest?

This has been answered through the literature review in Section 2.3.

The second objective is to determine the nature of these wastewaters, in terms of volume, location and composition.

2. i. What volumes of wastewater arise from different industries?
2. ii. Where do wastewater volumes arise in South Africa?
2. iii. What parameters are used to describe wastewater composition?

The third objective is to report on the state of wastewaters and their characterisation and reporting in terms of quality and accessibility. The key questions are:

3. i. How comprehensive, accurate and consistent is characterisation reporting?
3. ii. How accessible is wastewater characterisation information?

CHAPTER 3: Research approach and methodology

Figure 21 provides an overview of the methodological approach.

An initial literature review of existing research, reports and databases informed the scope of the remaining research. This first literature review addressed the first objective and key question. The industries of interest are: pulp and paper; fish processing; power generation; mining and petroleum.

To answer the second objective and key questions, it was critical to gain access to information. This stage of the research was founded on building a relationship with a number of different partners. It involved informal and formal requests for accessing information.

Wastewater characterisation information was taken from three types of secondary data sources. The first was published literature. A review into each industry of interest told of process overviews and the qualitative nature of industrial wastewaters.

This was followed by a synthesis of information from preceding research and databases. This was the second source. New information was extracted from existing data and databases.

The third source was using accessed data in which wastewaters were characterised. This was interpreted in case studies.

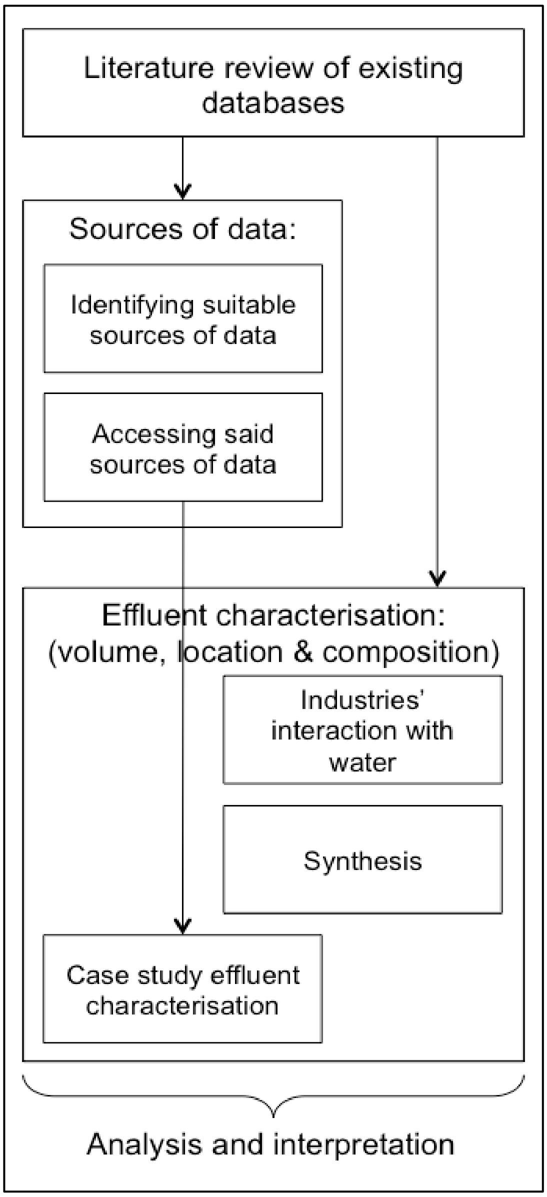

Figure 21: Overview of the research approach

These results, along with analysis and interpretation thereof, feed into answering the research questions.

3.1. Determining major industries of interest

This first step was based on existing, known and public information, in the form of previous research. Two databases were identified, including the work of van der Merwe et al. (2009) and Cloete et al. (2010).

Pulp and paper, fish processing, power generation, gold and coal mining, and petroleum industries were identified as major wastewater generating industries in terms of volume.

Databases were reanalysed to extract new information from the existing databases. This reanalysis also allowed for the identification of gaps in existing, known and public information. One such gap identified was that composition/wastewater characterisation information was limited to crude characterisation parameters. Crude parameters, such as salinity, do no provide insights into what species could be in the wastewater, and the relative quantities of each, and is not sufficient in terms of assessing treatability.

3.2. Data mining

In addition to a review of existing databases, finding other suitable sources of data was necessary. Possible data sources can be grouped as: published, public and private data. Published data was information found in journal papers and WRC reports. Public data is information that is held by the state. This information includes operating and discharge licences and permits. Private data is information that is held within company records. Such information includes testing and monitoring of wastewater quality.

3.2.1. Published data

Published data provided a preliminary insight into industrial processes that use water and processes that generate wastewater. It began to provide initial insights into what volumes of wastewaters are generated and what species may be found in wastewaters. It allowed comment on what the qualitative nature of liquid wastewaters could be expected from different processes within each industry of interest.

Furthermore, where published research investigated wastewater streams, partial characterisation data available for said streams could be extracted or possibly calculated depending on the available information. This extracted information provided insight into quantitative nature of liquid wastewaters.

A recent comprehensive study on the pulp and paper industry was published in a second edition of the NATSURV 12, by the WRC. Water use and wastewater generation information was included and formed a significant portion of the secondary data used for the pulp and paper industry and case study.

3.2.2. Public data

Public data include records held by various governmental and municipal departments. To be of use, one must first identify which records contained relevant information. Databases from different departments, operating and discharge licenses, and environmental permits issued may all be of interest.

Coastal Water Discharge Permits (CWDP) contain information of wastewater discharged to a marine environment. These are public documents that are issued by the Department of Environmental Affairs: Oceans and Coasts.

Water Use Licences (WULs) contain information on wastewater discharge or disposed to a receiving environment. These are "records available from The Department [of Water and Sanitation] without a person having to request access in terms of PAIA" (DWAF, nd). The NWA also requires companies that have been issued WUL to submit compliance reports, in which wastewater characterisation information may or may not be reported.

3.2.3. Private data

Private companies operating within the industries of interest are another potential source of information. Private companies monitor water use and quality over the plant and capture this in existing records, reports, research, permits and compliance reports. These sources can possibly provide comprehensive characterisation information for wastewaters in South African industry.

Major companies in each industry were identified. Each was contacted informally (as described in Section 3.3.1 to follow) to build relationships. One desired outcome of the relationships with industry partners was to gain access to detailed wastewater characterisation information. At least three major companies from each industry were contacted (except the power generation industry), more if possible. It was hoped that three major players would be able to provide a representative sample of wastewaters from each industry.

3.3. Accessing public and private data

Once appropriate data sources have been identified, the question becomes: Can they be accessed?

3.3.1. Informal routes to access: Building relationships and trust

Public and private data sources are largely inaccessible until relationships and trust have been built. (Even then, they may remain inaccessible). Both public and private bodies were reluctant to release information that is perceived to be confidential, and information that is sensitive and/or could damage the reputation and public perception of the body. Therefore to access such data sources effort must be invested in establishing contact, building relationships, building trust, and agreeing on the terms of sharing data. Ethics approval from the university was the first step in this process before reaching out to people who worked in public and private bodies.

Building a relationship and establishing contacts was initially achieved either through telephone calls or alternatively via email. This research reached out to members of the WRC's steering committee for this project, contacts of the research group, contacts of the Chemical Engineering department and contacts of other departments in the Faculty of Engineering and Built Environment. Accessing data was surprisingly difficult. Even though the WRC, research group and university has many well established contacts and networks, the ability of these contacts to grant access to information was severely limited. They were bound by the legal structures and confidentiality agreements of their respective companies.

A total of 87 people from 42 companies or institutions were contacted. This includes major companies in each industry of interest, as well as individuals in governmental bodies and for legal advice. At least four companies in each industry were contacted, with the exception of Eskom in the power generation industry. Fourteen companies were contacted in the mining industry.

After initial contact communication was continued via telephone calls, emails, Skype meetings, face-to-face meetings, and site visits. A flow diagram of possible outcome after an initial phone call (in my experience) is illustrated in Figure 22.

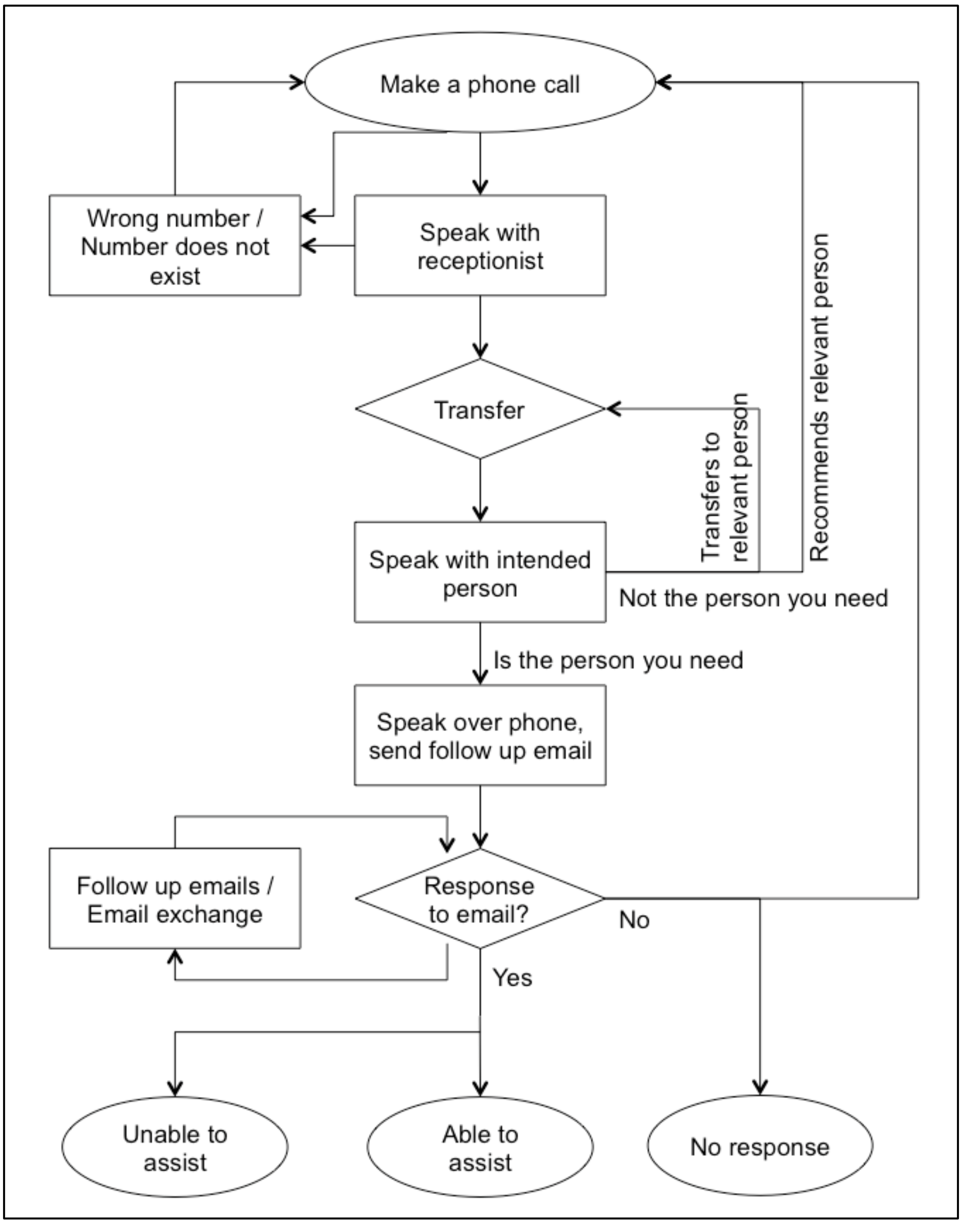

Figure 22: Flowchart of possible outcomes when establishing contacts informally

The initial phone call was often with a receptionist. However, one might find the telephone number is wrong or does not exist. This was common when the contact details were obtained from the internet.

After introducing the project and myself, the receptionist would typically transfer the phone call to a more appropriate person. Again, the project was introduced, with a more detailed description of the project and request. The speaker may or may not have been the most appropriate person to speak with, and if they were not, they would often recommend or transfer the call to a more appropriate person. If or when a phone call was with a person who was able and willing to assist, this was followed up via email, with the project details and specific request in writing.

The follow up email re-identified myself, reintroduced the project including details of my supervisors and WRC partner, and detailed the desired information in terms of wastewater quality. A guideline questionnaire was attached, outlining the information of interest. This document is included in Appendix A1. The email also noted that the project had been granted ethics approval and a willingness to respect sensitive information.

Ideally, an email exchange would follow, and a meeting would be scheduled, via Skype, in person, or on site. Site visits and/or meetings were semi-structured interviews, using the guideline questionnaire sent in preceding emails. Information from the fish processing and power generation industries were accessed through relationships established in this way.

3.3.2. Formally requesting access to information

The above methods can be ineffective, especially when companies are concerned about sensitive information reaching the public domain or media outlets. There are concerns around protecting company reputations and public perception. Hence a legal approach may be required to access this information. The Promotion of Access to Information Act (PAIA) provides the framework for this legal request.

Every company and government department is required to publish and update a PAIA manual. The PAIA manual lists information that is automatically available, and information that must be formally requested. “Automatically available” information still requires the information be requested from the information officer. However, there is no application form to complete. A PAIA application for other information must be requested via a specific form with a small initial payment for administrative costs.

Two PAIA applications were submitted. The first to the Department of Environmental Affairs: Oceans and Coast, for access to all CWDP issued. These are environmental permits for land-based discharges to a marine environment. The second was to the Department of Water and Sanitation for WUL and associated compliance reports. WULs are environmental permits for land-based wastewaters discharged to land-based environments. The PAIA applications can be found in Appendix A2.

3.4. Using accessed information

A major hurdle in this research process was in accessing data. Once published, private, public or formally requested documents were received, they were analysed.

3.4.1. Literature review

The literature review used data that was readily available in academic publications, WRC publications and other. The corresponding results appear in Section 2.3, answering the first objective, detailing a process overview for each of the major industries as well as qualitative descriptions of the nature of industrial wastewaters.

3.4.2. Synthesising new information

Chapter 4 is the first results chapter, presenting preliminary results drawing on data presented in previous research and databases. One of the challenges with published data on wastewater characterisation is that it is sparse or difficult to access.

The first preliminary result was to map the location of wastewater volumes by WMAs. The database developed by van der Merwe et al. (2009) listed wastewater generators, which could be located using Google Maps. This meant that each wastewater could be placed in a WMA. The wastewaters were collected by WMA and by industry, and then mapped. This result contributes to the second objective of the research by locating industrial wastewaters in South Africa.

The second preliminary result is wastewater characterisation information, in terms of composition, by key parameters to each industry. The data was collected from a number of local and global academic literature sources, including journal articles, and plotted to show the range of key parameters in wastewaters from each of the industries of interest. Local sources reporting on local South African industrial wastewater streams were not necessarily available.

3.4.3. Wastewater characterisation information

The sources for more detailed wastewater characterisation data were public and private records. These were accessed either through relationships and networks, or formally via the PAIA procedure. The available data was limited accessibility.

The data sources and number of wastewater characterisation parameters listed in each wastewater stream were considered in Section 5.2. This was to address the third research question around the norms of wastewater characterisation reporting. Case studies of wastewater characterisation for each industry are presented, to provide more detail regarding wastewater characterisation data in terms of composition in Section 5.3.

3.5. Summary

Table 3 summarises the questions and approach guiding this research. It considers the linkages between the objectives, key questions, theory and literature review, the methodology, and what results can be expected.

Table 3: Summary of the objectives, key questions, theory and literature, and methodological approach to this research

Research questions	Objectives	Key questions	Theory and literature review	Methodology	Results
What is the nature of South African industrial wastewaters?	Determine major industrial generators of wastewater South Africa.	What are the major industries of interest?	Research by van der Merwe et al. (2009) and Cloete et al. (2010) was considered.	A literature review of existing research and databases on wastewater generation.	This result guided the remaining research and is discussed in the literature review in Section 2.3.
	Determine the nature of these wastewaters, in terms of volume, location and composition.	What volumes of wastewater arise from different industries?	Global wastewater and local wastewater generation was considered.	The information in existing databases was mapped by location, volume and industry.	Volumes of wastewater by industry are presented in Section 2.3 and mapped in Section 4.1.
		Where do wastewater volumes arise in South Africa?			Industrial wastewaters are mapped by location and volume in Section 4.1.
		What parameters are used to describe wastewater composition?	Parameters used to characterise water were considered.	Informal and formal processes were used to gain access to wastewater information, which was analysed.	Partial characterisation data is presented in Section 4.2. More detailed wastewater characterisation results are presented as case studies by industry in Section 5.3.
What are the norms of South African industrial wastewater characterisation and reporting?	Determine the norms of wastewater characterisation reporting in terms of quality and accessibility.	How comprehensive, accurate and consistent is characterisation reporting?	The legal framework around the environment and access to information was considered.	Analysis and interpretation of the accessed documents.	The level of detail of wastewater characterisation reporting is considered in Section 5.2 and discussed in Section 5.4.
		How accessible is wastewater characterisation information?		Informal and formal routes were investigated to access information.	Outcomes of informal and formal processes are presented in Section 5.1.

CHAPTER 4: Results and discussion – Wastewater location, volume and composition

This project has undertaken to explore the nature and norms of industrial wastewater characterisation and reporting. To prioritise key industries, it is necessary to understand the **volume** of wastewater generated by each. In order to identify environmental hotspots, it is necessary to know **where** wastewaters are being generated. To understand the resource or risk associated it is necessary to understand their **composition** characterisation.

The literature review in Section 2.3.1 detailed previous research exploring volumes of wastewater generated by various industries, thereby answering the first key question and defining the scope of this work. This chapter will locate these volumes in South Africa, and will show the parameters used to partially characterise wastewaters based on the key parameters in each industry if interest.

4.1. Wastewaters by location

Locating wastewaters geographically illustrates hotspots in terms of volumes of wastewater generated. It was possible to locate each of the companies identified in the van der Merwe et al. (2009) database into WMAs.

WMAs are defined, bounded, catchment-based areas originally developed to distribute the responsibility of managing water resources. They were first established in 1999, defined by the Department of Water Affairs and Forestry (DWAF, 2004). There are 19 WMAs based on South Africa's physical geography. Therefore they do not necessarily align with provincial boundaries and are generally smaller than the provinces.

The total volumes of wastewater streams released to the environment (to both marine and inland environments) are mapped in Figure 23. Lighter shading of an area represents low volumes, while darker shading represents high volumes released. Figure 24 overlays this map with pie charts showing the contribution by industry to in each WMA. Alongside each pie chart, there is a percentage indicating the contribution of wastewater volume in a particular WMA to the total wastewater volume, based on database developed by van der Merwe et al. (2009).

Figure 23 considers all contributions to wastewater volumes, in different WMAs. Figure 24 considers the five industries of interest. The food and beverage and textile industries have been included as "other". Gold and coal mining are considered individually, with light and dark orange colours respectively.

Figure 23: Total volume density of wastewater streams, by WMAs
Adapted from van der Merwe et al., 2009; and DWAF, 2004.

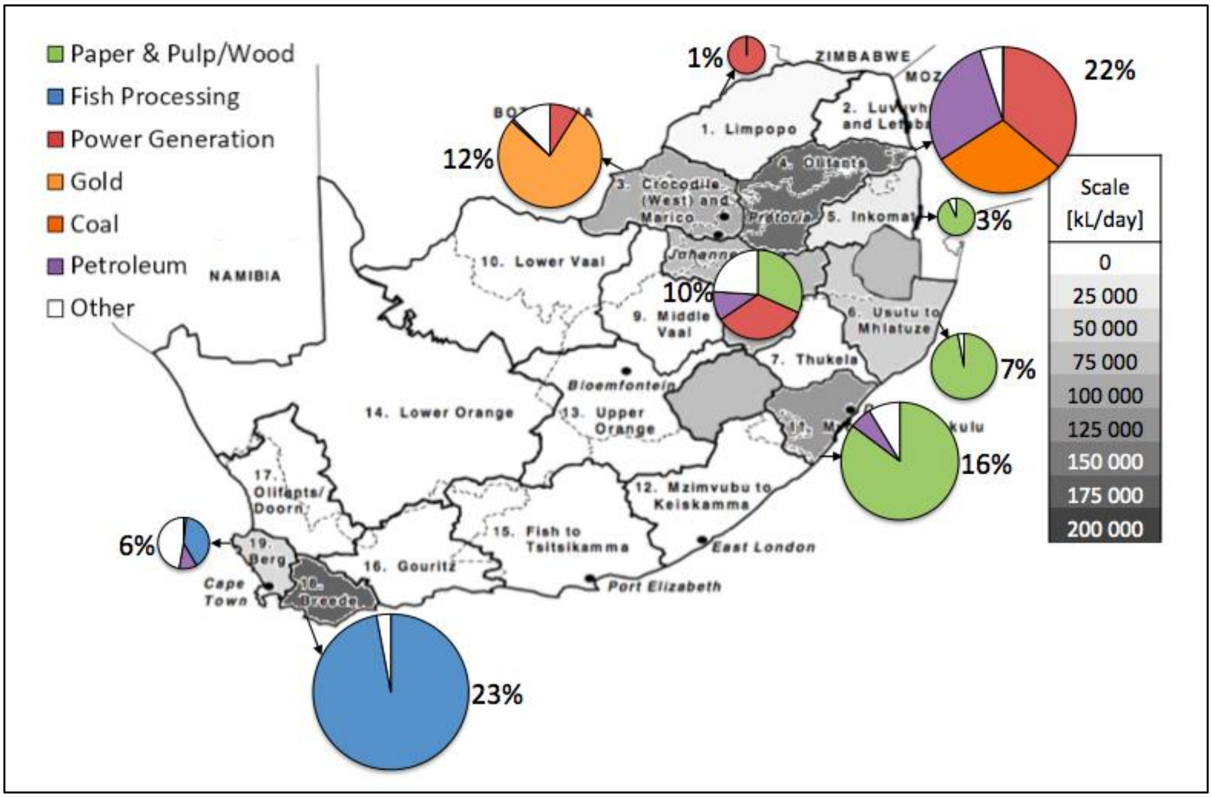

Figure 24: Contribution by industry to the wastewater volume in each WMA.
The percentage alongside each pie chart shows the contribution of that WMA to the total wastewater. This corresponds to the shading of the map and relative sizes of the pie charts.
Adapted from van der Merwe et al., 2009; and DWAF, 2004.

WMA 18 in the Western Cape has the greatest volume of saline streams produced (206 000 kL/day on average over the year). 97% of this arises out of the fish processing industry. All the volume from the fish processing industry in WMA 18 is released to the marine environment.

WMA 4 in parts of Limpopo and Mpumalanga has the second largest volume (195 000 kL/day); followed by WMA 11 in KwaZulu-Natal with 141 000 kL/day. In WMA 4 100% is released inland compared to only 6% in WMA 11. Wastewaters in WMA 4 are from power generation (36%), coal mining (30%) and petroleum (29%). Over half (57%) of the total wastewater from power generation arises in WMA 4.

Approximately two-thirds of wastewater streams generated in the petroleum industry are located in WMA 4. A further 12% and 10% from the petroleum industry are generated in WMA 8 and 11.

Gold and coal mining occurs in WMAs 3 and 4.

WMA 11 in KwaZulu-Natal is dominated by paper and pulp, contributing 85% to the volume there. Just under half (49%) of the total wastewater streams from the pulp and paper industry are generated in WMA 11. A further quarter (27%) is generated in WMA 6 (northern part of KZN). WMA 5 and 8 generate 11% and 12% respectively.

Figure 19 in Section 2.4.3 showed (limited) compliance information available for combined WMAs. Although there is some compliance information for WMAs 16 and 18 (together called Breede Gouritz) the RWQO do not apply to streams discharged to a marine environment. There is no compliance data available for the Olifants WMAs (WMA 2 and 4), which has the second largest discharge volume of 24%. Similarly there is no compliance data for Pongola Mtamvuna (WMAs 6, 7 and 11) while this area also receives 25% of wastewater volumes discharged.

The Limpopo WMAs (WMA 1 and 3) have some compliance information available; and collectively receive 15% of wastewater volumes from the power generation and mining industries. These WMAs are: 43% compliant in pH; 29% compliant in ammonia; 57% complaint in phosphate; and 71% compliant for electrical conductivity.

WMAs 8, 9 and 10 (collectively the Vaal WMAs) receive 12% of wastewater volumes discharged from pulp and paper, mining, petroleum and other industries. There is compliance information available for this region. These WMAs are: 100% compliant in pH; 80% compliant in ammonia; 73% complaint in phosphate; 66% compliant in chloride; 62% complaint in sulphate; and 45% compliant for electrical conductivity.

4.2. Preliminary partial characterisation

Literature and preceding research interested in wastewater streams and their treatment report the compositions of wastewaters from various industries. The following sections report the common parameters often recorded in wastewater. These components are general and are considered key to each industry. The results below draw on local and global wastewater characterisation literature from each industry of interest. Local published data on the wastewater characterisation of South African industrial streams was not available for each industry of interest.

The compositions of wastewaters are related to the processing unit in which they arise. Below the compositions are reported in relation to the process in which they were generated, and for the overall plant.

4.2.1. Pulp and paper

Figure 25 shows the (a) pH, (b) TSS, (c) COD and (d) BOD of liquid wastewaters from various stages of processing within the pulp and paper industry. Each data point is sourced from a piece of literature. The exact data and references are captured in Appendix A3. The x-axis labels indicate stages/unit operations within pulp and paper processing. These are referred to in Figure 13 (page 18), where: 1. Wood preparation; 2. Pulping; 3. Bleaching; 4. Washing; 5. Paper making; and 6. Overall process. The data in Figure 25 and Appendix A3 report compositions of wastewaters prior to secondary treatment.

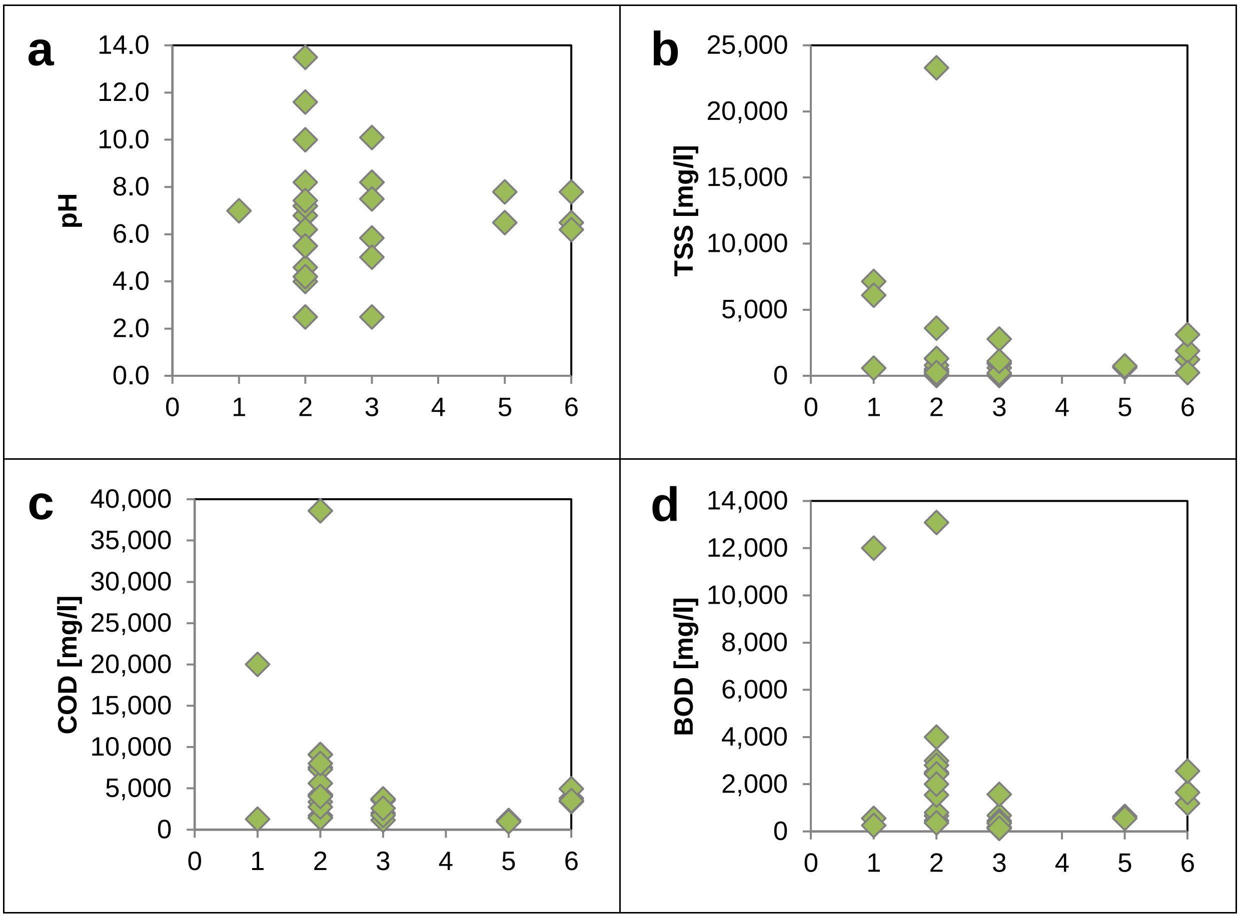

Figure 25: Possible ranges of (a) pH, (b) TSS, (c) COD and (d) BOD for various stages of operation in the pulp and paper industry
The numbers on the x-axis represent various stages of processing: 1. Wood preparation, 2. Pulping, 3. Bleaching, (4. Washing), 5. Paper making, 6. Overall.
Data points are sourced from literature referenced in Appendix A3.

The pH ranges from an acidic value of 2.5 to a basic value of 13.5. The range of pH values is the greatest in the pulping phase of processing (2 on the x-axis in Figure 25a). This is because of various methods for pulping wood or recycled materials. Chemical pulping methods have the highest pH values. As pulping methods combine more mechanical and thermal methods the pH drops; with thermo-mechanical having the lowest pH of the different pulping methods. Whether the pH is basic or acidic depends on the process units operating and chemicals that are chosen to perform the required duties. The pH values for bleaching also show a range of values, from acidic to basic.

Where no information about the reference quality of a receiving environment is known in South Africa the recommended standard for pH is between 6.0 and 9.0 (Table 2). Many of the data points in Figure 25a are outside of this recommended range.

The TSS is generally below 10 000 mg/l. An outlier of 23 300 mg/l is generated in a digester house, for pulping (2 on the x-axis in Figure 25b). Excluding the outlier, the range for TSS is largest in the wood preparation stage (1) and also has the highest values. This is due to the presence of sand, dirt, wood chips, bark, and small solid material in the wastewater. These solids are removed in this step of processing. The recommended standard for suspended solids, given in Table 2, is 25mg/l, which is well below the reported values.

The COD is shown in Figure 25c. During wood preparation (1) a high value of 20 000 mg/l is from a chip wash process. In the pulping stage (2) the bulk of data lie between 1 000 and 10 000 mg/l. An outlier of 38 600 mg/l is from a digester house. The recommended standard for COD, given in Table 2, is 75mg/l. This is at least an order of magnitude smaller than the reported values.

The BOD is smaller than the COD (as expected from Section 2.1.3), showing a narrower range. (Note the y-axis scales between Figure 25c and d). In wood preparation (1) the largest BOD is associated with a chip wash operation, as for COD. The bulk data in the pulping stage lie between 300 and 4 000 mg/l; with a higher value of 13 000 mg/l from a digester house. No recommended standards are given for BOD by the DWAF (2007), in Table 2.

The pulp and paper industry generates liquid wastewaters with significant BOD, COD and potentially xenobiotic compounds (Savant et al., 2006). The organic material is rich in nutrients that promote microbial activity and may simultaneously starve receiving water bodies of oxygen. The xenobiotic compounds are harmful to life in receiving water bodies. One challenge is that each pulp and paper site generates a unique wastewater stream based on the unit processes chosen, as well as a host of other factors. As a result of unique wastewaters and processing steps, there is no straightforward process/es to treat these wastewaters.

4.2.2. Fish processing

The fish processing industry generates liquid wastewaters with BOD, COD and salinity. However, the wastewater can have a composition similar to that of seawater (such as wastewater from abalone farms). Figure 26 shows the (a) pH, (b) TSS, (c) COD and (d) BOD of liquid wastewaters from various stages of processing within the fish industry. The exact data and references are captured in Appendix A3. The x-axis labels refer to the same unit operation as in Figure 14 (page 20), where: 1. Receiving and storage; 2. Filleting/Evisceration; 3. Washing; 4. Cooking, salting or smoking; 5. Overall fish processing operation; 6. Overall cannery operation; and 7. Plant cleaning.

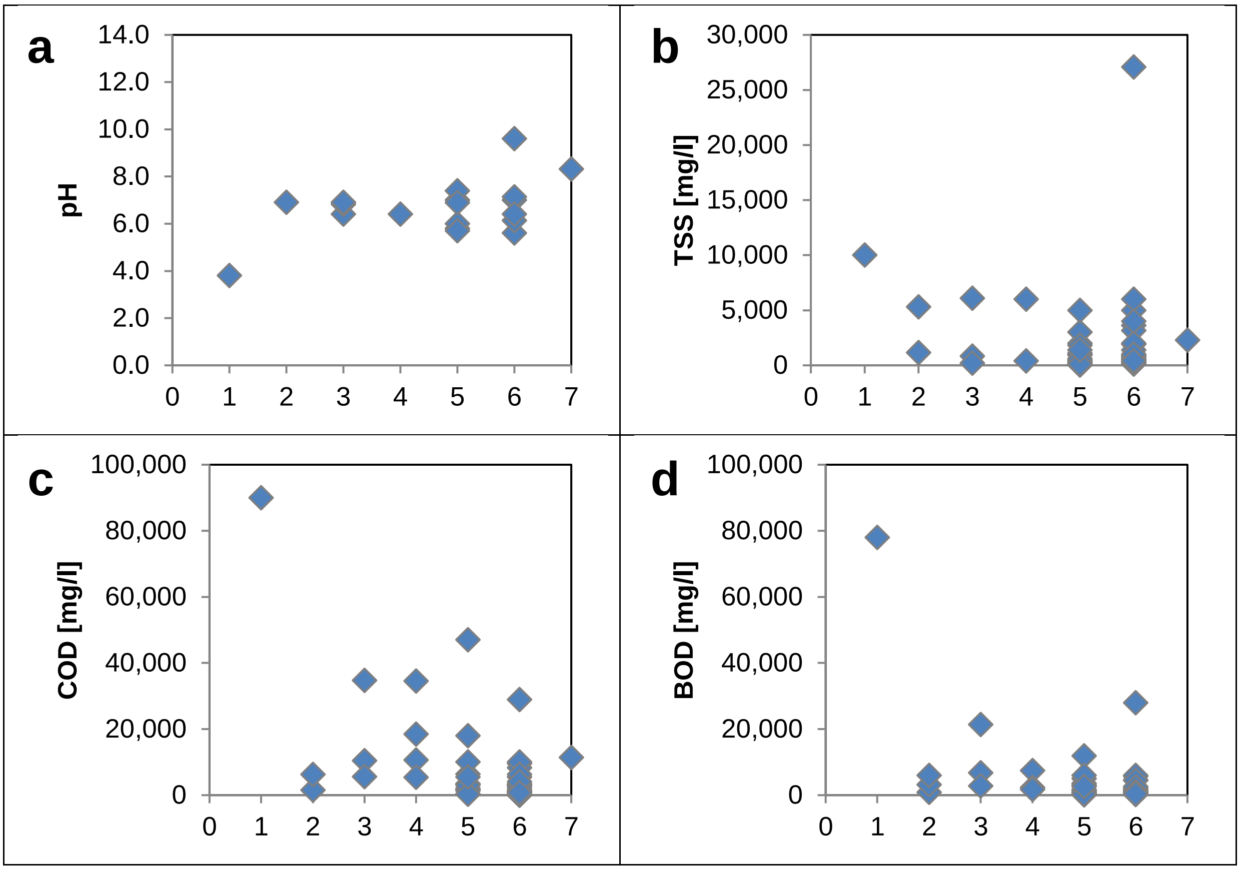

Figure 26: Possible ranges of (a) pH, (b) TSS, (c) COD and (d) BOD for various stages of operation in the fish processing industry
The numbers on the x-axis represent various stages of processing: 1. Receiving & storage, 2. Filleting/Evisceration, 3. Washing, 4. Precooking, cooking, salting or smoking, 5. Overall fish processing operation, 6. Overall cannery operation, 7. Plant cleaning.
Data points are sourced from literature referenced in Appendix A3.

The pH ranges from 3.8 to 9.5, shown in Figure 26a. The average pH lies about or just below a neutral pH of 7. The minimum value is from receiving and storage of herring fish in a cannery. The maximum value is from a cannery for sardines, mackerel and tuna. A pH of 8.3 is for cleaning water of a tuna processing operation. The bulk of the data are within the recommended standard for pH given in Table 2.

The bulk of the data for TSS, in Figure 26b, lies below 6 000 mg/l. A higher value of 10 000 mg/l occurs for receiving and storage of herring fish in a cannery. A data point with TSS of 27 000 mg/l is from sardines, mackerel and tuna cannery. As with pulp and paper, these data points are well above the recommended standard for suspended solids of 25mg/l (Table 2).

COD and BOD are relatively similar in range, in Figure 26c and d. Many COD data points are clustered below 20 000 mg/l. Higher values between 30 000 – 50 000 mg/l occur for tuna washing, tuna cooking, overall processing and canning. An outlier, at 90 000 mg/l, occurs for receiving and storage of herring fish in a cannery. These are all above the recommended standard of 75mg/l (Table 2).

BOD is largely below 12 000 mg/l. Two data points between 20 000 and 30 000 mg/l are for tuna washing and canning of sardines, mackerel and tuna. The maximum value, of 78 000 mg/l, occurs for receiving and storage of herring fish in a cannery. No recommended standards are given for BOD.

4.2.3. Power generation and mining

Suitable data for South African power generation was not available. Figure 27 illustrates the (a) pH, (b) TSS, (c) COD and (d) TDS of a wastewater stream from a coal fired power station in India before treatment, over time in weeks on the x-axis.

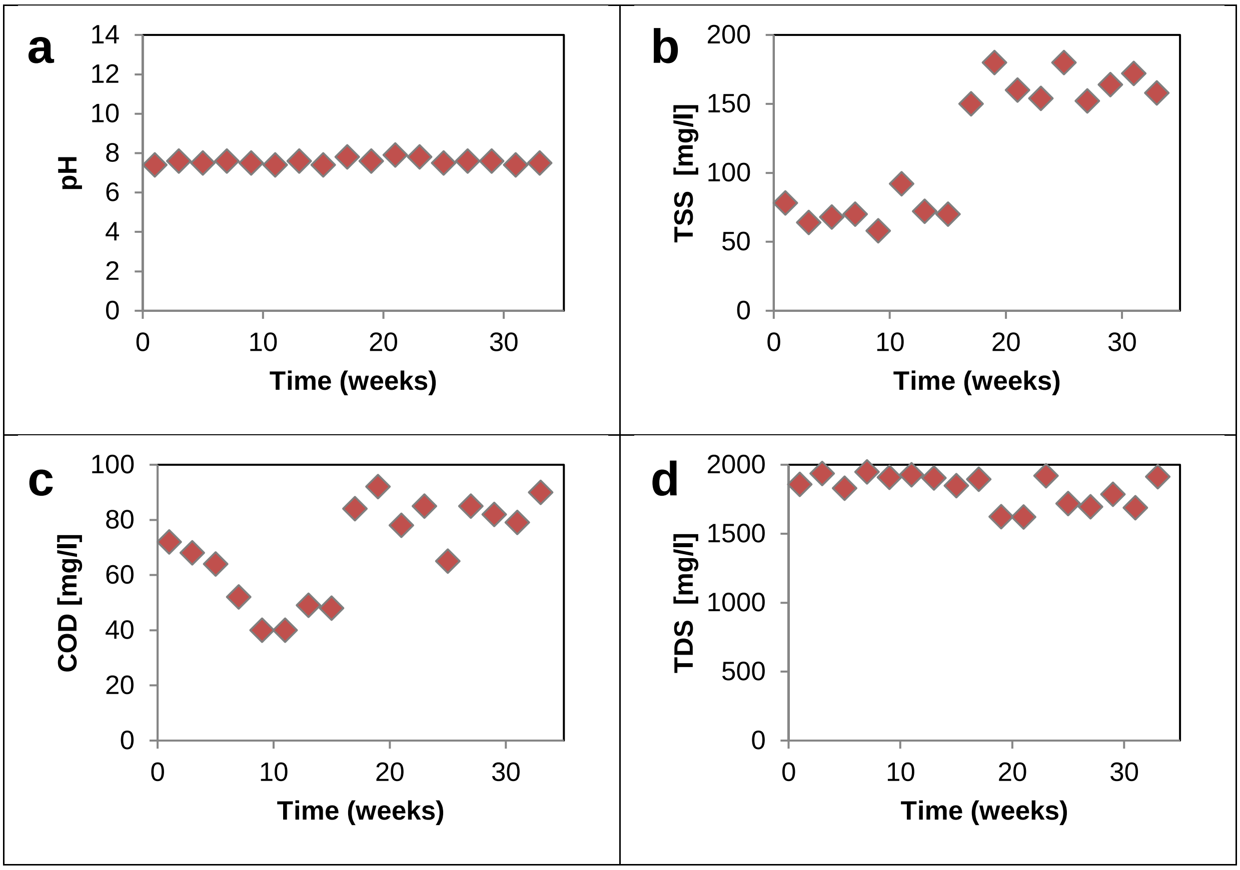

Figure 27: Ranges of a. pH, b. TSS, c. COD and d. TDS of a wastewater from a coal power station in India The x-axis shows time in weeks.
Data points are sourced from literature referenced in Appendix A3.

Kamdi et al. (2012) studied wastewater from a coal-based power station in India over a period of nine months. It was a mixed wastewater, but a major contributor to the volume was cooling tower blowdown. In India, 70-80% of power is supplied from coal-fired power stations. They measured pH, COD, TDS, TSS, phosphates, chromium, copper, iron and zinc.

The pH in Figure 27a consistently ranges between 7.4 and 7.9. COD was below 100 mg/l, illustrated in Figure 27c. TSS ranged up to 200 mg/l, while TDS ranged up to 2 000 mg/l, in Figure 27b and d respectively. The TDS value indicates a slightly saline stream, using the definition given by USGS (2016b) in Section 2.1.1.4. This study did not consider sulphates, which is a common ion found in South African wastewaters. This could be owing to different geologies between India and South Africa.

As in India, the majority of South Africa's electricity is generated in coal-fired power stations. Therefore the wastewaters from the power generation industry and coal mining industry are related. The coal is a shared resource; with coal as a product of mining and coal as a feed for power generation.

Water-saving measures at Eskom have created another shared waste/resource. The coal mines that supply Eskom generate significant volumes of wastewater (Pather, 2004). Eskom treats this wastewater to a quality suitable for cooling water. This is currently practised at Tutuka and Lethabo power stations. Treatment includes microfiltration and RO trains (Pather, 2004).

4.2.4. Mining

There were challenges with extreme lack of available data for the mining industry, and therefore what follows is brief.

Mining impacted waters are a function of their geology and location. They are often characterised by high concentrations of sodium, chloride and sulphate (Apsey and Lewis, 2013; Lewis et al., 2010). Figure 28 plots (a) pH, and (b) sodium, chloride and sulphate concentrations from RO brines in the mining industry. The data points in Figure 28 are across the mining and metallurgical industries, coal mining, platinum, as well as 'typical' and estimated brine concentrations. The x-axis is arbitrary and related to the sources of information, given in Appendix A3.

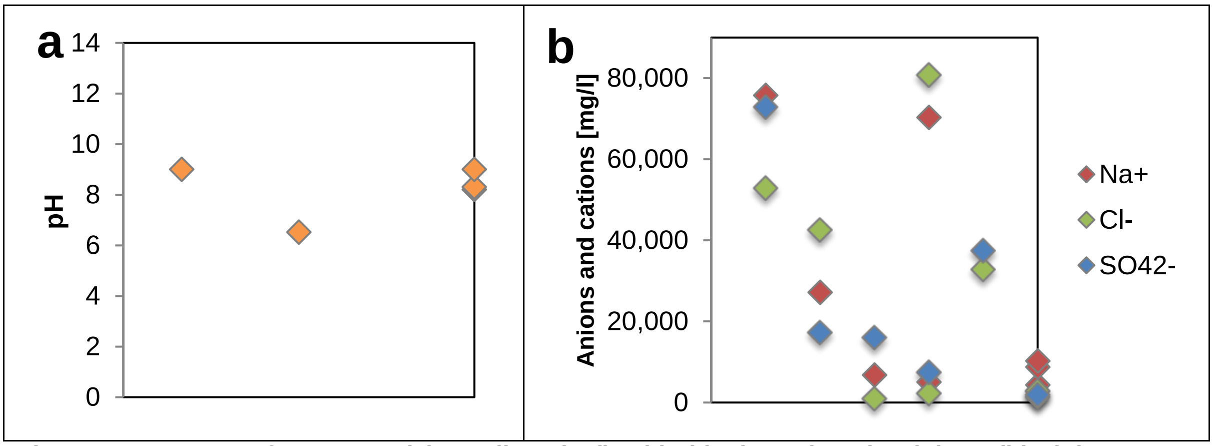

Figure 28: Ranges of a. pH, and b. sodium (red), chloride (green) and sulphate (blue) in reverse osmosis brines from the mining industry
The x-axis is arbitrary and related to data sources
Data points are sourced from literature referenced in Appendix A3.

Only half of the available sources reported pH, with values ranging from 6.5 to 9.0. Each of sodium, chloride and sulphate were present in various concentrations depending on the stream. Sodium (red in Figure 28) ranged from 4 300 to 75 800 mg/l. Chloride (green) ranged from the concentration of 1 000 to 80 800 mg/l. Sulphate concentrations (blue) ranged between 1 800 and 72 900 mg/l.

Potassium, calcium and magnesium were present in lesser concentrations as compared to sodium, chloride and sulphate. Potassium did not exceed concentrations of 1 810 mg/l; calcium had concentrations of less than 1 350 mg/l, and magnesium was present in concentrations smaller than 400 mg/l.

4.2.5. Petroleum

Figure 29 shows (a) pH, (b) TSS, (c) COD, and (d) BOD ranges in wastewaters from refineries. The data and references are in Appendix A3. The x-axis shows processing stages, where: 1. Desalter wastewater; 2. Sourwater; 3. Cooling tower blowdown; and 4. Overall petroleum refinery wastewater.

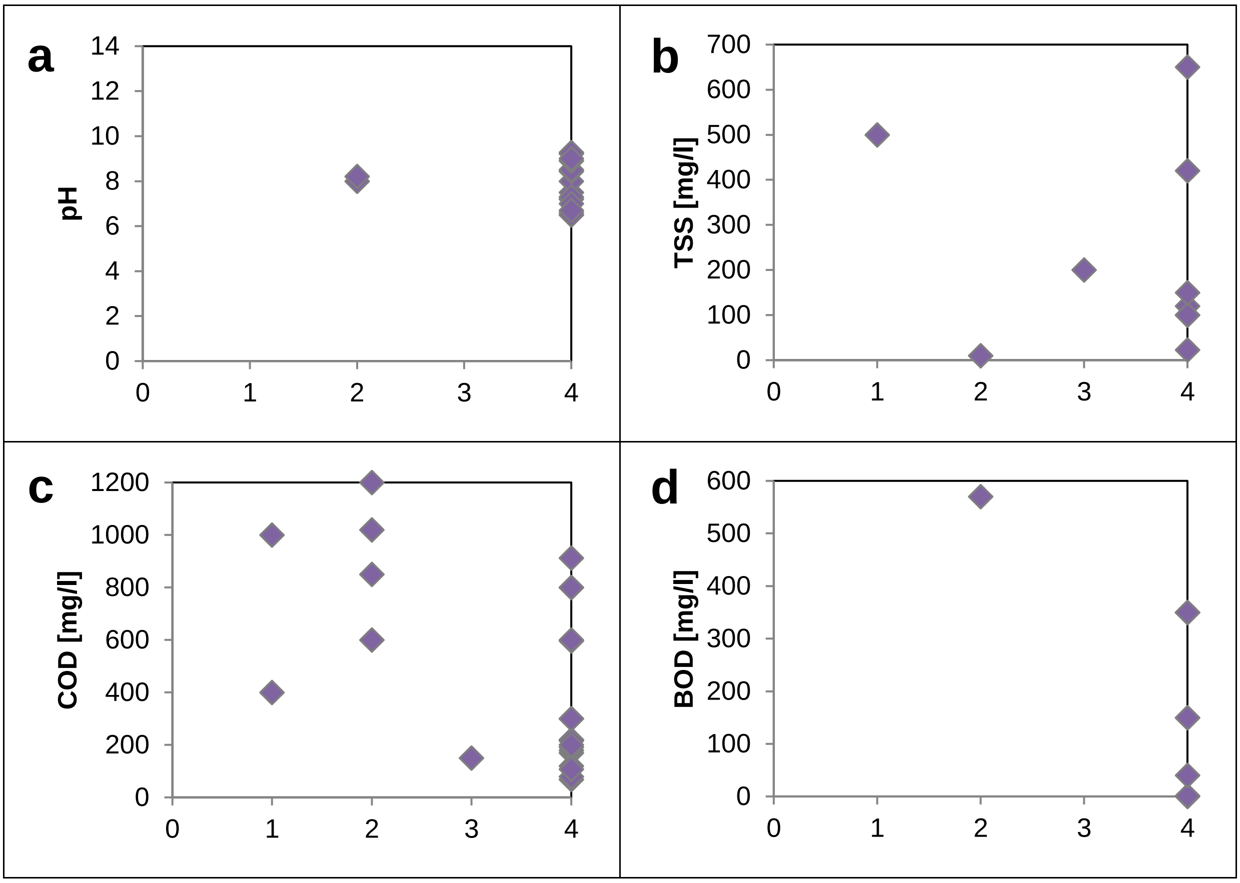

Figure 29: Possible ranges of a. pH, b. TSS, c. COD, and d. BOD, for various stages of operation in the petroleum industry
The numbers on the x-axis represent various stages of processing: 1. Desalter wastewater, 2. Sourwater, 3. Cooling tower blowdown and 4. Overall petroleum refinery wastewater.
Data points are sourced from literature referenced in Appendix A3.

The volume of wastewater from petroleum refineries can be significant. Coelho et al. (2006) estimate wastewater generated is 0.4 to 1.6 times the volume of oil processed. Al Zarooni and Elshorbagy (2006) estimate 3.5 to 5.0 m^3 of wastewater are produced for every ton of crude oil (approx. 1.2 m^3) processed with recycling.

Majority of the data was for an overall refinery wastewater (4 on the x-axis). This is because many refineries collect their wastewater in a common sump. Limited data was available for desalter wastewater (1 on the x-axis), sourwater (2), and cooling tower blowdowns (3). Sourwater and desalter wastewaters may or may not be handled separately owing to unique and toxic species present.

The pH generally ranges between 6 and 10 (Figure 29a). TSS is present up to 650 mg/l. Figure 29c and d show COD and BOD ranges respectively. COD ranges from 50 - 1 000 mg/l in refinery wastewaters and up to 1 200 mg/l in sour water. BOD ranges from 0 - 400 mg/l in refinery wastewaters, and up to 570 mg/l in sour water.

pH largely lies within the range given by the DWS (Table 2); while TSS and COD are beyond the given recommended limits for South African receiving water quality.

4.3. Comparisons and evaluations

Figure 23 and Figure 24 mapped the volumes of wastewater discharged into Water Management Areas, as well as the contribution from each industry to the volumes. Figure 30 plots water criticality in South Africa (Sonderegger et al., 2015). Water criticality assesses supply risk, vulnerability to supply restrictions and implications for the environment, in a score from 0 to 100. Inland areas of South Africa are facing medium to high water criticality (with scores ranging from 58.7 to 74.6). The darkest area on the maps scores 100 in terms of supply risk. This affects the mining, power generation, and petroleum industries. The Western Cape is experiencing moderate levels of water criticality, but this is unlikely to affect fish processing, as they abstract and discharge seawater.

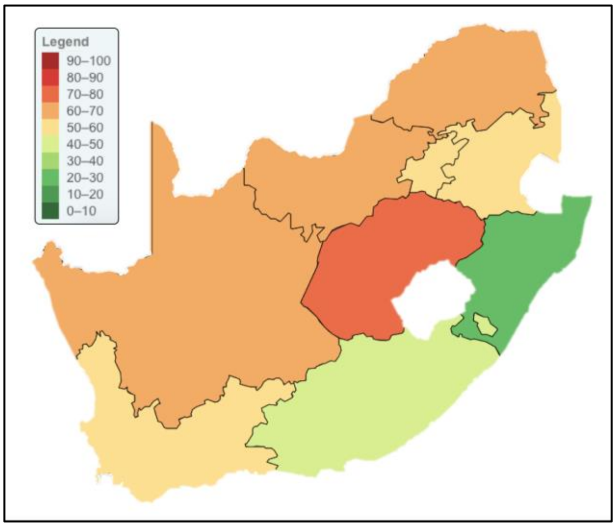

Figure 30: Water criticality in South Africa, by provinces

Figure 19 showed the levels of compliance in grouped WMAs, which can be compared with the locations of wastewater (Figure 24). However, there were no values available for 10 of 19 WMAs (2 and 4: Olifants; 5: Inkomati Usuthu; 6, 7 and 11: Pongola Mtavuna; 13 and 14: Orange; 17 and 19: Berg Olifants). There was some compliance information for: WMAs 1 and 3 (Limpopo), relating to power generation and mining; WMAs 8, 9 and 10 (Vaal), relating to pulp and paper, power and petroleum; as well as WMAs 16 and 18 (Breede Gouritz), but these do not apply to marine discharges; and WMAs 12 and 15 (Mizmvubu Tsitsikamma) in which there are no wastewater discharges.

Comparing Figures 25 thorugh to 29, the pulp and paper industry has the greatest pH range across its processing steps. This is followed by the fish processing industry. Power generation, mining and petroleum range between 6 and 10.

The TSS were highest for the fish processing and pulp and paper industry, both ranging up to 10 000 mg/l with outliers at 27 000 mg/l and 23 000 mg/l respectively.

TSS is usually removed by physical separation, such as filtration. TDS should be known for further treatment. However TDS is not well reported in the literature sources used above. Furthermore, the amount and identity of the dissolved solids, can inform practitioners of the potential value in the stream.

COD and BOD were captured for the pulp and paper, fish processing and petroleum industries. Fish processing had the highest values for both of these parameters. The pulp and paper and fish processing industries had values, with units of mg/l, in the order of 10 000's; while the petroleum industry had values in the order of 1 000's.

The power generation and mining industries did not measurement organics. These industries placed more value on inorganic dissolved salts, which were reported in more detail. In the mining industry, each of sodium, chloride and sulphate were present in concentrations up to 70 000 mg/l.

The literature generally reports well on broad priority parameters for wastewater characterisation. Each industry has priority contaminants/species in their wastewaters that are well reported on. For example, the pulp and paper, fish processing and petroleum industries are well represented in published sources with regards to COD and BOD. The mining industry reported major ions in their wastewaters. Greater detail of specific wastewater streams and their characterisation data will be presented in Chapter 5.

CHAPTER 5: Results and discussion – Wastewater characterisation and reporting norms

The research questions ask of the nature and norms of wastewater characterisation and reporting. Section 5.1 below will present results on the question of access; Section 5.2 will broadly consider what information is held in accessed documents; and Section 5.3 will present case studies to provide some insight into each industry.

5.1. How to access information

It is understood that wastewater information is sensitive. Building relationships and requesting information consumed a significant portion of this research process.

5.1.1. The successes and failures of an informal approach to access

Figure 22 in the methodology section (Section 3.3) illustrated an informal, relational route to requesting information. Figure 31 and Figure 32 below illustrate the different outcomes of informal requests, as experienced in this research endeavour.

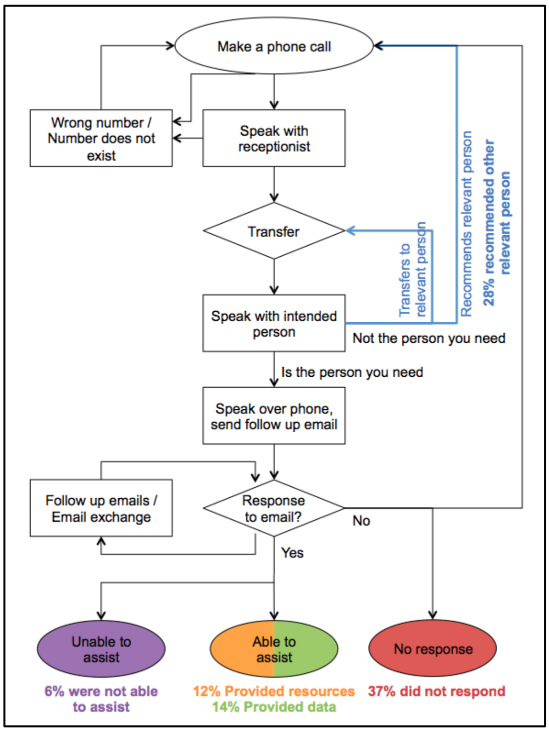

Figure 31: Flow diagram of possible outcomes when informally establishing relationships

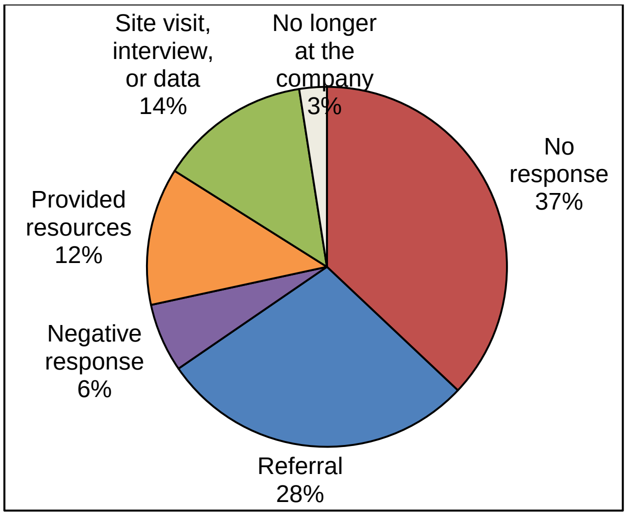

Figure 32: Outcomes of establishing relationships

The most common outcome (37%) was of no response to emails and/or phone calls after initial contact was established. This outcome includes several follow-up attempts with much waiting and few replies.

For example, initial contact was established with a company in the fish processing industry. Two site visits and a meeting were arranged, and a week was spent on site testing their wastewater to analyse its potential value. While on site we learnt that the company had an environmental report regarding their wastewater discharges. For concerns of confidentiality it was agreed to sign a non-disclosure agreement (NDA). However, after leaving site, and without the signed NDA, it was not possible to contact any of the people with whom relationships had been built. Therefore no NDA was signed, and the environmental report was neither received nor read.

The second most common response was for an individual to refer the request to a different, more suitable or more relevant person (28% of outcomes).

Another possible outcome was to speak with a relevant and interested person, who could escalate the request to their supervisor, superior or legal team. In 6% of cases, companies would report back with a negative response (such as “we are unable to assist you”; or “I am sorry to disappoint you but…”).

There are many possible reasons as to why a request around wastewater is received with reluctance. The first explanation is because of fear. Wastewater information is sensitive, and companies fear a number of undesired outcomes. Amongst other possibilities the research could damage their reputation; public opinion of their companies could be hurt; there may be costs implications if the research recommended additional treatment measures for their wastewater stream. These outcomes echo the experiences of Cloete et al. (2010).

Another reason is limited time and capacity that can be given to research endeavours (that may or may not be useful for the companies). For example, the pulp and paper industry has recently been surveyed and studied for the NATSURV publication, and some companies expressed a concern of being over researched.

Finally, recognising the researcher’s position in this work, the request could be viewed with low priority and importance because it originates from a student. The request may have been better received from somebody well know in academia or industry. However, academics or other well-respected people in the field may also struggle to access information. This may be because they are be perceived to pose a larger threat in terms of ability to hold industry to account (Personal communication, WRC reference group meeting, 2 November 2018).

One or many of these were at play simultaneously. In cases where companies were unable or reluctant to assist these were the reasons given; and where companies were not responding it can be assumed it would be for similar reasons. Where companies were reluctant it was possible to proceed with more formal procedures.

In 26% of cases companies were able to assist by providing resources or a meeting. In 14% of cases, the person contacted was able to provide resources (such as theses, databases or unpublished appendices to published reports). In 12% of cases the contact could provide a site tour, samples or wastewater characterisation data.

Two cases provided data (Eskom and a fish smoking facility); two cases hosted a site visit (both in abalone farming); one willingly shared their CWDP. Contacts from the Department of Environmental Affairs: Oceans and Coast and the Department of Water and Sanitation (DWS) were interviewed and helped further PAIA applications.

5.1.2. Discussion of (formal) PAIA applications

Wastewater information is not confidential (as defined in NEMA). Every company is required to publish a PAIA manual, which must indicate what records are available and how to submit a PAIA application (Section 14 of PAIA for public bodies, and Section 51 for private bodies). One can request information from individual companies, or submit a PAIA application to governmental bodies.

Section 14 (2) of PAIA states that public bodies "*must, if necessary, update and publish its manual … at intervals of not more than one year*". Private bodies must also update their manuals "*on a regular basis*", Section 51 (2) of PAIA. In reality, updates as frequent as this is not practised in all cases. This creates difficulties for a requester, especially when the listed information officer responsible is not the current information officer. Contact details may also be incorrect and out-dated.

As an example, the DWS's PAIA manual was written in the name of the Department of Water Affairs and Forestry (DWAF). The DWAF underwent restructuring in 2009, during which forestry was transferred to the Department of Agriculture, Foresty and Fisheries (DAFF). The DWS was formed in 2014 after the restructuring. However, their PAIA manual had not been updated since either of these changes. Consequently the information officer and contact details were incorrect. Therefore finding the current information officer took time. This has major implications for citizens attempting to hold public or private bodies to account. This process required time and money, as well as access to telephones, internet and email. These are available to a researcher, but the same is not necessarily true for citizens.

The manual (of public bodies) must also list "*the categories of records of the body which are available without a person having to request access in terms of [PAIA]*", in Section 14 (1) (e). Private bodies must do the same, as per Section 51 (1) (c).

A request for automatically available information proved to be more problematic than the formal process. In the formal process there are specified, legally binding timelines for a response (namely, 30 days). With the request for automatically available information, the requirement to respond and strict timelines did not exist. Therefore emails requesting access to information without the formal PAIA process, in this research experience, went unanswered. This route of requesting available records was abandoned. Instead formal PAIA request even for records of "automatic availability" that were "voluntar[ily] disclose[d]" (DWAF, nd) were submitted.

It must be noted that information that was "publically available" in legislation, may not be publically available in practice, and were certainly not "automatically available".

Two PAIA applications were submitted and both applications were successful; the first for CWDPs from the DEA, and the second for WULs and compliance reports from the DWS. However, only some of the documents requested in the PAIA application to the DWS were received. This was because not all compliance reports had been submitted to the DWS in the first place; therefore there were no documents to be forward as per the PAIA request. The documents received were later accompanied by an affidavit accounting for the missing records.

5.2. What information is available

Informal processes to access detailed wastewater characterisation information were unsuccessful in many cases, with some exceptions. Formal PAIA processes hold more traction, with legal timeframes and responsibilities. The following section will consider the information within accessed documents, from PAIA applications and industry cooperation.

5.2.1. Sources of wastewater characterisation information

Figure 33 shows the number of wastewater streams characterised within different sources of information. A total of 65 wastewater streams were characterised in the various source documents. There are other possible sources of data that could have been, but were not, explored. Other sources such as municipal data on water use and wastewater could have been requested from municipalities, or PAIA applications could have been submitted directly to companies. Applications were only submitted for WULs, compliance reports and CWDPs because of an assurance that these documents contained relevant information. Furthermore, both relational routes and formal PAIA processes take time and money. The PAIA applications took two and three months from submitting the request to receiving documents. However, this was preceded with time establishing contacts in the relevant departments, determining the information officer, determining the available documents and what information they contain. Because the PAIA process is a legal one, the request must be for specific records, from listed companies, over a given period. The initial time invested in making a PAIA application is critical for a successful application.

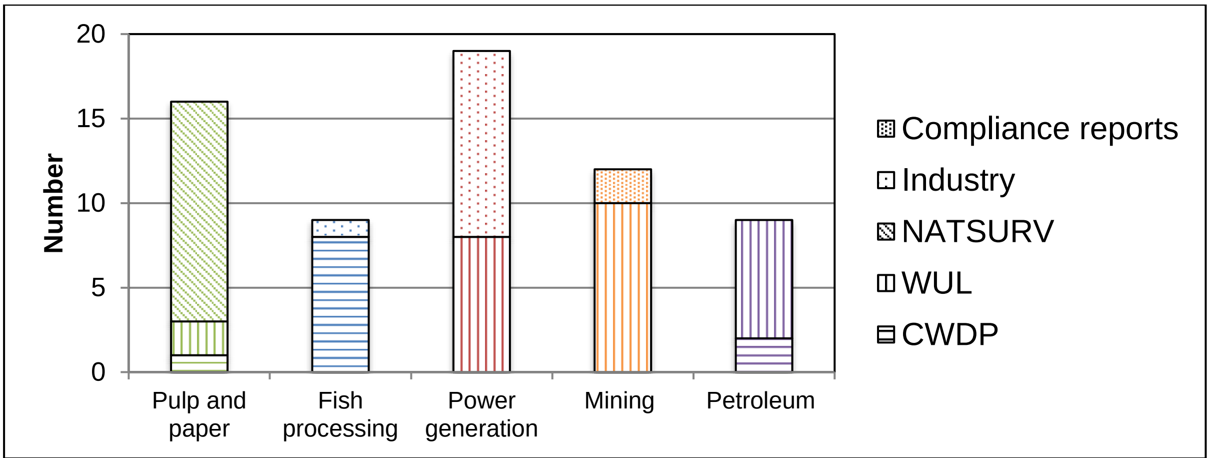

Figure 33: Number of wastewater streams characterised and accessed from each industry, with data sources

The horizontal stripes in Figure 33 show wastewater streams characterised within CWDPs. Unsurprisingly fish processing wastewaters are largely characterised in this type of document. This is because streams from the fish processing industry are generally discharged to marine environments, as is illustrated in Figure 9. One stream from the pulp and paper industry is characterised in CWDPs, and two streams in the petroleum industry. Again referring back to Figure 9, a portion of wastewaters arising from both the pulp and paper and petroleum industry are discharged to marine environments (van der Merwe et al., 2009). This is also mapped in Figure 24 with some of these industries in coastal regions.

The vertical stripes show information sourced from WULs. It is unsurprising that this type of document captures power generation, mining and petroleum industries. This is because WULs apply to inland water use and discharge, as discussed in Section 2.4.2. All wastewaters from the power generation and mining industries are released inland, while the majority of wastewaters from petroleum are released inland, as illustrated in Figure 8. This is mapped into WMAs in Figure 24, where red (power), orange (mining) and purple (petroleum) pie chart segments are largely found inland.

The diagonal stripes show information from the NATSURV collection published by the WRC. Although the collection reports on a number of different industries, the second edition was incomplete at the time of writing, and therefore relevant information could only be sourced for the pulp and paper industry.

The loosely dotted blocks show information sourced directly from industry partners. There is one stream from the fish processing industry, and ten from Eskom.

Two streams in the mining industry were sourced from compliance reports submitted as part of compliance with WULs, illustrated with tightly dotted blocks.

The power generation industry is best represented in the data, with 19 streams characterised. Pulp and paper are also well represented, with 16 streams characterised. Mining is represented in 12 streams. Fish processing and petroleum both have nine streams characterised.

5.2.2. Breadth of wastewater characterisation parameters

A large number of characterisation parameters are captured across the source documents studied. Categories include:

- Stream details (such as volume, temperature);
- General parameters (such as pH, EC, solids, salinity, acidity and alkalinity);
- Organic parameters (including, but not limited to, measurements of TOC, COD, BOD, and soap, oil and grease);
- Biological and microbiological parameters (coliforms, faecal coliforms, E.coli);
- Nitrogen systems (including total nitrogen, total organic nitrogen, ammonia, nitrate and nitrite);
- Anions and cations;
- Metals and non-metals
- Other.

A range of parameters was recorded across the source documents. Figure 34 shows box and whisker plots of the number of parameters listed for each stream within each industry of interest. The "box" represents the central 50% of the data, either side of the median. The "whiskers" extend to the minimum and maximum number.

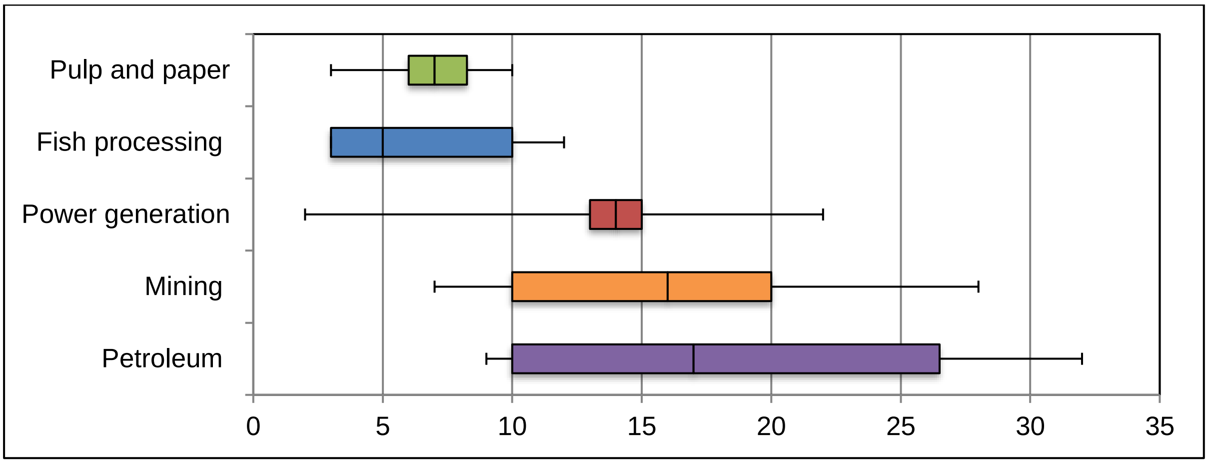

Figure 34: Box and whisker plots showing the number of parameters listed within each industry

Pulp and paper industry (green) used ten or less parameters to characterise their streams. This is related to the limited information in the NATSURV series. In the fish processing industry (blue) 75% of the streams are characterised by ten or fewer parameters. Power generation (red) measured between 2 and 22 parameters, with the bulk of the data about the median at 14. The mining industry has between 7 and 28 parameters listed in WUL and compliance reports, with a median of 16. The petroleum industry (purple) has the largest range, highest maximum and highest minimum.

Figure 34 shows that the number of parameters recorded in environmental permits, licenses, and by industry are inconsistent. For example, one CWDP in the fish processing industry listed the wastewater quality in terms of three parameters, while another listed 12 parameters. In the petroleum industry, in a number of different WULs issued to a single company: one listed wastewater quality in terms of nine parameters, while a second was in terms of 32 parameters.

Differences in the number of parameters listed may be because different parameters are important to each industry. Figure 35 shows stream details, general parameters and hardness information captured across the industries of interest. The y-axis shows the number of times each parameter was listed in the sources studied.

The most commonly reported parameter is pH. It is recorded in 56 of 65 cases (86%). The next most commonly reported parameter is an indication of volume, listed in 49 cases (75%). The volume may be listed as discharge volume per day, month or year, or specific wastewater volume per ton of product. Specific wastewater volume was commonly used in the pulp and paper industry. Electrical conductivity (65%), TSS (51%)and TDS (38%) were also commonly listed parameters.

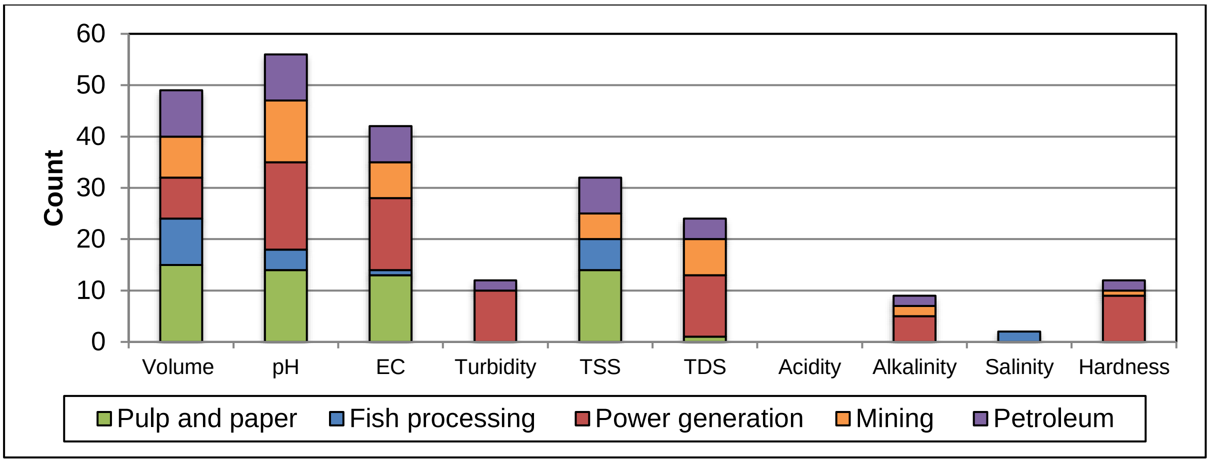

Figure 35: Number of wastewater stream parameters, including volume, general parameters and hardness, captured in the source documents for each industry of interest

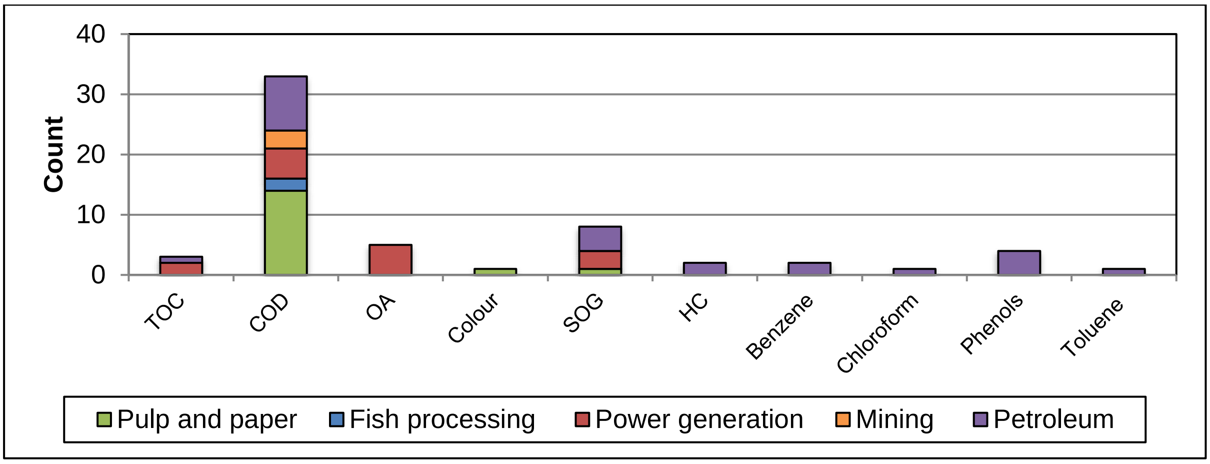

Figure 36: Number of organic parameters measured in wastewaters captured in the source documents for each industry of interest
TOC – total organic carbon; COD – Chemical oxygen demand; OA – oxygen absorbed; SOG – Soap, oil and grease; HC – hydrocarbons; Phenols – Phenol and phenolic compounds.

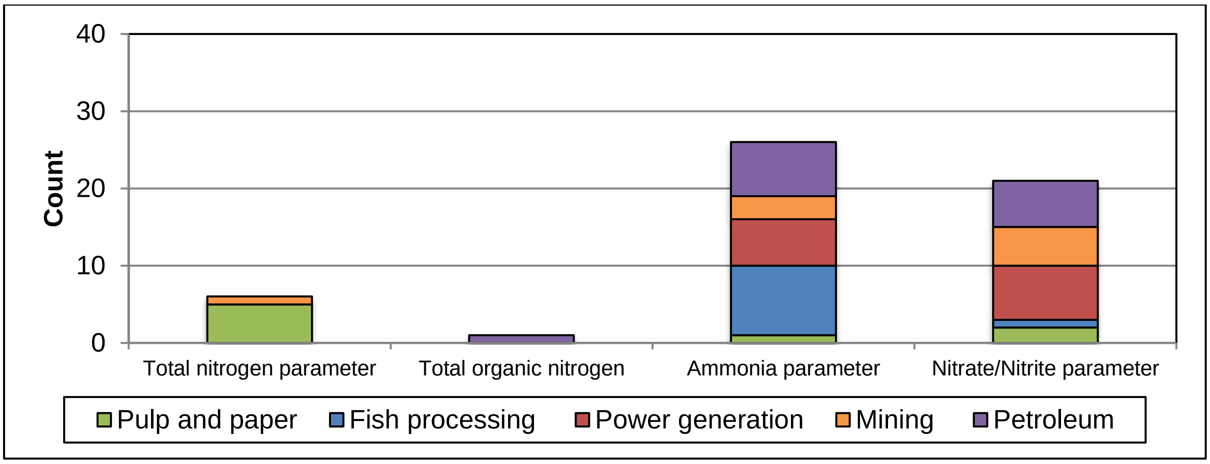

Figure 37: Number of parameters measuring any form of nitrogen captured in the sources documents for each industry of interest

Figure 36 shows the organic parameters captured. The most commonly captured organic parameter is COD, in 33 of 65 cases (51%). COD is listed for 100% of streams in the petroleum industry, and 88% of streams in the pulp and paper industry. The petroleum industry is concerned with other organic parameters, such as hydrocarbons, benzene, chloroform, phenolic compounds, and toluene.

Figure 37 shows parameters measuring any form of nitrogen in each industry. Some form of nitrogen is measured in 41 of 65 cases (63%). WULs, CWDPs, NATSURV or industry may list nitrogen in one (or more) of the following forms: total nitrogen, organic nitrogen, ammonia nitrogen or ammonia, nitrate or nitrite. Of these parameters for ammonia and nitrate/nitrite are most commonly listed. Ammonia is listed in 26 cases (40%), and nitrate and/or nitrite parameter in 21 cases (32%).

Figure 38 shows the anions and cations measured across the different sources.

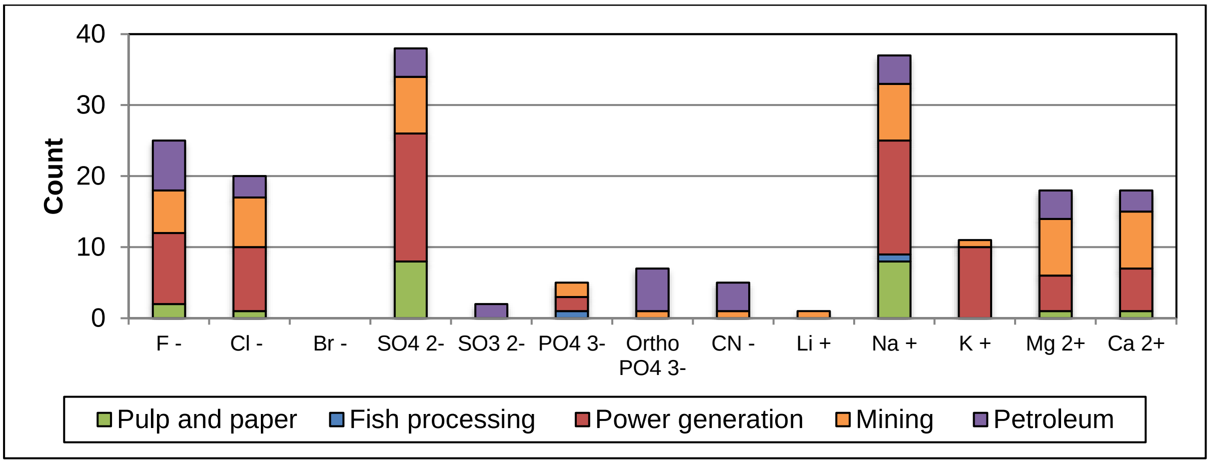

Figure 38: Number of anions and cations measured in wastewaters captured in the source documents for each industry of interest

Sulphate is the most common anion, captured in 38 of 65 cases (58%). Sulphate is listed for 95% of the streams in power generation; 60% of cases in mining; and 50% of the streams in pulp and paper. Thereafter fluoride and chloride are commonly listed anions, in 25 (38%) and 23 (35%) cases. Fluoride is listed for 78% of streams in the petroleum industry, and chloride is listed for 90% of streams in mining.

Sodium is most commonly listed cation, in 37 of 65 cases (57%). It is recorded for 84% of the streams in the power generation industry; 60% of the streams in mining, and 50% of the streams in the pulp and paper industry. Overall the power generation and mining industries are most likely to record ion concentrations.

Figure 39 shows the non-metals and metals captured in each of the sources. These parameters are captured more infrequently as compared with the previous ones, noting the different scale on the y-axis. The most commonly listed metal is iron, 18 times. Manganese is also relatively commonly recorded, in 17 cases. Power generation and mining, as well as petroleum, are most likely to list base metals.

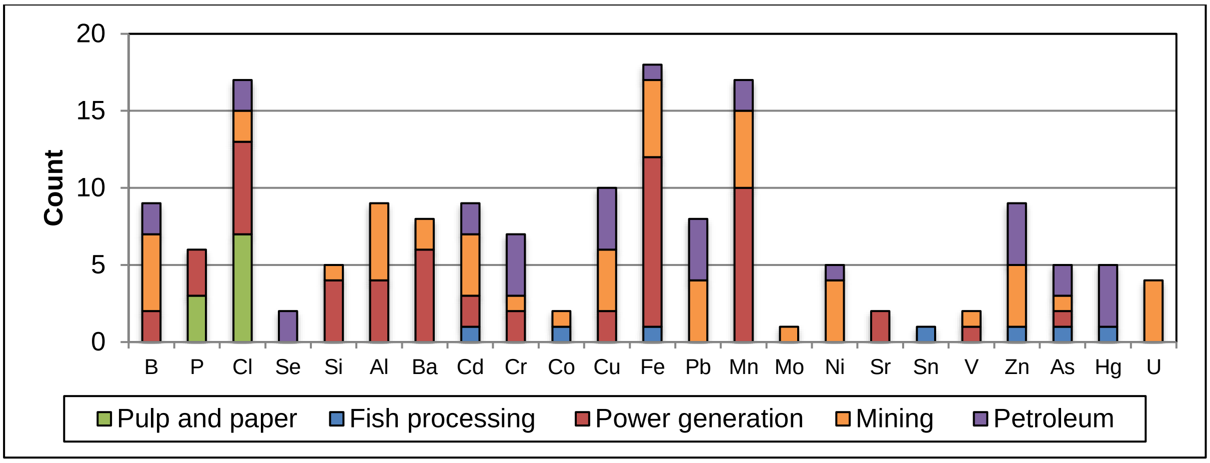

Figure 39: Number of non-, base-, trace- and semi-metals (present in wastewater as ions) measured in wastewaters captured for each industry of interest

Seven parameters are listed in more than half of the cases captured in the source documents studied. They are: pH (86%); volume (75%); electrical conductivity (65%); some form of nitrogen (63%); sulphate (58%); sodium (57%) and COD (51%).

5.3. Case studies of South African wastewaters

For progressive research and policy, it is important to have a rich understanding of wastewater characterisation information. This makes research into treatment technologies context specific and locally relevant. The following section will consider case studies of wastewater characterisation and reporting. It will show what information is known, unknown and how it compares (or cannot be compared) to limits. The case studies show a "grab sample" within each industry of interest and are not claiming to be representative of the whole industry. A full table of all streams characterised against a comprehensive list of parameters is given in Appendix A4.

Finding appropriate limits with which to compare the case studies' data was difficult. The RWQO and recommended standards (Table 2) are for instream water quality. It is anticipated that discharged streams could have higher limits, depending on the desired instream quality (Equation 3). Therefore these limits and recommended standards are not the same as the end-of-pipe discharge standards. End-of-pipe discharge standards are varied and based on a number of conditions. Furthermore, the RWQO for each and every water resource is not readily available or accessible. Therefore the value of comparing the case studies to these standards is limited.

Each of the figures in the following section are read similarly. The x-axis shows the parameters that have been used to characterise a wastewater stream. Each parameter has a corresponding maximum value and unit shown at the top of the graph. The y-axis reports a fraction of this maximum. The maximum value is an arbitrary number based on the data considered and is not reflective of any environmental or other limit. Coloured points indicate wastewater details; vertical boxes show minimum, average and maximum values; black lines, crosses, and outlines illustrate discharge limits.

5.3.1. Pulp and paper

The second edition of NATSURV 12 anonymously reported wastewater characterisation data for pulp and paper mills in South Africa (van der Merwe-Botha et al., 2017). Figure 40 plots wastewaters from paper only (light green diamonds) and integrated paper and pulp mills (dark green triangles), and discharge limits. The limits depend on the intended use or discharge (irrigation, wastewater treatment facility, to sea) and the location (each municipality has different limits).

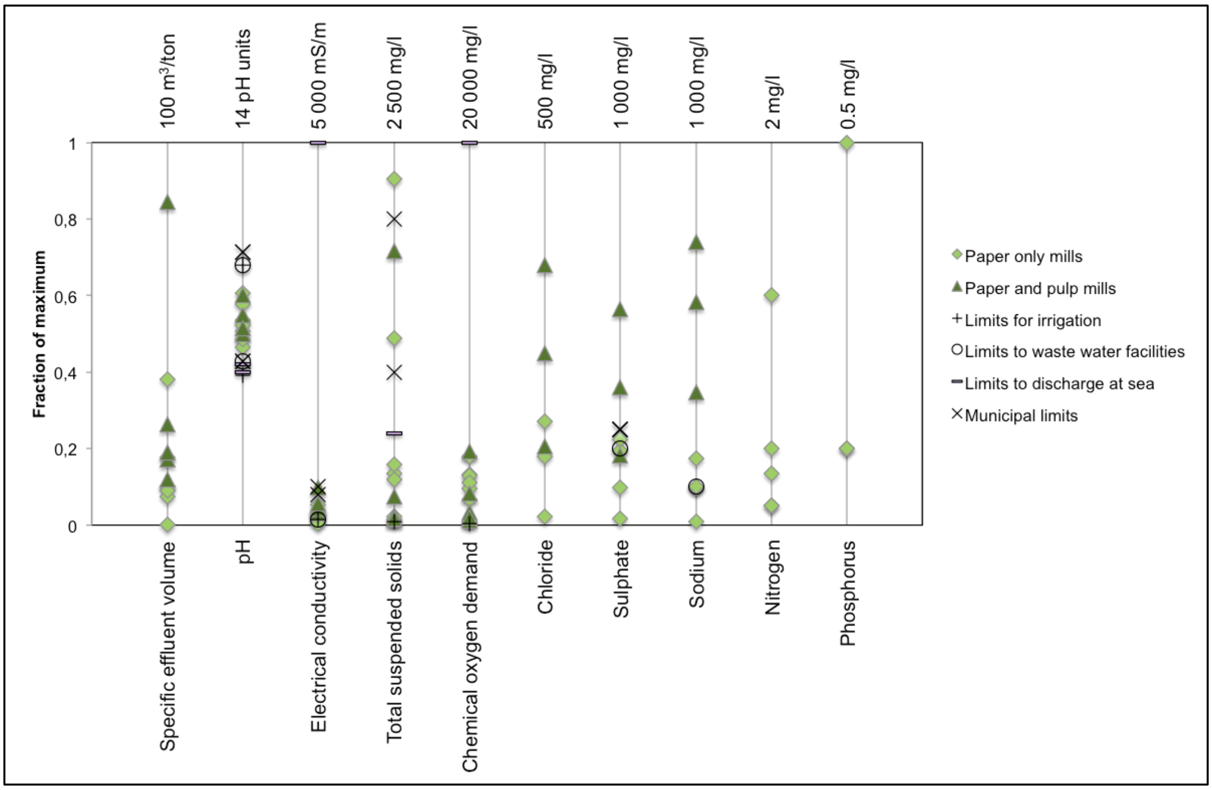

Figure 40: Wastewater characterisation infomration and limits in the pulp and paper industry

The specific effluent volume (SEV) in paper only mills ranged between 0.08 and 38.2 m^3/ton of product. In paper and pulp mills, this range was from 12.0 to 84.5 m^3/ton. One of the factors that influence the SEV is the type of facility. Integrated mills generally have a larger SEV, as seen in Figure 40, because they have more processing steps. More processing requires more water; noting that specific water intake (SWI) is linked to SEV (van der Merwe-Botha et al., 2017). Other site-specific factors that influence SEV are: age of the facility; processing technology used; feed material; and product type. There are no given limits for SEV.

The pH ranged from 6.5 to 8.5 in paper only mills, and from 7.0 to 8.4 in pulp and paper mills. The lower limits for pH are between 5.5 and 6.0 pH units, and the upper limits are around 9.5 and 10.0 pH units. In every case, for both paper only and integrated mills, the pH is within all the given limits.

Electrical conductivity is an indicator of the dissolved inorganic substances in discharge. In paper only mills this ranges between 21 and 273 mS/m; while in integrated mills electrical conductivity ranges from 169 to 497 mS/m. These are all relatively small values compared to the limit for discharges to a marine environment (5 000 mS/m). However, the limits for irrigation and discharge to wastewater facilities are 70 mS/m, with only one stream below this value.

The TSS range from 34 to 2 260 mg/l in paper only mills, and between 38 to 1 790 mg/l in paper and pulp mills. There are two points indicated for municipal limits; one value of 1 000 mg/l and a second value of 2 000 mg/l. These limits are for small and large works within the same municipality. A small works was defined as discharging less than 25Ml/day, and a large works discharging more than this.

The COD for streams from paper only mills ranges between 165 and 3 598 mg/l, and for integrated mills between 238 and 3 853 mg/l. As with the electrical conductivity, these values are much smaller than the discharge limit to a marine environment; where the limit is 20 000 mg/l. The COD in each of the wastewaters are less than 20% of this. The limit for irrigation however is low, at 75 mg/l, with no streams complaint to this particular limit.

Chloride and sulphate are the major anions given in the NATSURV report. Chloride ranged from 90 to 340 mg/l across all types of mills; while sulphate ranged between 16 and 565 mg/l. The most prevalent cation is sodium, which ranged between 10 and 582 mg/l. This suggests that sodium sulphate and sodium chloride would be dominant salts if RO or crystallisation techniques were applied as treatment.

In general integrated paper and pulp mills have higher measures for the characterisation parameters. This is true for six of the eight parameters considered here. The first exception is pH, where the difference is marginal. The second exception is TSS. Speculatively, this may be because of prohibitive costs of treatment in smaller mills.

Van der Merwe-Botha et al. (2017) report that large mills achieve 95-100% compliance with limits posed either in municipal by-laws or their WULs. They report that compliance is lower for smaller mills, because of the cost of treatment.

Wastewater characterisation information and reporting has improved between the first and second editions of NATSURV 12, with research completed in 1990 and 2015 respectively. The number of mills surveyed increased, thereby improving representation of mills and the industry. Furthermore, the quality of wastewaters improved, illustrated in Figure 41.

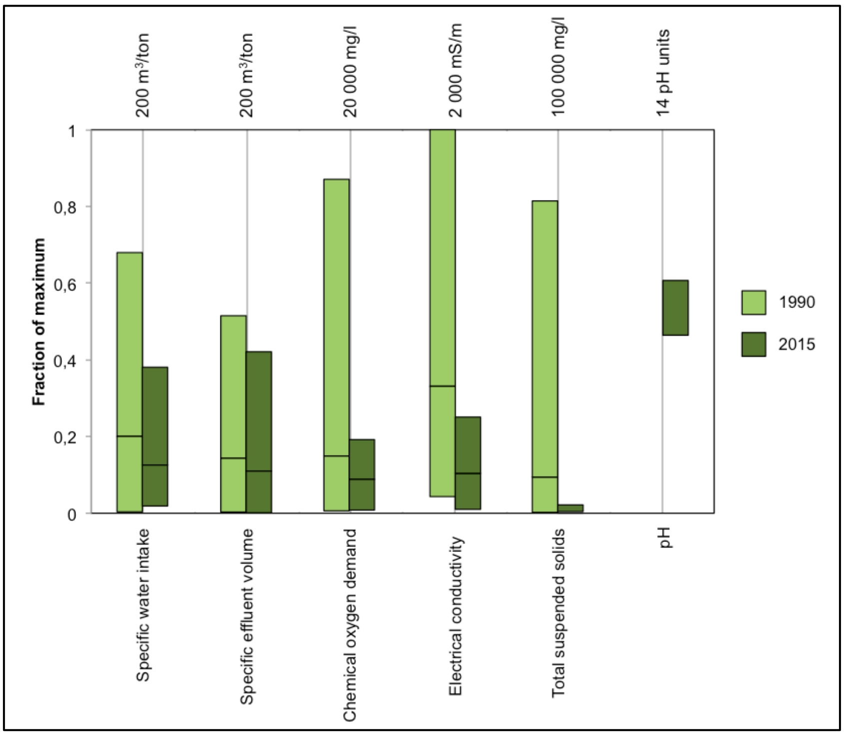

Figure 41: Wastewaters in the pulp and paper industry in 1990 and 2015 (Adapted from NATSURV 12, 2017)

Average and maximum specific water intake (SWI) and specific effluent volume (SEV) both decreased in the industry between 1990 and 2015. In one case the mill indicated that their "specific effluent volume [was] classified as intellectual property and was not released for [the] study". This is incongruous with the definition of confidential information in NEMA, which excludes waste and wastewater information.

The average and maximum COD, electrical conductivity and suspended solids decreased markedly. The maximum value for COD was 17 402 mg/l in 1990, compared to 3 853 mg/l in 2015; a 78% reduction. The maximum conductivity reduced from 2 000 mS/m in 1990 to 497 mS/m in 2015; a 75% reduction. Suspended solids were reduced by 97%, from 81 380 mg/l in 1990 to 2 260 mg/l in 2015. This is encouraging as it highlights improvements in wastewater quality over time.

5.3.2. Fish processing

A number of abalone farms and processing facilities operate in the Western Cape. Abalone farms abstract and return large volumes of seawater, but the composition of returned water is unchanged, if not better water quality (personal communication, DEA stakeholder meeting, 11 May 2017).

A particular fish cannery and particular fishmeal plant generate wastewaters in each facility. The cannery produces wastewater with high-quality fish oil. This wastewater also contains fish solids and water. This waste stream is potentially valuable because the oil could be recovered for human consumption. Currently, the wastewater is forwarded to the fishmeal plant where both the fish oil and solids are recovered for animal feed. The wastewater generated in the fishmeal plant is treated and discharged to the sea, with a composition similar to seawater but with added waste heat (personal communication, Kevin Changoo, 30 May 2016).

A fish filleting and smoking company shared details of their water use, wastewater generation and treatment within their plant. This site is inland in the Western Cape. The facility processes salmon and trout into smoked product. A block flow diagram of the factories and facilities is shown in Figure 42.

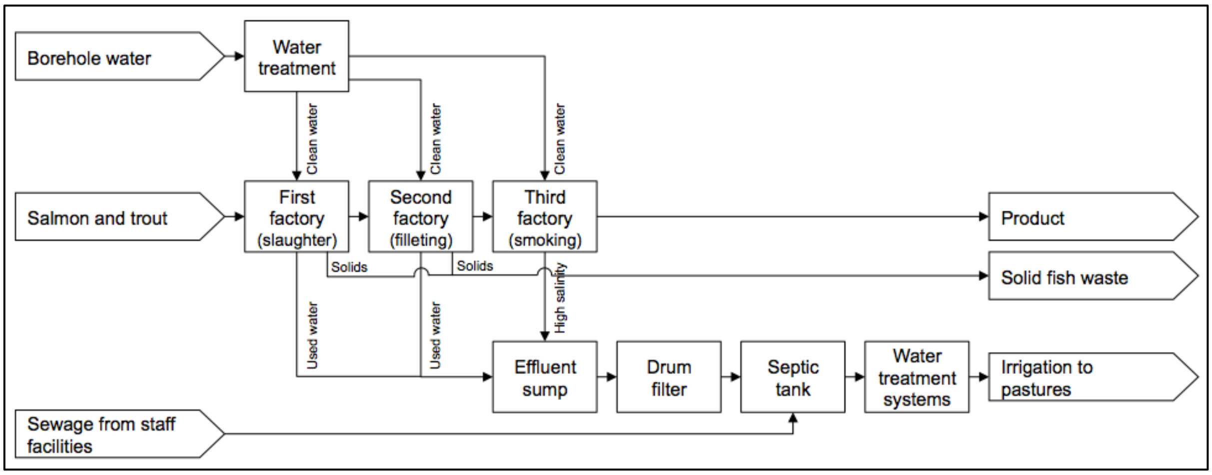

Figure 42: Block flow diagram of a fish filleting and smoking facility

Water is withdrawn from boreholes on site. Pre-treatment includes: filtration, chlorination, activated carbon and sterilisation with UV light.

They operate three main processing factories. The first factory is responsible for slaughtering, gutting and gilling the animals. The second factory fillets and trims the fish. The third factory prepares and smokes the fish. Each factory generates wastewater, which are forwarded to a sump and then sent through a drum filter.

Auxiliary facilities include wastewater treatment system and staff facilities. Sewage from the office and staff facilities joins the factory wastewaters in a septic tank. Together these pass through aerobic and anaerobic treatment systems. The treated water is used for irrigation of local pastures. Solid fish waste is sent offsite to a fishmeal plant.

The minimum, average and maximum treated water quality parameters are illustrated in Figure 43, along with the required limits for irrigation. The results are for treated wastewater used for irrigation between January 2014 and December 2016.

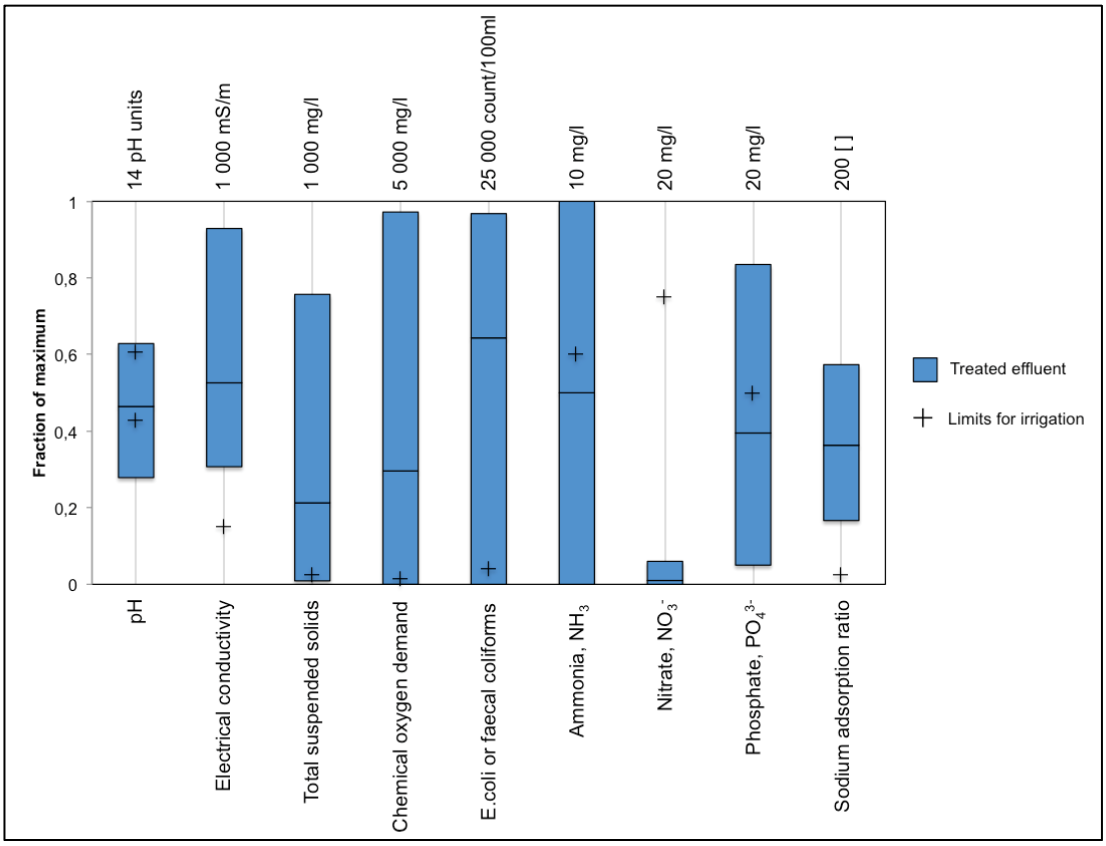

Figure 43: Treated wastewater quality and irrigation limits from a fish processing and smoking facility, in the fish processing industry

The discharge volumes, not indicated in Figure 43, ranged from 8.4 m^3/day to 180 m^3/day, with an average of 87.2 m^3/day. The discharge limit is 80 m^3/day, which was near the average value. The variation was related to seasons, what species of fish is processed, and the particular product.

The pH ranged between 3.9 and 8.8, with an average of 6.5. The pH limits were between 6.0 and 8.5. The average value was within limits, and the maximum value was just beyond the upper limit. The minimum value was well below the lower limit.

The conductivity, suspended solids and COD were consistently above the specified limits. The electrical conductivity has minimum, average and maximum values of 307, 526, and 929 mS/m respectively. These were all well above the limit of 150 mS/m. One possible source of high conductivity could have been the high salinity strength stream originating from the third factory and the salting procedure.

The TSS ranged between 9 and 757 mg/l, with an average of 213 mg/l. The limit was 25 mg/l, which was one-eighth of the average value.

The COD ranged from 1 to 4 860 mg/l, with an average of 1 480 mg/l and a limit of 75 mg/l. The average value is almost 20 times the given limit.

Ammonia ranges from 0 to 10 mg/l, with an average of 5 mg/l and limit of 6 mg/l. Nitrates are well below the required limit of 15 mg/l, with a maximum value of

1.2 mg/l. Phosphate has minimum, average and maximum values of 1, 7.9, and 16.7 mg/l respectively, and a limit of 10 mg/l.

Measurements for E.coli and faecal coliforms are usually well above the required limit of 1 000 counts/100ml. The average value is 16 080 counts/100ml with a maximum value of 24 196 counts/100ml. The average and maximum values are 16 and 24 times larger than the limit. However, 20 times out of 32 readings this value was exactly “24 196 org/100ml” correct to 5 significant figures. The similarity and exactness of this number raises suspicion about its accuracy and validity.

Sodium adsorption ratio (SAR) is a water quality parameter important for irrigation, as sodium in soil can negatively affect soil quality. The ratio compares sodium to calcium and magnesium, with the following formula (Ayers and Westcot, 1994):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Equation 4

The limit for this parameter is 5. However, the measured ratio is consistently larger than the limit, with minimum, average and maximum values of 33, 73 and 115 respectively. This is a concern because sodium in irrigated water can replace calcium and magnesium in the soil, thereby changing the soil properties.

5.3.3. Power generation

Wastewater streams from the power generation industry have been characterised by Eskom. Eskom provided characterisation data for reject streams from RO units in the water demineralisation plants (Figure 16). This information was available for several RO units at five power stations: Grootvlei, Lethabo, Komati, Medupi, and Tutuka. WULs from three power stations were available: Medupi, Hendrina and Kendal.

Wastewater characterisation information and discharge limits were both available for Medupi power station. This is plotted in Figure 44. The minimum, average and maximum values are analysed over a period of 6 months between April and September 2016 (personal communication, Anke Botha, 17 March 2017). The discharge limits are given in WUL 01/A42J/4055.

First, note that the RO reject stream is not the stream discharged, either by irrigation or to the environment. Therefore it is not appropriate to compare the wastewater values to the given limits. Instead, this illustrates the work that is needed by treatment processes before the RO reject can be safely, responsibly discharged.

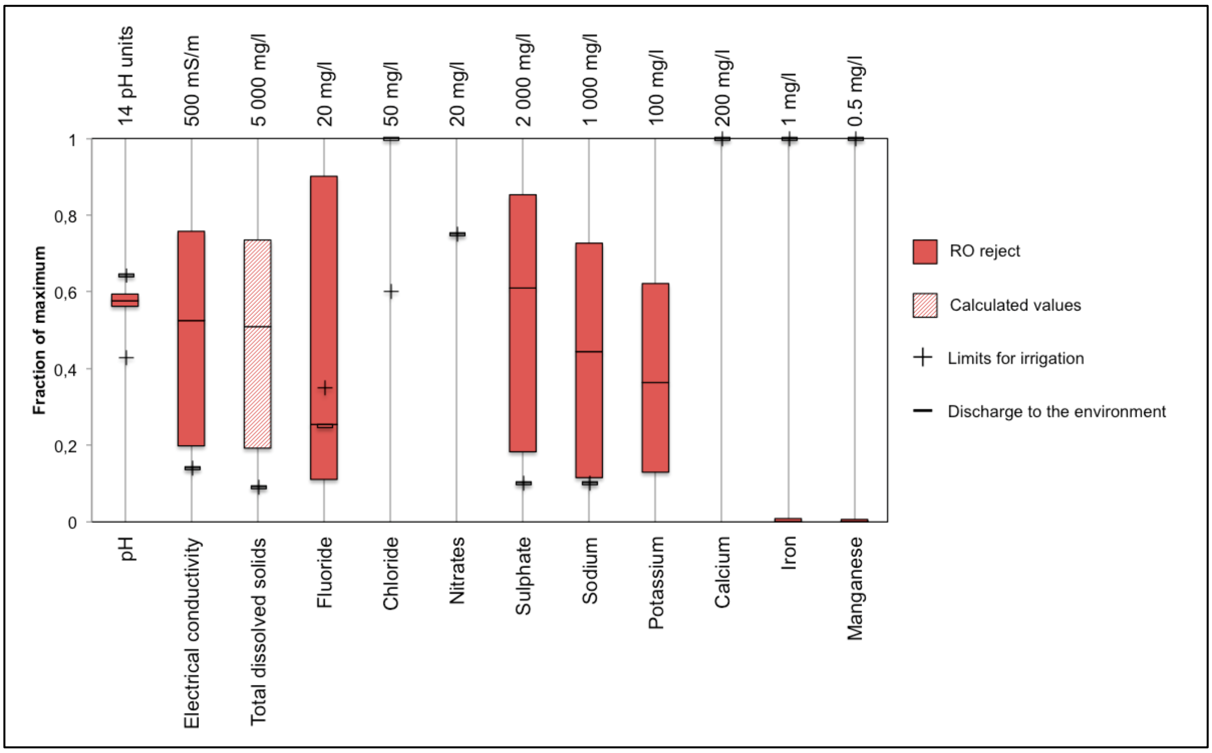

Figure 44: Wastewater characterisation information, in terms of minimum, average, maximum values, and discharge limits in the power generation industry

The measured pH lies between 7.9 and 8.3, which was already within limits for discharge, between pH values of 6.0 and 9.0.

The electrical conductivity has minimum, average and maximum values of 99, 263 and 379 mS/m respectively. The discharge limit for both irrigation and environmental release were 70 mS/m.

No measured values of TDS were given. However, using the conversion factor proposed by Hubert and Wolkersdorfer (2015) the TDS could be calculated using Equation 2. Applying this formula and a conversion factor of $f = 0.97$ the minimum, average and maximum TDS values calculated from electrical conductivity (in units of µS/cm) are 962, 2 547 and 3 676 mg/l respectively. The given limit for TDS was 450 mg/l for both irrigation and environmental release, therefore indicating that treatment would be required. It is anticipated that the electrical conductivity and TDS would be high for the RO reject, as this stream has been concentrated with the dissolved species in the RO units. This wastewater was slightly to moderately saline, using the definition given by USGS (2016b) in Section 2.1.1.4.

Fluoride, chloride, nitrate and sulphate were anions listed in the WUL. Measured values from Eskom were only available for fluoride and sulphate. Fluoride ranged between 2.2 and 18.0 mg/l, with an average of 5.1 mg/l. The limits for environmental discharge and irrigation were 5 and 7 mg/l. Sulphate is the most abundant ion, with values that ranged up to 1 707 mg/l. The discharge limits were 200 mg/l.

Sodium, potassium and calcium were cations listed between Eskom and their WUL. No discharge limits are indicated for potassium, and no measured values were given for calcium. Calcium does not present any environmental threat, but it is associated with scaling problem in treatment units. Sodium is the more abundant cation, compared with potassium. Sodium ranged from 115 to 726 mg/l, with an average of 444 mg/l. Potassium ranged between 13 and 62 mg/l.

From the indicated values, it is anticipated that sodium sulphate would be a common salt that could be recovered from this reject stream. Depending on the calcium concentration, calcium sulphate could also be present. Calcium sulphate, or gypsum, is a sparingly soluble salt and could cause scaling in downstream treatment.

The listed metals, iron and manganese, are already well below the given limits.

5.3.4. Mining

The mining industry was anxious or unable to share wastewater characterisation information. Nonetheless, the industry was represented in WULs and compliance reports. Three compliance reports for gold mining companies were received. No compliance reports were received for coal mining. The level of details contained in compliance reports is variable. Some of these reports indicate “compliant”, “non-compliant” or “partially compliant”; while others report wastewater characterisation data.

Where wastewaters are not characterised in compliance reports, “partial compliance” does not indicate how many parameters are within or outside of the given limits. “Partial compliance” does not indicate which specific parameters are outside of limits and whether they are outside of limits once off, occasionally or regularly. Furthermore, it is not indicated how far from the discharge limit/s a single or many parameters deviated. All this coupled with the non-identity of the offending parameter/s could be important if the parameters are associated with high toxicity.

As an example, a WUL (01/C23E/ABEFGJ/2802) issued to a gold mining company allows them to irrigate with wastewater, discharge wastewater into a water resource, and dispose of waste. These activities are licensed in terms of the NWA of 1998 and are subject to conditions set out in the license. This licence was issued in July 2015, and a compliance report was submitted to the DWS in December 2015.

This company is licensed to irrigate with wastewater on the condition that the quality of the wastewater does not exceed listed values. The irrigated area is a golf course. The compliance report notes “various exceedances” in a number of parameters. They also report that not all of the listed parameters are measured. The report goes on to say that nitrate, calcium and faecal coliforms were not tested for.

It appears that there has been an attempt to comply with the requirements of the WUL, while also being practical and implementable. The testing of irrigated water, where some variables are not tested for, may be owing to the expense of the additional tests. Nitrates are one of the parameters not tested. Nitrates are a nutrient to plants, and could, therefore, be beneficial to grass irrigated with this water. However excess nitrogen can cause problems (Ayres and Westcot, 1994).

Calcium provides soil stability and therefore can be beneficial in irrigation water. This is especially true if the sodium content in the water is high (Ayres and Westcot, 1994). However, sodium is not specified as a required parameter to monitor.

As the irrigated area is a golf course, it is likely to be frequented by members of the public. Therefore limiting the faecal coliforms in the irrigated water is an important control to protect human health (Pescod, 1992). Not testing for this parameter puts people using the golf course at risk of exposure to pathogens.

This company is also licensed to dispose of waste into receiving water resources. The compliance report states that no wastewater is discharged into the receiving environment. Therefore the auditors recommended that the WUL be amended to reflect this. Instead of discharge into the receiving environment wastewater is disposed of into wastewater facilities. The WUL requires that the waste received in these facilities must be within given limits. The compliance report states that no testing is done on wastewater streams entering these facilities, reasoning that it is not practical to do so. Testing is done in the return water dam. The compliance report recommends an application for an amendment to the WUL.

This example indicates a mismatch between the WUL and actual operation onsite. This could suggest difficulties in communication between the DWS and companies, as well as possible difficulties in amending WULs. Again, there is an attempt to uphold the law and protect the environment while being practical. This judgement is based on the fact that while the water may not be tested when entering the wastewater facility it is tested in the return water dam.

There are other examples when compliance reports include more detailed wastewater characterisation information. Two compliance reports submitted include this information. For example, a second company in the gold mining industry is authorised to undertake its activities in terms of section 21(a) (abstracting water), (f) (discharging wastewater) and (j) (decanting underground water) of the NWA in a WUL issued in December 2016 (10/C23E/AFJ/4787). An external auditing company completed a compliance report in June 2017, which included wastewater characterisation data. This is illustrated in Figure 45. Figure 45 shows two discharge streams at two different stretches of time: before (light orange diamonds) and after (dark orange triangles) a mineshaft began decanting.

The seepage increased the values of different parameters in most cases, negatively impacting the water quality. However, three parameters were beyond the limits both before and after seepage. These parameters were electrical conductivity, sulphate, and cadmium. Chloride, phosphate, boron, aluminium, copper and zinc were all within the required limits both before and after seepage. The remaining parameters were within limits before but beyond the limits after seepage. These parameters are suspended solids, sodium, magnesium, iron, lead, manganese, and uranium.

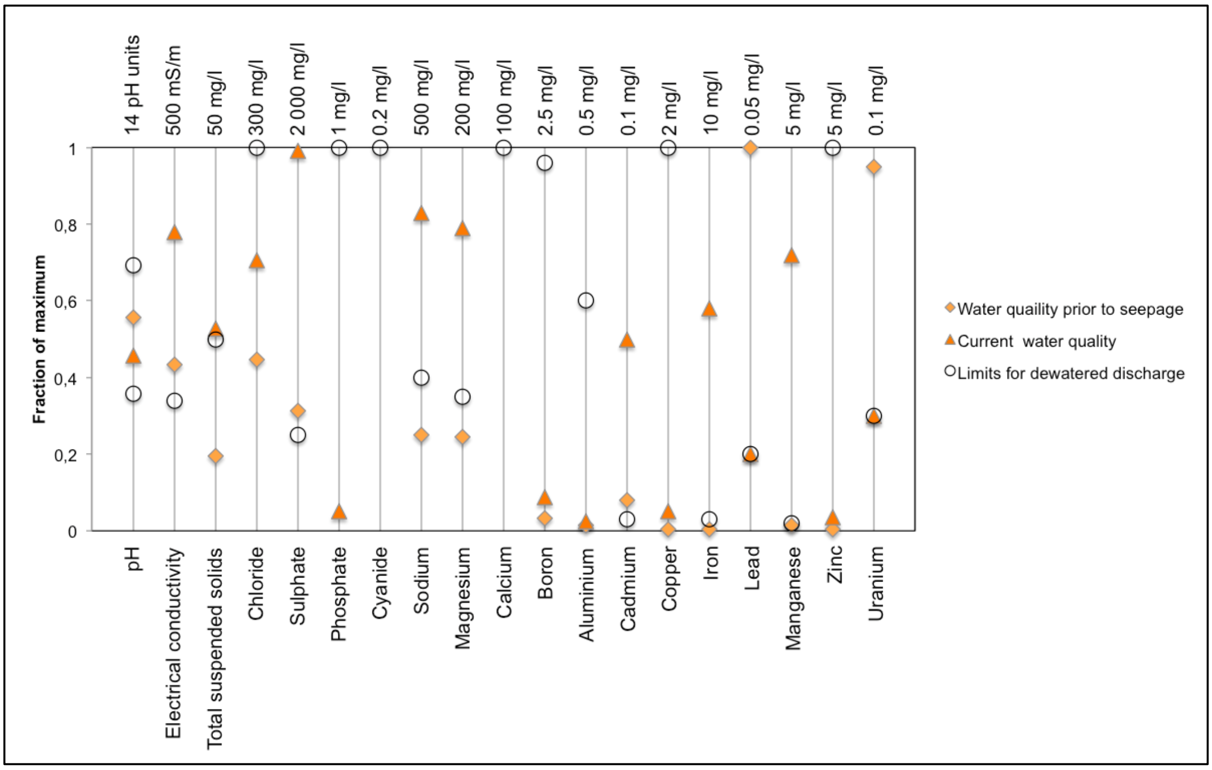

Figure 45: Wastewater characterisation information before and after seepage, and discharge limits in the gold mining industry

pH values before and after seepage are both within the specified limits. The pH before seepage was slightly alkaline, with a value of 7.8; while after seepage is slightly acidic, with a value of 6.4. The limits are between 5.0 and 9.7.

The electrical conductivity increased from 217 mS/m to 390 mS/m after seepage. Both values are above the limit of 170 mS/m. In the worst case, the fate of seepage is into natural water bodies. The impact of high electrical conductivity is dependant on the identity of dissolved species (DWAF, 1996).

The suspended solids were 10 mg/l before seepage, and 26 mg/l after seepage. This is beyond the limit of 25 mg/l.

Chloride, sulphate, phosphate and cyanide were anions listed in the WUL. Sulphate, followed by chlorides, were the most abundant anions, with values after seepage of 1 980 mg/l and 212 mg/l respectively. Sulphates were beyond their limit of 500 mg/l before and after seepage; chlorides were below their limit of 300 mg/l at both times.

Sodium, magnesium and calcium were cations listed in the WUL. Sodium was the most abundant, with 125 and 414 mg/l before and after seepage, compared to a limit of 200 mg/l. Magnesium had concentrations of 49 and 158 mg/l before and after seepage, compared to a limit of 70 mg/l. No measurement was given for calcium although a limit was listed in their WUL.

Salts of both sodium sulphate and magnesium sulphate could be recovered if this stream was to be further treated. The calcium concentration may cause scaling in treatment, depending on its concentrations, which is currently unknown.

The base metals are all present in concentrations below 6 mg/l. These metals could be targeted with lime precipitation in further treatment processes.

Cadmium was one metal beyond the given limits both before and after seepage. The limit is 0.003 mg/l. After seepage, cadmium concentration increased to 0.05 mg/l. This is 16 times greater than the limit. This is a concern because cadmium is highly toxic. Cadmium can bio-accumulate in plants and animals, and the degree of accumulation is linked to other water quality parameters. For example, low pH increases cadmium uptake (DWAF, 1996). Fortunately, the pH here was near neutral. However, the toxicity of cadmium is increased in the presence of copper, cyanide and zinc (DWAF, 1996). Both copper and zinc are measured in the water from this mine.

The seepage was not anticipated in the original WUL application. The compliance report recommended engagements with the DWS to amend the water quality limits to account for the seepage. While WULs must be conscious of the conditions on site, this recommendation appears to promote ease of compliance over environmental protection. An alternative recommendation may be to suggest corrective action to ensure water quality is within limits. While WULs need to be flexible and negotiated for practicality and cost-effectiveness, they primarily need to protect water resources.

A third gold mining company reports wastewater quality in their compliance/audit report. Their WUL (08/C23D/CGI/3297) was issued on July 2015 and the first audit report completed on April 2017. The audit reports indicated water quality compliance between January 2015 and December 2016. Water quality at two discharge locations, with 50^{th} and 95^{th} percentile values, and limits are shown in Figure 46.

The median pH at the first and second discharge locations was 8.1 and 7.1 respectively. The limits for pH are between 5.5 and 9.5. The 95^{th} percentile at the second discharge location exceeds this, with a value of 9.9.

The median electrical conductivity at each of the locations is 191 and 139 mS/m. Both of these are greater than the limit of 115 mS/m.

The given limit for suspended solids was 55 mg/l. The 95^{th} percentile values for both discharges exceed this limit, at 192 and 191 mg/l. The dissolved solids also exceeded their limit of 750 mg/l, with median values of 1 590 and 1 150 mg/l.

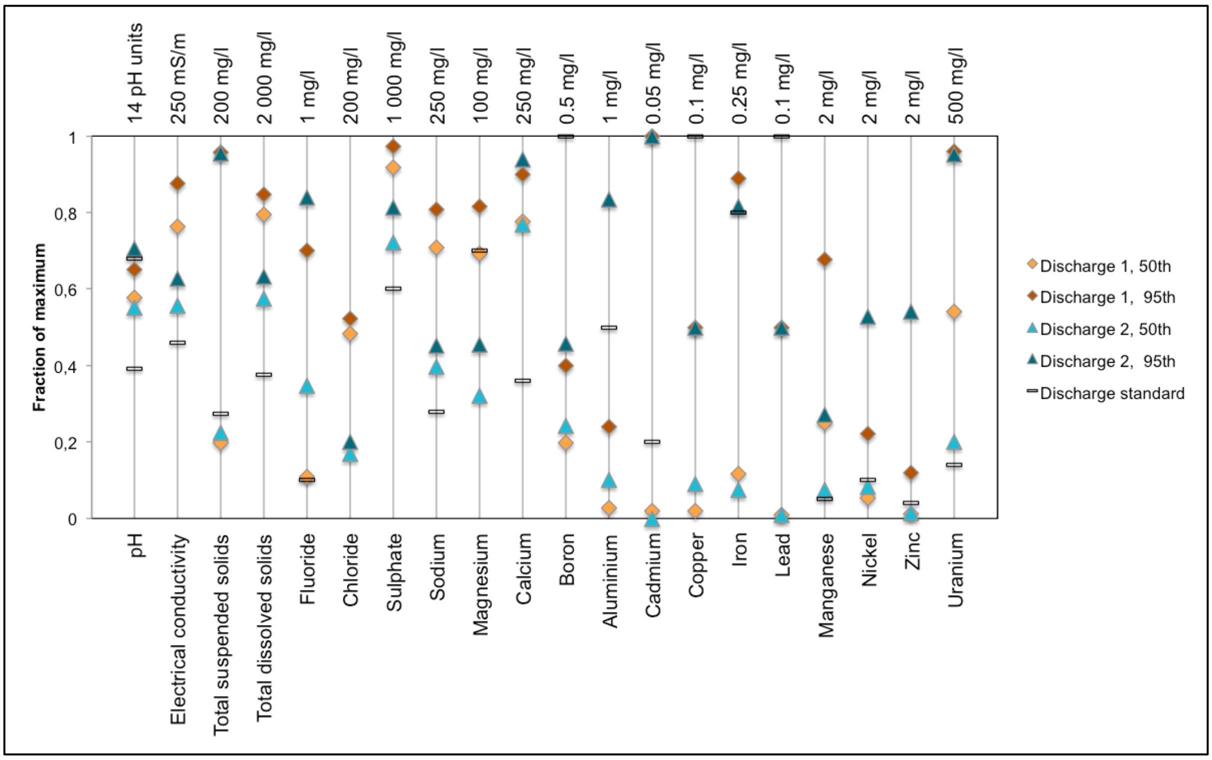

Figure 46: Wastewater discharges from two locations at a gold mine, and discharge limits

Fluoride, chloride and sulphate are the listed anions in these discharges. Sulphate is the most abundant with median values of 918 and 721 mg/l. Sodium, magnesium and calcium are the listed cations. Calcium is most abundant, followed by sodium.

Of the metals, manganese, nickel and zinc are present in the highest concentrations, with 95th percentile values of 1.354 (discharge 1), 1.084 (discharge 2) and 1.054 mg/l (discharge 2) respectively. These are followed by aluminium with a 95% percentile value of 0.835 mg/l (discharge 2).

The first discharge location is into a river. Twenty parameters are recorded to monitor this discharge, but only five parameters are compliant (pH, Al, B, Cu, Pb). Eight parameters are not compliant (EC, TDS, F^-, SO_4^{2-}, Na^+, Ca^{2+}, Mn, U). Six parameters are compliant at the 50th percentile measurement but not at the 95th percentile (TSS, Mg^{2+}, Cd, Fe, Ni, Zn). There is no limit for one parameter (Cl).

The second discharge is into the receiving environment. Again 20 parameters are recorded, with four parameters compliant (B, Cu, Pb, Mg). Eight parameters are non-compliant (EC, TDS, F^-, SO_4^{2-}, Na^+, Ca^{2+}, Mn, U). Seven parameters and compliant at the 50th percentile but beyond limits at the 95th percentile (pH, TSS, Al, Cd, Fe, Ni, Zn). There is no limit for one parameter (Cl).

The same eight parameters are non-compliant in both discharge locations. Electrical conductivity and TDS are related parameters, therefore it is anticipated that if one exceeds limits, the other would too.

Sulphate exceeds the required limits in both cases and is the most abundant anion. Fluoride is another exceedance. It is found in the earth's crust, and this may explain its presence in wastewater from mining operations. Fluoride is a toxic constituent in water (DWAF, 1996: pp4). Target water qualities for chronic exposure is 1.5 mg/l. The fluoride content in the discharges was below this limit, but above the recommended limit in their WUL.

Manganese is an essential micronutrient, but is toxic is high concentrations (DWAF, 1996). The target value for chronic exposure is 0.4 mg/l (DWAF, 1996). The 95th percentile value from the first discharge exceeds this.

Uranium is the only heavy metal listed, with median values of 271 and 100 mg/l, and 95th percentile values of 480 and 476 mg/l respectively. Uranium concentrations in drinking water is given in the order of micrograms per litre (μg/L). The limit for this wastewater is 70 mg/l. The 95th percentile values are over 6 times larger than this limit. Uranium bioaccumulates in plants and animals (USGS, 2016a).

The compliance report did not make recommendations to correct wastewater quality.

5.3.5. Petroleum

Much like the mining industry, companies were reluctant to share information regarding wastewaters. The WULs are useful to a limit, in indicating discharge limits. Compliance or audit reports can add additional value in terms of wastewater water quality, provided they include this level of detail. In some cases wastewater details were quantitative, as in the previous case studies from the mining industry; but in this case, additional detail was qualitative.

A particular company in the petroleum industry holds a WUL (14/C22K/FG/4958), issued in December 2016. This authorises them to discharge wastewater and to dispose of waste, in terms of Section 21(f) and (g) of the NWA. This license sets limits for wastewater discharge from two operations, and between two periods of time. The first period of time is within 18 months following the issuance of the WUL, and the second period of time is after those 18 months. Furthermore, for the more immediate time period (between December 2016 and June 2018) limits are given in terms of a 95th percentile and maximum limits.

Only the various discharge limits are illustrated in Figure 47. Many of the points overlap, indicating that some of the limits for particular parameters are the same over time and/or at both locations. No wastewater characterisation information was available.

The pH lower and upper limits are the same in every case, between 5.5 and 9.5. Electrical conductivity limits ranged between 120 and 200 mS/m depending on the time and location. TSS are limited at 25 mg/l in every case. COD is limited at 75 mg/l in every instance. Soap, oil and grease limits ranged between 2.5 and 3.5 mg/l. Phenolic compounds ranged from 0.1 to 1.0 mg/l. Ammonia is limited at 10 mg/l.

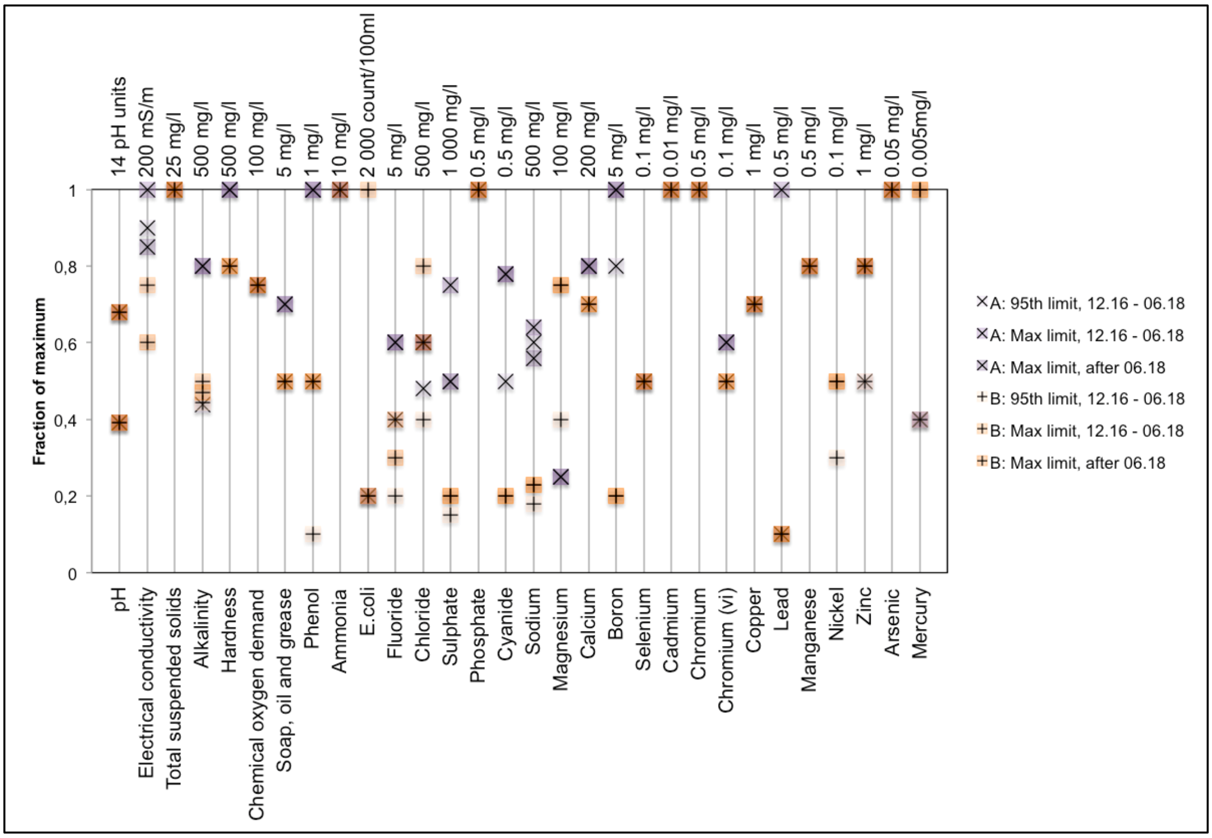

Figure 47: Wastewater discharge limits (95th percentile and maximum), at two sites, for two periods of time, in the petroleum industry

Anions of interest are fluoride, chloride, sulphate, phosphate and cyanide. Of these chloride limits ranged from 200 to 400 mg/l; while sulphate limits ranged from 150 to 750 mg/l. Limits for phosphate and cyanide are less than 0.5 mg/l. Cations of interest are sodium, magnesium and calcium. Limits for calcium range between 140 and 160 mg/l; while limits for sodium range from 90 to 320 mg/l.

Limits for base metals are less than or equal to 1 mg/l. Limits for heavy metals, arsenic and mercury, are 0.05 and 0.005 mg/l respectively.

Knowing the discharge limits can provide insight into the anticipated ranges of various parameters in the wastewater but does not tell of actual wastewater quality. One of the conditions of their WUL is that this company must submit the results of wastewater analysis monthly to the DWS. Although these documents were requested in a PAIA application, the documents received were cover letters without the “attached” monitoring data. While the monitoring data would have provided quantitative wastewater quality, the cover letters qualitatively indicate which parameters are within and beyond limits. Cover letters were received for three months (March, April and May 2017).

For discharge location A the wastewater was within required water quality limits for all three months. The second discharge location had one exceedance in each of the following over the three months: sodium, COD, TSS, and phosphate. Sodium exceeded the 95th percentile limit once in the month of May. This was associated with the chlorine plant onsite. One exceedance of COD was reported in the same month, associated with PVC fines. An exceedance of TSS was reported in April, also associated with PVC fines. An exceedance of phosphate was reported in March, but not attributed to any particular unit or operation.

Furthermore, the cover letters give information of dams and local river systems. The dam water quality is generally beyond limits in the following: nitrates, phosphates and ammonia; using the local water quality guidelines. The instream water quality in nearby rivers was within guidelines for many of the parameters. Exceptions included COD, calcium and magnesium which were beyond limits both upstream and downstream. Ammonia and phosphate exceeded the local water quality guidelines.

5.4. Discussion

5.4.1. Access

Figure 32 shows the outcomes informal approaches to gaining access to information. 87 people were contacted, and two of these contacts resulted in information from industry that was used for case studies. This could indicate an environment of mistrust between industry and university; or tension between fear and accountability.

Direct sharing of information was not the only means of accessing information. Some of the relationships that did not yield direct sharing of wastewater characterisation data yielded other positive outcomes. For example, the second edition of NATSURV 12 on the paper and pulp industry was a resource gained through relationships. This document formed the basis of the case study in that industry.

The tensions around sharing data required that the research approach considered alternative sources of information. Formal PAIA applications were submitted to access information that was not shared through relatoinship building. This route was initially unattractive because it was perceived as harsh.

Interestingly, the first PAIA application was cancelled, but the documents were received nonetheless. The information officer was not available to sign off on the PAIA application, but the requested documents were deemed as publically available, and the legal team found no confidential information or details that needed to be redacted.

The second PAIA application was successful, however an extension was requested before receiving the documents. The documents were accompanied by an affidavit accounting for missing documents because some compliance reports had not been submitted to the DWS. The compliance reports were used in three case studies.

5.4.2. Information

The parameters used for characterising a wastewater stream is related to the industry in which that wastewater arises. This is illustrated in Figure 35 to Figure 39, (as well as Figure 25 to Figure 29). For example, the petroleum industry reports a wide range of organic and hydrocarbon parameters where the other industries report fewer or none of these parameters. The mining, power generation, and petroleum industries are interested in a wide range of anions, cations and base metals; more so than the other industries.

These same figures show the range of number of parameters considered in the accessed documents. Seven parameters were reported for more than half of the wastewater streams characterised in the sources considered. These were: pH; volume; electrical conductivity; some form of nitrogen; sulphate; sodium; and COD.

5.4.3. Comparing the case studies

The case studies presented actual wastewater characterisation information, in all but one case. This is a small sample, with only one case study for each industry, and two for the mining industry. Nonetheless, they provide some insight into real industrial wastewaters in South Africa. Where differences in measured wastewater values and required limits exist, this indicates that work by treatment schemes is still required.

pH was a complaint in the pulp and paper, power generation, and petroleum industries. pH was non-compliant at the 95th percentile measurement in one of the cases from the mining industry and was not complaint in the case study from the fish processing industry.

In the information provided by Eskom, five of the ten streams had pH values greater than 14, in the order of 100's. This is an error because such numerical values are not possible in practise. It is possible that typing errors occurred when capturing the data (for example, should "987" rather be "9.87"?). A glaring error such as this can be easily identified, because of the impossibility of the value; but what of the subtler, numerically possible errors that cannot be easily identified?

Volume was not captured in each of the case studies. Where it was captured, the units differed between and within industries. These are not readily comparable because of other unknowns. For example, the pulp and paper industry reported volume as a SEV (per ton of product) but did not report the amount of product. The fish processing industry reported volumes as m^3/day, but this cannot easily be converted into a volume per annum because this industry does not operate every day, depending on fish hauls and seasons.

The maximum electrical conductivity occurred in the fish processing case study. This is not because of the use of seawater (as at this particular facility they abstract fresh groundwater). Instead, this high electrical conductivity could be associated with the high salinity wastewater from the fish salting process. The range of conductivities was between 300 and 900 mS/m, which exceeded the limit of 150 mS/m.

The pulp and paper industry is arguably compliant with their limits for conductivity, depending on which limits apply. All of the measurements are below 500 mS/m, compared to the maximum limit of 5 000 mS/m.

Neither of the power generation or mining industry was compliant in terms of conductivity. Both industries had conductivities ranging between 100 and 400 mS/m, but with limits at 70 mS/m for power, and 115 or 170 mS/m for the two mining case studies. It is not expected that the power generation stream would be compliant because the RO reject that was characterised is not the discharged stream.

Some form of nitrogen is measured in 63% of the streams captured. The pulp and paper industry measured nitrogen, with values between 0 and 1.2 mg/l with no limit. The fish processing case study measured ammonia and nitrates. Ammonia ranged from 0 to 10 mg/l, which in some instances exceed the limit. Nitrates were less than 2 mg/l, which was well below the limit of 15 mg/l. The power generation had a limit for nitrates at 15 mg/l, but no corresponding measured values. The mining industry did not report any nitrogen related parameter in the case studies. The petroleum case study had a limit as 10 mg/l, and no exceedance was reported.

Sulphate and sodium were the most commonly recorded ions. The mining and power generation industries recorded the highest values of sulphate, in ranges up to 2 000 mg/l. The pulp and paper and power generation had the highest values of sodium, up to 700 mg/l. The fish processing case study reported sodium absorption ratio because the treated wastewater is used for irrigation.

Electrical conductivity, dissolved solids and the ions present are all related to salinity. With the limited information available, one can add up the known ions concentrations to estimate a TDS where it is not given. This yields total known ion concentrations in the order of 1 500 to 3 000 mg/l. Considering the definition given by USGS these streams would be considered slightly saline (USGS, 2016b).

The fish processing and pulp and paper industry registered the largest measurements of COD, with values of up to 5 000 and 4 000 mg/l respectively. Petroleum also listed COD, with limits at 75 mg/l. The case studies from power generation and mining did not record this parameter.

Calcium was not measured in any of the case studies, even in two cases where limits for calcium were specified (power generation and mining). Calcium is an important parameter with respect to treatability of a stream. This is because calcium is associated with scaling.

The absence of this parameter suggests that characterisation is for compliance and not for treatability, more often than not. However, this evaluation is biased because of the source documents considered in this research. Sources such as WULs, compliance reports and CWDP would characterise streams in terms of compliance, as this is their primary function. These types of source documents contributed 40 of the 65 streams considered. Had more streams from industry been considered, it is possible that this observation might be different.

5.4.4. Quality of reporting

The WULs and compliance reports formed an essential source of information to this project, but more importantly, they are permits in place to safeguard the environment and society. With this in mind, some of the contents of the documents are alarming.

A minor concern was spelling errors and typos. For example, a parameter for “soap, oil and grease” was written as “soup, oil and grease”. This may seem pedantic, but it may indicate of the level of care taken in compiling these documents.

Other errors also raise alarm. For example, NEMA defines “storage of water” and “impeding or diverting flow of water in a water course” under Section 21 (b) and (c). However, in one of the WULs (08/C23B/AEFGJ/1209) these authorisations were given under the incorrect subsections (listed erroneously as Section 21 (e) and (f)).

In another case, the limit at the 95th percentile value was larger than the maximum permissible value. This is not numerically possible. Eskom reported similar non-practicably possible numerical errors in their pH measurements.

These errors, both minor and more significant, may indicate that applying for, processing and/or granting of WUL could be a rushed or careless process. This raises cause for alarm, as these permits are intended to ensure that companies protect the environment in which they are operating. If the documents are completed with little care, what might this indicate about the level of care for the environment?

Furthermore, the significant figures used to record some of the limits in the WUL are specific. For example, the required limit for chlorides in the mining industry is given as 15 415.1 mg/l (WUL04/B11E/ACEFGIJ/2591). This is six significant figures for a limit and seems unreasonably specific.

The final concern with the WUL is around the compliance reports. One of the conditions in the WUL is that a compliance or audit report is submitted, in most cases annually, to the DWS. In each of the case studies in the mining industry, an initial audit report was required six months after issuance of the license. In each case, this report was submitted after this time period. In some cases, the DWS has not received compliance reports (to date). This is known because of the affidavit that was received with other PAIA’ed documents in the place of missing reports. The concern is that these are legal documents, with legal implications, but still, their conditions are not met. In a world where these are excused, are other environmental injustices also excused?

CHAPTER 6: Conclusions and recommendations

This chapter will reflect back on the objectives and key questions, the results used to answer them, the conclusions that surface from the results and finally the recommendations arising from the conclusions. A summary is given in Table 4 at the end of the chapter.

6.1. Key questions and findings

There were three main objectives, each with related key questions. The first objective set the scope of the work, and the remaining two objectives addressed the research questions.

6.1.1. Major industries of interest

The first objective was to determine major industries of interest concerning wastewater generation in South Africa. This first result was answered through a literature review and was used to focus the remaining portion of the research. Two existing databases regarding wastewater generation were considered. Both identified four industries contributing greater than 5% to the total volume of brine or wastewaters. These industries were: pulp and paper, power generation, mining and petroleum. Furthermore one of the databases also identified the fish processing industry as a significant contributor.

6.1.2. Nature of South African industrial wastewaters

The second objective was to determine the nature of industrial wastewaters, in terms of volume, location and composition.

6.1.2.1. Volumes?

One of the key questions was: What volumes of wastewater arise from different industries?

This was answered by considering the existing databases described in Section 6.1.1. Estimates of wastewater volumes ranged from 70 – 350 Mm^3/annum. This is a large range with the former estimate 20% smaller than the latter. Nonetheless this estimate is within one order of magnitude.

These databases suggest that the pulp and paper industry contributed between 28 – 43% to volumes of industrial wastewater generated in South Africa. Petroleum contributed between 9 – 26%. Mining contributed between 10 – 15%. Fish processing contributed between 0 – 23%, depending on whether wastewater discharged to a marine environment is included or excluded. Power generation contributed between 7 – 14%.

6.1.2.2. Location?

The second key question asked: Where do wastewater volumes arise in South Africa?

The pulp and paper industry is located largely on the east coast of South Africa and is characterised by high COD. These streams also have concentrations of sulphate and sodium ions.

The fish processing industry has a range of operations, each of which has a different wastewater. For example, abalone farms abstract and discharge seawater, but an inland fish smoking facility abstracts groundwater and discharges wastewater through irrigation. The latter case had high measures of COD.

The power generation industry and mining industry are linked. Both are located inland in South Africa, in WMAs 1, 3, 4 and 8. They are concerned with similar parameters, measuring dissolved solids and identifying dissolved ions and base metals. Sulphate was the most abundant ion, along with sodium and chloride.

The petroleum industry is located inland and along the coast. They measured parameters indicating organics, hydrocarbons, ions and dissolved metals.

Wastewaters were mapped into WMAs (Figure 23) along with contributions by each industry (Figure 24). This identified inland areas as significant for mining (WMAs 3 and 4), power generation (WMAs 1, 3, 4, 8) and petroleum (WMAs 4, 8 and 11) industries; the east coast of South Africa as a major location for pulp and paper (WMAs 5, 6, 8, 11); and the Western Cape for fish processing (WMAs 18 and 19).

Simultaneously Figure 19 in Section 2.4.3 showed limited compliance information available for combined WMAs. There is some compliance information for inland WMAs 1, 3, 8, 9 and 10; but no compliance values available for WMAs 2, 4, 6, 7, 11.

6.1.2.3. Composition?

The final key question relating to this objective was: What parameters are used to describe wastewater composition?

Data mining in literature reveals four commonly listed characterisation parameters: These were pH, TSS, COD and BOD. Mining and power generation did not list BOD but placed importance on TDS and ion concentrations in their wastewaters.

Analyses of the parameters listed in various source documents were examined. This revealed seven parameters that were recorded in more than half of the wastewater streams characterised (65 streams in total). These parameters were: pH; volume; electrical conductivity; some form of nitrogen; sulphate; sodium and COD.

Finally, a case study within each industry was presented to provide characterisation details of real industrial wastewaters. pH ranges were largely compliant. Conductivity was often non-compliant with limits, but this does depend on which limits are used as a basis of comparison. Limits vary within space and time in South Africa. Sulphate and sodium were the most abundant ions, with ranges up to 75 000 mg/l in some of the streams considered. The case studies ranged up to 2 000 mg/l and 700 mg/l in the case studies for these two industries, for sulphate and sodium respectively. COD was relevant for the fish processing and pulp and paper industry, with concentrations up to 5 000 mg/l in the case studies, and up to 90 000 across the entire range of stream considered.

6.1.3. Norm of wastewater characterisation and reporting

The third objective was to determine the norms of wastewater characterisation and reporting. The first key question was about characterisation reporting quality: in terms of comprehensiveness, accuracy, and consistency. The second key question was about accessibility.

6.1.3.1. Quality, in terms of comprehensiveness?

The first part of the first key question was: How comprehensive is characterisation reporting?

A number of different parameters could be used to describe wastewaters. The parameters measured were usually those that appeared on the environmental permits or licences. In some cases not all the listed parameters were measured, with the reason given that the costs of testing samples were prohibitive.

One of the notable missing parameters was calcium. In two of the case studies (from power generation and mining) limits are given for calcium but there are no corresponding measured values. This could be because calcium is not an environmental hazard. However, calcium is associated with scaling, and is therefore an important parameter with respect to designing appropriate treatment schemes.

6.1.3.2. Quality, in terms of reporting?

The second part asked: How accurate is characterisation reporting?

Efforts have been made to characterise industrial wastewaters in South Africa. Government regulates water users and wastewater generators though environmental permits. These are audited, showing an intention to protect the environment. However, there are a number of data capturing and reporting errors.

Careless errors and numerical errors raise alarm regarding the care taken in compiling environmental permits. Spelling mistakes were common in environmental permits. There were a few numerical errors such as 95th percentile limits larger than maximum limits. These minor errors may or may not have implications for the care taken with respect to protecting the environment.

Data capturing errors also arise in industry. For example, Eskom reported a pH value of “987”, which presumably was an actual value of “9.87” that was incorrectly captured. This, and the errors above, are obvious or numeric errors not practicably possible. They prompt the question: What errors are not as glaring, but nonetheless inaccurate?

6.1.3.3. Quality, in terms of consistency?

The third part asked: How consistent is characterisation reporting?

There is a range in the number of parameters used to describe wastewaters within and between industries. For example, published literature often only noted few, broad characterisation parameters while environmental permits tended to record more details. However, the quality of reporting differed within source documents. For example one CWDP characterised a stream in terms of three parameters, and another from the same industry characterised a stream in terms of 12 parameters.

An important source of information was compliance reports submitted as part of requirements of WULs. The reporting of wastewater characterisation information was variable in these documents. Some compliance reports qualitatively described wastewaters, while other reports quantified wastewater parameters over time. This shows inconsistencies in the level of detail captured within and between source documents.

6.1.3.4. Accessibility?

The second key question was: How accessible is wastewater characterisation information?

Accessing information was a challenge. Wastewater and waste information is not confidential, as defined in NEMA, but nonetheless it was not readily accessible.

Informal relational routes to access information, through building relationships, emails and telephone calls, were hindered by mistrust and fear. Industry feared information sharing on many counts; citing concerns of confidentiality, damage to reputation, increased treatment costs or prosecution. The reasons given in this research experience were similar to findings of previous research.

Formal processes, such as PAIA applications, were hindered by incorrect information online, incorrect information officers listed, and time.

6.2. Conclusions

Conclusions were drawn based on the findings summarised above.

6.2.1. Possible inland water supply risk

From the literature review it was concluded that an estimated 56% of wastewater is generated inland in South Africa (Figure 8). This is largely from the power generation and mining industries. In addition it was predicted that inland areas of South Africa will face medium to high water criticality in the near future (Figure 30). This suggests there is a risk to water security in the future.

The wastewater generated inland could be part of the solution for water security, through improved wastewater management.

6.2.2. Parameters beyond limits

Through the case studies, it was highlighted that some parameters in wastewaters are beyond given limits. This shows that there is remaining work to be done by secondary and tertiary treatment units. Deciding on appropriate treatment schemes should be informed by comprehensive characterisation data.

6.2.3. Characterisation for compliance

From the WULs and compliance reports it was observed that wastewater quality monitoring was completed, only as far as was practical, for compliance. For example, calcium was not measured in compliance reports in two of the case studies although the parameter was specified in permits. Calcium is an important parameter for many treatment units because of it scaling potential.

From this it is concluded that wastewater characterisation is performed and reported for compliance purposes (provided testing was practical and not prohibitively expensive) and not for treating wastewaters.

6.2.4. Reporting errors

There have been improvements in wastewater characterisation information over time (as illustrated in the case study from the pulp and paper industry). However, errors, numerical values that are not possible in practise and mistakes raise concern about the correctness of wastewater parameters and data that are reported. There is room to improve, primarily through eliminating errors in WULs and wastewater data capturing. Furthermore the consistency in the parameters and number of parameters measured within sources and industries could improve and increase.

6.2.5. Tension between fear and accountability

A significant portion of this research process was spent on developing approaches and methods to accessing data. Mistrust exists between industry, government and research institutions, and this inhibits transparency and access to information.

6.3. Recommendations

Recommendations were made based on the conclusions above.

6.3.1. Wastewater management to augment supply

Inland areas of South Africa are predicted to face medium to high water criticality and stress. Wastewater streams generated inland could be used to augment supply in a future facing supply risk. These wastewaters are an available resource, but would require appropriate treatment. Characterisation of these streams would need to consider important parameters for treatability.

6.3.2. Expand parameters to include ones for treatability

It was found that certain parameters important for treatment are absent from current characterisation information available. Therefore, the parameters that are used to characterise wastewaters should be expanded to include these components. One such component is calcium.

As industry continues to move toward ideals of ZLD, liquid waste streams are increasing in complexity. Therefore more capable treatments are required. As technologies develop, the parameters required in the wastewater characterisation become more targeted. This should be an iterative process between characterisation analysis, reporting, and treatment, to identify missing parameters in increasingly complex streams.

Research institutions cooperating with industry and government can contribute to identifying missing parameters that are important for treatment.

6.3.3. Enhance synergies

Synergies between governmental bodies, research institutions and industry can facilitate the development treatment technologies (Section 6.2.2), eliminate errors (Section 6.2.4) and identifying important parameters that are currently absent from characterisation information (Section 6.2.3 and 6.3.1). Synergetic relationships can only be achieved in an environment that fosters trust and transparency.

6.3.4. Improve trust and transparency

In order to realise synergies between government, research and industry, it is first necessary to create an environment of trust and transparency. This will contribute to improving trust, decreasing fears, and increasing accountability (Section 6.2.5). The legal framework in South Africa can be used to motivate for and support transparency with respect to waste and wastewaters.

Synergies and trust opens possible access to sensitive wastewater information, which can support research institutions in performing relevant and locally appropriate research. This can further the development of contextually relevant treatment technologies. These can feed back into industry to support them in their waste management endeavours. This all aids the government in achieving goals of water security, environmental sustainability and realising the constitutional rights of South African citizens.

6.4. Summary

A summary of the research questions, objectives, key questions and associated results, conclusions and recommendations are given in Table 4.

Table 4: Summary of the objectives, key questions, results, conclusions and recommendations of this research

Research questions	Objectives	Key questions	Results	Conclusions	Recommendations
What is the nature of South African industrial wastewaters?	Identify major industrial generators of wastewater South Africa.	What are the major industries of interest?	Pulp and paper (28-43%); Fish processing (0-23%); Power generation (7-14%); Mining (10-15%); Petroleum (9-26%).	(This result was used to set the scope of the remaining research).	
	Assess the nature of these wastewaters, in terms of volume, location and composition.	What volumes of wastewater arise from different industries?	Wastewater volume estimates ranged from 70 – 350 Mm^3/annum.	56% of volume released inland, coupled with medium to high water criticality and 100 score for supply risk inland, suggests that water availability may be a concern in the future.	Wastewater can be an important resource to consider when planning for water security. Consider wastewater treatment, recycling and reuse further.
		Where do wastewater volumes arise in South Africa?	Inland: Power generation and mining. Both: Pulp and paper and petroleum. Coastal: Fish processing.		
		What parameters are used to describe wastewater composition?	Common parameters were: pH, volume, electrical conductivity, nitrogen, sulphate, sodium and COD. Sulphate and sodium were dominant ions. Calcium was not measured.	Measured wastewater parameters were often beyond limits, indicating further treatment is required. More often than not characterisation is for compliance and not to assess treatability.	Expand parameters measured to include species that are important for treatment. Synergies between government, research institutions and industry can exist to improve wastewater management. Improving trust and transparency is required to facilitate synergies.
What are the norms of South African industrial wastewater characterisation and reporting?	Assess the norms of wastewater characterisation reporting in terms of quality and accessibility.	How comprehensive is characterisation reporting?	Range of qualitative to quantitative information.		
		How accurate is characterisation reporting?	Non-practicably possible numerical values reported.	Limited care is taken with wastewater characterisation, in some cases.	
		How consistent is characterisation reporting?	Range within and between industries.		
		How accessible is wastewater information?	Not confidential, but not readily accessible.	Tensions between fear and accountability.	

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Appendices

A.1. Guideline questionnaire

This questionnaire was developed to guide the semi-structured interviews and inform participants of the kind of information this research was interested in.

QUESTIONNAIRE GUIDELINE
South African industrial water users

South African industrial liquid effluents and their characterisation

Please note, it is at your discretion that you choose to answer, or not answer, any of the questions below. Your participation is voluntary and if you choose not to participate, there will be no negative consequences.

We are interested in respecting and protecting your information that is sensitive, and are willing to participate in Confidentiality and Nondisclosure agreements.

1. Process and water use
   a. Please give a general description of the processes operating on your plant.
   b. Please provide a PFD if available.
   c. Please describe how water is used within the processes.
   d. Please describe what process streams, chemicals and materials water contacts/interacts with in the process.

2. Effluent stream generation and management
   a. Please describe the waste streams that are generated.
   b. Please describe which streams are discharged? To where are streams discharged?
   c. Please describe if/how effluent streams are treated? What treatment technologies are operated? What is the capacity of treatment operations? Are further (concentrated) waste streams generated via treatment?

3. Effluent stream details
   a. Are all effluents collected in a common sump?
   b. What is the flowrate of the effluent streams?
   c. What are the compositions of effluent streams?

4. Effluent stream range and variation
   a. Are there daily/monthly/seasonal variations in the flowrates and/or compositions of effluent streams?
   b. Why do these variation arise?
   c. What are the typical ranges in flowrates and/or compositions of effluent streams?

Kind regards,

Genevieve Harding

A.2. PAIA applications

We submitted an application to access Coastal Water Discharge Permits in terms of the Promotion of Access to Information Act, on 13 March 2017. We received the requested documents on 19 April 2017. Below is the PAIA application.

ANNEXURE A

FORM A

REQUEST FOR ACCESS TO RECORD OF PUBLIC BODY

(Section 18(1) of the Promotion of Access to Information Act, 2000

(Act No. 2 of 2000))

[Regulation 6]

FOR DEPARTMENTAL USE

Reference number:___________________

Request received by ____(state rank, name and surname of information officer/deputy information officer) on ______________________(date) at ____________________(place).

Request fee (if any): R..............................

Deposit (if any): R..............................

Access fee: R..............................

____

SIGNATURE OF INFORMATION OFFICER/DEPUTY INFORMATION OFFICER

A. Particulars of public body

The Information Officer/Deputy Information Officer:

Ntasha Bajnath Pillay (Control Environmental Officer Grade B, Directorate Coastal Pollution Management, Department of Environmental Affairs, Branch Oceans and Coasts, East Pier Shed, 2 East Pier Rd, V&A Waterfront, Cape Town, 8002)

Ms Phumzile Sabeka (PAIA Administrator Department of Environmental Affairs, Environment House, 473 Steve Biko Road corner Steve Biko and Soutpansberg Road, Arcadia, Pretoria)

B. Particulars of person requesting access to the record

(a) The particulars of the person who requests access to the record must be given below.

(b) The address and/or fax number in the Republic to which the information is to be sent, must be given.

(c) Proof of the capacity in which the request is made, if applicable, must be attached.

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Full names and surname: Miss Genevieve E Harding Prof Alison E Lewis

Identity number: 9305040082087 6304190107086

Postal address: 206 Trinity Gardens, Upper Maynard Street, Vredehoek, 8001 5th level, New Engineering Building, Madiba Circle, Upper Campus, University of Cape Town, Rondebosch

Fax number: NA

Telephone number: GEH 073 122 4335 AEL 021 650 2702 E-mail address: GEH HRDGEN002@myuct ac za AEL alison lewis@uct ac za

Capacity in which request is made, when made on behalf of another person:

NA

C. Particulars of person on whose behalf request is made

This section must be completed ONLY if a request for information is made on behalf of another person.

Full names and surname: ______________________

____

Identity number: ______________________

D. Particulars of record

(a) Provide full particulars of the record to which access is requested, including the reference number if that is known to you, to enable the record to be located.

(b) If the provided space is inadequate, please continue on a separate folio and attach it to this form. The requester must sign all the additional folios.

1. Description of record or relevant part of the record:

The request is for all Coastal Water Discharge Permits (CWDP) issued up to and including 1 April 2017. The full permit is requested in each case.

____

____

____

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2. Reference number, if available: ____________________________

3. Any further particulars of record:

____

____

____

E. Fees

(a) A request for access to a record, other than a record containing personal information about yourself, will be processed only after a request fee has been paid.

(b) You will be notified of the amount required to be paid as the request fee.

(c) The fee payable for access to a record depends on the form in which access is required and the reasonable time required to search for and prepare a record.

(d) If you qualify for exemption of the payment of any fee, please state the reason for exemption.

Reason for exemption from payment of fees

____

F. Form of access to record

If you are prevented by a disability to read, view or listen to the record in the form of access provided for in 1 to 4 below, state your disability and indicate in which form the record is required.

Disability:________________________	Form in which record is required:
________________________	________________________
	________________________

Mark the appropriate box with an X. NOTES: (a) Compliance with your request for access in the specified form may depend on the

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Form in which the record is available. (b) Access in the form requested may be refused in certain circumstances. In such a case you will be informed if access will be granted in another form. (c) The fee payable for access to the record, if any, will be determined partly by the form in which access is requested.

1. If the record is in written or printed form:	
copy of record* x	inspection of record

2. If record consists of visual images - (this includes photographs, slides, video recordings, computer-generated images, sketches, etc.):		
view the images	copy of the images*	transcription of the images*

3. If record consists of recorded words or information which can be reproduced in sound:	
listen to the soundtrack (audio cassette)	transcription of soundtrack* (written or printed document)

4. If record is held on computer or in an electronic or machine-readable form:		
printed copy of record* x	printed copy of information derived from the record*	copy in computer readable form* (stiffy or compact disc)

	YES	NO
*If you requested a copy or transcription of a record (above), do you wish the copy or transcription to be posted to you? Postage is payable.		x

Note that if the record is not available in the language you prefer, access may be granted in the language in which the record is available.
In which language would you prefer the record? English

G. Notice of decision regarding request for access

You will be notified in writing whether your request has been approved/denied. If you wish to be informed in another manner, please specify the manner and provide the necessary

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Particulars to enable compliance with your request.

How would you prefer to be informed of the decision regarding your request for access to the record? By email (HRDGEN002@myuct.ac.za) or by telephone (0731224335)

Signed at CAPE TOWN this 10 day of MARCH 20 17

SIGNATURE OF REQUESTER / PERSON ON WHOSE BEHALF REQUEST IS MADE

A second PAIA application for Water Use Licenses and associated compliance reports was submitted on 16th May 2017, and documents received on 25th July 2017. An affidavit for missing documents was received on 16th August 2017. Below is a copy of the PAIA application.

ANNEXURE: A

PRESCRIBED FORMS FOR ACCESS

Forms can also be obtained from the website of THE DEPARTMENT:
www.The Department.gov.za/documents/other/PIA

FORM A

REQUEST FOR ACCESS TO RECORDS OF THE DEPARTMENT

[Section 18(1) of the Promotion of Access to Information Act, 2000 (Act No. 2 of 2000)]

FOR DEPARTMENTAL USE:

Reference number: ....

Request received by (state rank, name and surname of information officer / deputy information officer) ....on (date)......................................at ....(place)

Request fee (if any): R..

Deposit (if any): R ....

Access fee: R ....

SIGNATURE OF INFORMATION OFFICER/DEPUTY INFORMATION OFFICER

A. PARTICULARS OF PUBLIC BODY

The Information Officer / Deputy Information Officer: Mr Putseletso Loselo

B. PARTICULARS OF PERSON REQUESTING ACCESS TO THE RECORD

(a)The particulars of the person who requests access to the record must be recorded below.
(b)Furnish an address and/or fax number in the Republic to which information must be sent.
(c)Proof of the capacity in which the request is made, if applicable, must be attached.

Full names and surname: Identity number: Postal address:
Genevieve Harding. 9305040082087. 206 Trinity Gardens. Upper Maynard Street, Vredehoek, Cape Town, 8001.

Fax number: Telephone number: E-mail address:
No Fax number. Cell: 073 122 4335. Email: HRDGEN002@myuct.ac.za

Capacity in which request is made, when made on behalf of another person:
NA.

C. PARTICULARS OF PERSON ON WHOSE BEHALF REQUEST IS MADE

This section must be completed only if a request for information is made on behalf of another person.

Full names and surname: ....

Identity number: ....

D. PARTICULARS OF RECORD

(a) Provide full particulars of the record to which access is requested, including the reference number if that is known to you, to enable the record to be located.
(b) If the provided space is inadequate, please continue on a separate folio and attach it to this form. The requester must sign all the additional folios.

1. Description of record or relevant part of the record: Water Use Licenses and annual reports for the following water users - See attached folio.
2. Reference number, if available: ....
3. Any further particulars of record: ....

E. FEES

(a)	A request for access to a record, other than a record containing personal information about yourself, will be processed only after a reques
(b)	You will be notified of the amount required to be paid as the request fee.
(c)	The fee payable for access to a record depends on the form in which access is required and the reasonable time required searching for and preparing a record.
(d)	If you qualify for exemption of the payment of any fee, please state the reason for this.

Reason for exemption from payment of fees: NA

F. FORM OF ACCESS TO RECORD

If you are prevented by a disability to read, view or listen to the record in the form of access provided for in 1 to 4 below, state your disability and indicate in which form the record is required.

Disability:NA		**Form in which record is required:** Printed copies of requested documents.			
Mark the appropriate box with an "X". NOTES: (a) Your indication as to the required form of access depends on the form in which the record is available. (b) Access in the form requested may be refused in certain circumstances. In such a case you will be informed if access will be granted in another form. (c)The fee payable for access to the record, if any, will be determined partly by the form in which access is required.					
1. If the record is in written or printed form:					
X	Copy of record*			Inspection of record	
2. If record consists of visual images: (This includes photographs, slides, video recordings, computer-generated images, sketches, etc.)					
	View the images		Copy of the images*		Transcription of the images*
3. If record consists of recorded works or information that can be reproduced in sound:					
	Listen to the soundtrack (audio cassette)			Transcription of soundtrack*(Written or printed document)	
4. If record is held on computer or in an electronic or machine-readable form:					
X	Printed copy of record*		Printed copy of information derived from the record*		Copy in computer readable form*(stiffy or compact disc)
*If you requested a copy or transcription of a record (above), do you wish the copy or transcription to be posted to you? (A postal fee is payable.)				YES	NO
Note that if the record is not available in the language you prefer, access may be granted in the language in which the record is available. In which language would you prefer the record?					

We will arrange for a courier to collect the documents.

G. NOTICE OF DECISION REGARDING REQUEST FOR ACCESS

You will be notified in writing whether your request has been approved/denied. If you wish to be informed in another manner, please specify the manner and provide the necessary particulars to enable compliance with your request.

How would you prefer to be informed of the decision regarding your request for access to the record?
Please inform me of the decision via email: HRDGEN002@myuct.ac.za

Signed at Rondebosch, Cape Town this 16th day of May 2017

Signature of requester / person on whose behalf request is made Nadia

I would like to request the Water Use Licences and the associated annual reports for the last three years (2016, 2015 and 2014) from the following water users:

Pulp and Paper Industry
- Sappi Gondwana
- Sappi Saiccor
- Mondi

Power Generation Industry
- Eskom power stations, incl. Majuba, Marimba, Meduip, Kendal, Camden, Hendrina, Koeberg, Kriel, etc.

Petrochemical Industry
- PetroSA
- Sasol Secunda
- Sasol Sasolburg

Coal Mining Industry
- Anglo Coal Inyosi: Kriel colliery
- Matla mine
- Glencore Tweefontein
- Optimum mine

Gold Mining Industry
- Anglo Asanti Gold
- Sebanye Gold
- South Deep gold mine
- Harmony Gold

Signed at Rondebosch, Cape Town, on this 16th day of May 2017.
Signature of the requester:

Genevieve Harding

A.3. Effluent characterisation in literature

Table 4: Effluent stream at various stages in pulp and paper processing

Process step	Unit operation and description	pH	COD [mg/L]	BOD_5 [mg/L]	TSS [mg/L]	Reference
1. Wood preparation	Wood yard and chipping: Pulpwood storage, debarking, and chipping	7,0	1 275	556	7 150	(Avşar and Demirer, 2008); pp427
1. Wood preparation	Wood preperation			250	600	(Ashrafi et al., 2015); pp147
1. Wood preparation	Chip wash		20 000	12 000	6 095	(Ashrafi et al., 2015); pp147
2. Pulping	Kraft cooking section	13,5	1 670	460	40	(Wang et al., 2007); pp199
2. Pulping	Kraft mill	8,2	4 112		3 620	(Ashrafi et al., 2015); pp147
2. Pulping	Dilute black liquor from Kraft pulp plant	6,8-7,2	1 400	660		(Buzzini and Pires, 2007); pp1840
2. Pulping	Dilute black liquor	6,8-7,2	1 400	800		(Buzzini and Pires, 2002); pp709
2. Pulping	Alkaline peroxide mechanical pulping effluent	7,4	7 521	3 000	350	(Liu et al., 2011); pp7362
2. Pulping	Chemi-thermomechanical process	5,5	9 065	2 440	1 309	(Avşar and Demirer, 2008); pp427
2. Pulping	Chemi-thermomechanical pulping	6,2	7 300	2 500	500	(Ashrafi et al., 2015); pp147
2. Pulping	Thermo-mechanical pulping	4,0-4,2	3343-4250		330-510	(Qu et al., 2012) in (Kamali and Khodaparast, 2015); pp327
2. Pulping	Thermo-mechanical pulping whitewater	4,6	2 713	1 541	127	(Ashrafi et al., 2015); pp147
2. Pulping	Thermo-mechanical pulping	4,2	5 600	2 800	810	(Ashrafi et al., 2015); pp147

2. Pulping	Pulping, screening, washing, thickening, bleaching, kraft repulping	5,5	9 065	2 440	1 309	(Avşar and Demirer, 2008) in (Kamali and Khodaparast, 2015); pp327
2. Pulping	Pulping	10,0		360	256	(Ashrafi et al., 2015); pp147
2. Pulping	Digester house	11,6	38 588	13 088	23 319	(Ashrafi et al., 2015); pp147
2. Pulping	Sulfite mill	2,5	4000-8000	2000-4000		(Ashrafi et al., 2015); pp147
3. Bleaching	Spent bleach liquor effluent - Mill 1	5,9	1 990	678	616	(Kansal et al., 2008); pp188
3. Bleaching	Spent bleach liquor effluent - Mill 2	5,0	3 540	452	2 800	(Kansal et al., 2008); pp188
3. Bleaching	Spent bleach liquor effluent - Mill 3	8,2	3 680	352	950	(Kansal et al., 2008); pp188
3. Bleaching	Bleach Kraft mill	10,1	1124-1738	128-184	37-74	(Ashrafi et al., 2015); pp147
3. Bleaching	Bleaching: A combination of chlorination and alkaline extraction	8,2	3 680	352	950	(Kansal et al., 2008) in (Kamali and Khodaparast, 2015); pp327
3. Bleaching	Bleaching	2,5		140	216	(Ashrafi et al., 2015); pp147
3. Bleaching	Bleached pulp mill	7,5	2 572	1 566	1 133	(Ashrafi et al., 2015); pp147
5. Paper making	Paper machine	6,5	1 116	641	645	(Avşar and Demirer, 2008); pp427
5. Paper making	Paper making	7,8	953	561	760	(Ashrafi et al., 2015); pp147
6. Overall	Integrated pulp and paper mill	6,5	3 791	1 197	1 241	(Avşar and Demirer, 2008); pp427
6. Overall	Recycled paper mill	6,2-7,8	3380-4930	1650-2565	1900-3138	(Zwain et al., 2013); pp63
6. Overall	Newsprint mill		3 500		250	(Ashrafi et al., 2015); pp147

Table 5: Effluent stream at various stages in fish processing

Process step *	Unit operation and description	pH	COD	BOD_5	TSS	Reference
			[mg/L]	[mg/L]	[mg/L]	
1	Herring; in brine (fish canning operation)	3,8	90 000	78 000	10 000	Balslev-Olesen et al., 1990 in (Chowdhury et al., 2010); pp443
1	Fish freezing	6,9	1 472	814		(Prasertsan et al., 1994) in (Chowdhury et al., 2010); pp443
2	Herring; filleting		6 255	3200-6000	1150-5310	Riddle & Shikaze; 1973 in (Chowdhury et al., 2010); pp443
3	Tuna; Washing water	6,4	34 723	21 400	6 100	(Achour et al., 2000); pp1015
3	Tuna; Washing water	6,8	10 425	6 700	820	(Achour et al., 2000); pp1015
3	Tuna; Washing water	6,9	5 551	2 800	200	(Achour et al., 2000); pp1015
4	Mussels; Cooking		18 500			Mendez et al., 1992 in (Chowdhury et al., 2010); pp443
4	Tuna; Cooking		34 500			Mendez et al., 1992 in (Chowdhury et al., 2010); pp443
4	Tuna; Pre-cooking process and wastewater	6,4	10 582	7 460		(Prasertsan et al., 1994) in (Chowdhury et al., 2010); pp443
4	Fish salting		5 400	2 300	6 000	NovaTech, 1994 in (Chowdhury et al., 2010); pp443
4	Fish smoking			1 700	400	NovaTech, 1994 in (Chowdhury et al., 2010); pp443
5	Bottom fish; Processing plant effluent			192-1726	300	Riddle & Shikaze; 1973 in (Chowdhury et al., 2010); pp443
5	Catfish; Processing plant effluent				400	Carawan, 1991 in (Chowdhury et al., 2010); pp443
5	Fish processing		326-1432	3 500	918-1000	del Valle & Aguilera, 1990 in (Chowdhury et al., 2010); pp443
5	Fish processing	5,8	46 955	11 874		(Prasertsan et al., 1994) in (Chowdhury et al., 2010); pp443

5	Fish processing wastewater	6-7				Najafpour et al., 2006 in (Chowdhury et al., 2010); pp443
5	Fisheries, British Columbia	5,7-7,4	316-3460	128-2680	2000-3000	Tech Report Series, FREMP, 1994 in (Chowdhury et al., 2010); pp443
5	Halibut; Processing plant effluent			145-420	95-245	Riddle & Shikaze; 1973 in (Chowdhury et al., 2010); pp443
5	Non-alaskan bottom fish plant	6,9				Carawan, 1991 in (Chowdhury et al., 2010); pp443
5	Redfish			40-114	14-101	Riddle & Shikaze; 1973 in (Chowdhury et al., 2010); pp443
5	Salmon			397-3082	40-1824	Riddle & Shikaze; 1973 in (Chowdhury et al., 2010); pp443
5	Squid; Processing			1000-5000		(Park et al., 2001) in (Chowdhury et al., 2010); pp443
5	Surimi		6400-18000			Green et al., 1984 in (Chowdhury et al., 2010); pp443
5	Surim; Processing plant		1500-2000			Okumura & Uetana, 1992 in (Chowdhury et al., 2010); pp443
5	Tuna			695	1 091	Riddle & Shikaze; 1973 in (Chowdhury et al., 2010); pp443
5	Tuna		1300-3250	500-1500		Carawan, 1991 in (Chowdhury et al., 2010); pp443
5	Tuna		1 600	700	500	Carawan, 1991 in (Chowdhury et al., 2010); pp443
5	Herring		3000-10000	1200-6000	600-5000	Carawan, 1991 in (Chowdhury et al., 2010); pp443
5	Salmon		300-5500	250-2600	120-1400	Carawan, 1991 in (Chowdhury et al., 2010); pp443
6	Sardines, Mackerel and/or tuna; Fish canning wastewater sump, Average	7,0	9 590	5 668	3 615	(Cristóvão et al., 2016); pp269
6	Sardines, Mackerel and/or tuna; Fish canning wastewater sump, Minimum	5,6	464	241	212	(Cristóvão et al., 2016); pp269
6	Sardines, Mackerel and/or tuna; Fish canning wastewater sump, Maximum	9,6	28 889	27 946	27 090	(Cristóvão et al., 2016); pp269

6	Fish canning wastewater, Minimum over three months	6,1	1 147	463	324	(Cristóvão et al., 2015); pp608
6	Fish canning wastewater, Maximum over three months	7,1	8 313	4 569	3 150	(Cristóvão et al., 2015); pp608
6	Fish canning		2 900	1 400	1 900	NovaTech, 1994 in (Chowdhury et al., 2010); pp443
6	Fish canning	6,4	3 320	1 733		(Prasertsan et al., 1994) in (Chowdhury et al., 2010); pp443
6	Herring; Canned and Preserved seafood processing industry		3000-10000	1200-6000	600-5000	(Carawan, 1991) in (Islam et al., 2004); pp106
6	Salmon; Canned and Preserved seafood processing industry		300-5500	250-2600	120-1400	(Carawan, 1991) in (Islam et al., 2004); pp106
6	Tuna; Canned and Preserved seafood processing industry wastewater		1 600	700	500	(Carawan, 1991) in (Islam et al., 2004); pp106
6	Shrimp; Canned and Preserved seafood processing industry		3 300	2 000	900	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
6	Non-breaded shrimp; Canned and Preserved seafood processing industry		2 300	1 000	800	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
6	Breaded shrimp; Canned and Preserved seafood processing industry		1 200	720	800	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
6	Crab; Canned and Preserved seafood processing industry		6 300	4 400	620	(Carawan, 1991/(Park et al., 2001) in (Islam et al., 2004); pp106
6	Clams; Canned and Preserved seafood processing industry		1000-4000	500-2500	600-6000	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
6	Oysters; Canned and Preserved seafood processing industry		500-2000	250-800	200-2000	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
6	Scallops; Canned and Preserved seafood processing industry		300-1100	200-1000	1000-4000	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
6	Catfish; Canned and Preserved seafood processing industry		700	340	400	(Carawan, 1991)/(Park et al., 2001)in (Islam et al., 2004); pp106
7	Tuna; Cleaning water	8,3	11 361		2 300	(Achour et al., 2000); pp1015

*** 1. Receiving & storage; 2. Filleting/Evisceration; 3. Washing; 4. Pre-cooking, Cooking, Salting or Smoking; 5. Fish processing; 6. Fish canning plant; 7. Cleaning.**

Table 6: Effluent stream over time from a coal-fired power station in India

Week	Unit operation and description	pH	COD [mg/L]	TDS [mg/L]	TSS [mg/L]	Reference
1	Coal-fired power station in India Overall effluent before treatment	7,4	72	1856	78	Kamdi et al., 2012
3		7,6	68	1936	64	Kamdi et al., 2012
5		7,5	64	1830	68	Kamdi et al., 2012
7		7,6	52	1948	70	Kamdi et al., 2012
9		7,5	40	1907	58	Kamdi et al., 2012
11		7,4	40	1926	92	Kamdi et al., 2012
13		7,6	49	1903	72	Kamdi et al., 2012
15		7,4	48	1848	70	Kamdi et al., 2012
17		7,8	84	1894	150	Kamdi et al., 2012
19		7,6	92	1623	180	Kamdi et al., 2012
21		7,9	78	1620	160	Kamdi et al., 2012
23		7,8	85	1920	154	Kamdi et al., 2012
25		7,5	65	1718	180	Kamdi et al., 2012
27		7,6	85	1694	152	Kamdi et al., 2012
29		7,6	82	1784	164	Kamdi et al., 2012
31		7,4	79	1688	172	Kamdi et al., 2012
33		7,5	90	1912	158	Kamdi et al., 2012

Table 7: Effluent streams from various mining operations

Unit operation and description	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	Reference
		[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	
Brine from a platinum operation	9	75 756	256	47	27	52 889	72 870	Apsey & Lewis, 2013; pp416
Typical RO retentate in the mining and extractive metallurgical industries		27 128				42 544	17 291	Lewis et al., 2010; pp1291
RO brine from eMalahleni water reclaimation plant	6,52	6 720	1 810	1 340	75	955	16 000	Randall et al., 2011; pp258
Typical mine water brine 1		5 027				2 260	7 440	Nathoo et al., 2009; pp432
Typical mine water brine 2		70 300				80 800	37 400	Nathoo et al., 2009; pp432
Coal mining brine in Poland				462	383	32 800	1 824	Turek, 2004; pp357
Estimated RO brine composition (best case) from treatment of Grootvlei decant mine water	8,2	4 327	135	132	30	1 317	7 587	Schoeman & Steyn, 2001; pp17
Estimated RO brine composition (probable case) from treatment of Grootvlei decant mine water	8,3	8 756	554	262	45	2 750	12 730	Schoeman & Steyn, 2001; pp17
Estimated RO brine composition (worst case) from treatment of Grootvlei decant mine water	9	10 217	237	326	73	2 838	16 920	Schoeman & Steyn, 2001; pp17

Table 8: Effluent stream at various stages of the petroleum industry

Process step *	pH	COD	BOD_5	TSS	Phenol	Oil & Grease	Sulphide	Ammonia	Reference
		[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	
1		400-1000		<500	10-100		<100	<100	(IPIECA, 2010); pp10
2		600-1200		<10	<200		<10	<100	(IPIECA, 2010); pp12
2	8,0-8,2	850-1020	570		98-128	12,7	15-23	5,1-21,1	(Coelho et al., 2006); pp179
3		150		<200					(IPIECA, 2010); pp18
4		300-800	150-350	100	20-200	3000			(Al Zarooni and Elshorbagy, 2006) in (Diya'uddeen et al., 2011); pp103
4	6,6	596		120			887		(El-Naas et al., 2010) in (Diya'uddeen et al., 2011); pp103
4	6,5-7,5	170-180		420-650					(Saien and Nejati, 2007) in (Diya'uddeen et al., 2011); pp103
4		68-220	0,2-1,2		0,85-3,75	1,1-3,5		0,21-21,23	(Rahman and Al-Malack, 2006); pp23
4	8	80-120	40,25	22,8	13				(Abdelwahab et al., 2009); pp712
4	7,19-9,22	192-220					1,6-2,2		(Altaş and Büyükgüngör, 2008); pp464
4	8,44-9,28	216					20,8-22,0		(Altaş and Büyükgüngör, 2008); pp465
4	6,5-8,5	800	350	100	8	3000	17		(Demırcı et al., 1998); pp3496
4	7,3-8,9	108-912			23,8-36,2				(Jou and Huang, 2003); pp466
4	7-9	300-600	150-350	<150		<50		10-30	(Ma et al., 2009); pp598
4	6,7	200			3,7	23		70	(Santos et al., 2006); pp452

*** 1. Desalter effluent; 2. Sourwater; 3. Cooling tower blowdown; 4. Petroleum refinery effluent**

A.4. South African industrial effluents

Table 9: Characterisation of effluent streams from the pulp and paper industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (1 of 2)

			CWDP	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	WUL	WUL
			Maximum discharge standard	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Max. limits for waste water used for irrigation	Max. limits for wastewater to waste facilities
Stream details	Discharge volume	m^3/annum	48 650 000														730000	15877500
	Discharge volume	m^3/day	133 288		18000	15500	20600			16400	53900	25900	5600	1300		7200		
	Discharge volume	m^3/hour																
	Specific effluent volume (SEV)	m^3/t product		10	17,2	10	84,5		17,6	38,2	26,2	18,9	12,0	7,4	0,08	9		
	Pressure	kPa																
	Temperature	°C	55															
General parameters	pH		5,6 - 5,9	8,1	7,0	6,5	7,7	7,5	7,1	7,3	8,4	7,2			8,5	6,8	5,5 - 9,5	6 - 9,5
	Electrical conducitivity	mS/m	5 000	21	169	273	222	164		121	497	277			171	158	70	70
	Turbidity	NTU																
	Total suspended solids	mg/L	600		38	2 260	62	34	338	59	41	189	1 790	1 220	300	399	25	
	Total dissolved solids	mg/L	20 000															
	Acidity	mg/L																
	Alkalinity	mg/L																
	m-Alkalinity	mg/L																
	p-Alkalinity	mg/L																
	Salinity	mg/L																
	Salinity	psu (g/kg)																
Hardness	Total Hardness CaCO3	ppm																
	Ca Hardness as CaCO3	ppm																
	Mg Hardness as CaCO3	ppm																
	Precipitation potential	ppm																
Organic parameters	Total organic carbon	ppm																
	Chemical oxygen demand	mg/L	20 000		666	1 898	238	1 358	2 663	165	378	1 648	3 853	3 598	2 600	2 210	75	
	Lignin	mg/L	6 000															
	Colour	hazen units	3 000															
	Oxygen absorbed	mg/kg																
	Total (petroleum) hydrocarbons	mg/L																
	Soap, oil and grease	mg/L															2,5	
	Benzene	mg/L																
	Chloroform	mg/L																
	mp-Xylene	mg/L																
	o-Xylene	mg/L																
	Phenol	mg/L																
	Phenolic compounds (QOH)	mg/L																
	Toluene	mg/L																
	Vinyl chloride	mg/L																
	E.coli	count/100ml																
	Faecal coliform	count/100ml																
Nitrogen systems	Nitrogen (N)	mg/L		0,27				0,1		1,2					0,4	0,1		
	Total nitrogen	mg/L																
	Total organic nitrogen (TKN)	mg/L																
	Total ammonia nitrogen (TAN)	mg/L																
	Ammonia	mg/L																
	Ammonia (as N)	mg/L															3	
	Nitrate	mg/L																6
	Nitrate (as N)	mg/L																
	Nitrate/Nitrite as Nitrogen	mg/L															15	

Table 10: Characterisation of effluent streams from the pulp and paper industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (2 of 2)

			CWDP	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	NATSURV 12, 2nd ed	WUL	WUL
			Maximum discharge standard	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Treated effluent composiiton	Max. limits for waste water used for irrigation	Max. limits for wastewater to waste facilities
Anions	Phosphate (PO_4)	mg/L																
	Orthophosphate	mg/L																
	Sulphate	mg/L		16	182	194	360	224		98		565						200
	Sulphide	mg/L																
	Bromide	mg/L																
	Chloride	mg/L																100
	Cyanide	mg/L																
	Flouride	mg/L															1	0,7
Cations	Barium	mg/L																
	Calcium	mg/L																80
	Lithium	mg/L																
	Magnesium	ppm																70
	Potassium	mg/L																
	Sodium	mg/L		10		174	347			97	740	582			100			100
Base metals	Aluminium	mg/L																
	Cadmium	mg/L																
	Chromium	mg/L																
	Chromium (vi)	mg/L																
	Cobalt	mg/L																
	Copper	mg/L																
	Iron	mg/L																
	Lead	mg/L																
	Manganese	mg/L																
	Nickel	mg/L																
	Zinc	mg/L																
Heavy metals	Arsenic	mg/L																
	Mercury	mg/L																
	Molybdenum	mg/L																
	Strontium	mg/L																
	Uranium	mg/L																
	Vanadium	mg/L																
Non metals	Boron	mg/L																
	Chlorine	mg/L		11	103	90	340			136		224						
	Total chlorine (Cl_2)	mg/L																
	Free chlorine (Cl_2)	mg/L															0,25	
	Flourine	mg/L																
	Phosphorus	mg/L						0,1		0,5						0,1		
	Total phosphorus	mg/L																
	Selenium	mg/L																
	Silica	ppm																
	Silica dioxide (SiO_2)	ppm																
	Sodium absorbtion ratio																	

Table 11: Characterisation of effluent streams from the aquaculture industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (1 of 2)

			CWDP	CWDP	CWDP	CWDP	CWDP	CWDP	CWDP	CWDP	Company records			
			Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Treated irrigation for effluent. Minimum	Treated irrigation for effluent. Average	Treated irrigation for effluent. Maximum	Treated irrigation for effluent. Limit
Stream details	Discharge volume	m^3/annum												
	Discharge volume	m^3/day	1 440	60 000	93 600	24 000	43 875	189 600	35 000	33 000	8,4	87,2	180,0	80,0
	Discharge volume	m^3/hour							23,197183	14				
	Specific effluent volume (SEV)	m^3/t product												
	Pressure	kPa												
	Temperature	°C	21,3						Ambient + 1°C	Ambient + 1°C				
General parameters	pH		9,54						7,3 - 8,2	7,3 - 8,2	3,9	6,5	8,8	6,0 - 8,5
	Electrical conducitivity	mS/m									307	526	929	150
	Turbidity	NTU												
	Total suspended solids	mg/L	N/A	5	5	5	5	5			9	212,7	757	25
	Total dissolved solids	mg/L	N/A											
	Acidity	mg/L	N/A											
	Alkalinity	mg/L	N/A											
	m-Alkalinity	mg/L												
	p-Alkalinity	mg/L												
	Salinity	mg/L	N/A											
	Salinity	psu (g/kg)							36	36				
Hardness	Total Hardness CaCO3	ppm												
	Ca Hardness as CaCO3	ppm												
	Mg Hardness as CaCO3	ppm												
	Precipitation potential	ppm												
Organic parameters	Total organic carbon	ppm												
	Chemical oxygen demand	mg/L	22,1								1	1480	4860	75
	Lignin	mg/L												
	Colour	hazen units												
	Oxygen absorbed	mg/kg												
	Total (petroleum) hydrocarbons	mg/L												
	Soap, oil and grease	mg/L	N/A											
	Benzene	mg/L												
	Chloroform	mg/L												
	mp-Xylene	mg/L												
	o-Xylene	mg/L												
	Phenol	mg/L	N/A											
	Phenolic compounds (QOH)	mg/L												
	Toluene	mg/L												
	Vinyl chloride	mg/L												
	E.coli	count/100ml									0	16080	24196	1000
	Faecal coliform	count/100ml												
Nitrogen systems	Nitrogen (N)	mg/L												
	Total nitrogen	mg/L	N/A											
	Total organic nitrogen (TKN)	mg/L												
	Total ammonia nitrogen (TAN)	mg/L		0,6	0,6	0,6	0,6	0,6						
	Ammonia	mg/L	0,91						0,6	0,6	0	5	10	6
	Ammonia (as N)	mg/L												
	Nitrate	mg/L									0	0,2	1,2	15
	Nitrate (as N)	mg/L												
	Nitrate/Nitrite as Nitrogen	mg/L												

Table 12: Characterisation of effluent streams from the aquaculture industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (2 of 2)

			CWDP	CWDP	CWDP	CWDP	CWDP	CWDP	CWDP	CWDP	Company records			
			Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Maximum discharge standard	Treated irrigation for effluent. Minimum	Treated irrigation for effluent. Average	Treated irrigation for effluent. Maximum	Treated irrigation for effluent. Limit
Anions	Phosphate (PO_4)	mg/L									1	7,9	16,7	10
	Orthophosphate	mg/L												
	Sulphate	mg/L	N/A											
	Sulphide	mg/L												
	Bromide	mg/L	N/A											
	Chloride	mg/L	N/A											
	Cyanide	mg/L	N/A											
	Flouride	mg/L	N/A											
Cations	Barium	mg/L	N/A											
	Calcium	mg/L	N/A											
	Lithium	mg/L	N/A											
	Magnesium	ppm												
	Potassium	mg/L	N/A											
	Sodium	mg/L	N/A											
Base metals	Aluminium	mg/L	N/A											
	Cadmium	mg/L	109											
	Chromium	mg/L	N/A											
	Chromium (vi)	mg/L												
	Cobalt	mg/L	60											
	Copper	mg/L	N/A											
	Iron	mg/L	59											
	Lead	mg/L	N/A											
	Manganese	mg/L	N/A											
	Nickel	mg/L	N/A											
	Zinc	mg/L	65											
Heavy metals	Arsenic	ppb	5,10											
	Mercury	mg/L	203											
	Molybdenum	mg/L	N/A											
	Strontium	mg/L												
	Uranium	mg/L	N/A											
	Vanadium	mg/L	N/A											
Non metals	Boron	mg/L	N/A											
	Chlorine	mg/L												
	Total chlorine (Cl_2)	mg/L												
	Free chlorine (Cl_2)	mg/L												
	Flourine	mg/L												
	Phosphorus	mg/L												
	Total phosphorus	mg/L	N/A											
	Selenium	mg/L												
	Silica	ppm												
	Silica dioxide (SiO_2)	ppm												
	Sodium absorbtion ratio										33,3	72,6	114,7	5

Table 13: Characterisation of effluent streams from the power generation industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (1 of 6)

			Company records	Company record, Lethabo			Company record, Lethabo			Company record, Lethabo			Company records, Komati			Company records, Medupi		
			Grab sample RO plant	Average (RO1 reject)	Minimum (RO1 reject)	Maximum (RO1 reject)	Average (RO2 reject)	Minimum (RO2 reject)	Maximum (RO2 reject)	Average (RO3 reject)	Minimum (RO3 reject)	Maximum (RO3 reject)	Average (RO1 skid 3 conc.)	Minimum (RO1 skid 3 conc.)	Maximum (RO1 skid 3 conc.)	Average (RO1 reject)	Minimum (RO1 reject)	Maximum (RO1 reject)
Stream details	Discharge volume	m^3/annum																
	Discharge volume	m^3/day																
	Discharge volume	m^3/hour											23,197	14,000	93,000			
	Specific effluent volume (SEV)	m^3/t product																
	Pressure	kPa											1 190,296	942,000	7 260,000			
	Temperature	°C																
General parameters	pH		8,15	6,648	2,700	10,700	8,084	2,160	729,000	8,665	1,900	708,000				8,074	7,870	8,320
	Electrical conducitivity	mS/m	101,4	966,317	0,154	1 697,000	960,632	8,490	1 472,000	973,049	308,900	10 655,000	471,924	1,600	826,000	262,538	99,135	378,975
	Turbidity	NTU	0,181	0,468	0,076	6,480	0,473	0,062	20,000	0,469	0,140	25,000				0,240	0,010	0,830
	Total suspended solids	mg/L																
	Total dissolved solids	mg/L																
	Acidity	mg/L																
	Alkalinity	mg/L																
	m-Alkalinity	mg/L	0															
	p-Alkalinity	mg/L	174,5															
	Salinity	mg/L																
	Salinity	psu (g/kg)																
Hardness	Total Hardness CaCO3	ppm														386,654	0,000	922,910
	Ca Hardness as CaCO3	ppm		1 308,054	1,490	34 440,000	1 300,603	0,000	8 430,000	1 176,420	40,000	12 540,000				285,233	0,000	606,160
	Mg Hardness as CaCO3	ppm		292,690	1,500	3 387,000	329,225	0,000	3 295,000	274,409	0,000	3 252,000				219,320	141,670	316,750
	Precipitation potential	ppm	84,3															
Organic parameters	Total organic carbon	ppm	48													16,203	5,010	27,000
	Chemical oxygen demand	mg/L																
	Lignin	mg/L																
	Colour	hazen units																
	Oxygen absorbed	mg/kg																
	Total (petroleum) hydrocarbons	mg/L																
	Soap, oil and grease	mg/L	N/A															
	Benzene	mg/L																
	Chloroform	mg/L																
	mp-Xylene	mg/L																
	o-Xylene	mg/L																
	Phenol	mg/L																
	Phenolic compounds (QOH)	mg/L																
	Toluene	mg/L																
	Vinyl chloride	mg/L																
	E.coli	count/100ml																
	Faecal coliform	count/100ml																
Nitrogen systems	Nitrogen (N)	mg/L																
	Total nitrogen	mg/L																
	Total organic nitrogen (TKN)	mg/L																
	Total ammonia nitrogen (TAN)	mg/L																
	Ammonia	mg/L	539															
	Ammonia (as N)	mg/L																
	Nitrate	mg/L	25,7															
	Nitrate (as N)	mg/L		74,460	<0.040	920,000	66,961	6,200	419,000	93,964	<0.040	3 022,000						
	Nitrate/Nitrite as Nitrogen	mg/L																

Table 14: Characterisation of effluent streams from the power generation industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (2 of 6)

			Company records	Company record, Lethabo			Company record, Lethabo			Company record, Lethabo			Company records, Komati			Company records, Medupi		
			Grab sample RO plant	Average (RO1 reject)	Minimum (RO1 reject)	Maximum (RO1 reject)	Average (RO2 reject)	Minimum (RO2 reject)	Maximum (RO2 reject)	Average (RO3 reject)	Minimum (RO3 reject)	Maximum (RO3 reject)	Average (RO1 skid 3 conc.)	Minimum (RO1 skid 3 conc.)	Maximum (RO1 skid 3 conc.)	Average (RO1 reject)	Minimum (RO1 reject)	Maximum (RO1 reject)
Anions	Phosphate (PO_4)	mg/L	0													2,014	0,088	9,207
	Orthophosphate	mg/L																
	Sulphate	mg/L	879,7	4 303,188	22,000	23 229,000	4 693,223	971,000	20 623,000	4 065,068	38,800	10 747,000				1 219,962	365,666	1 706,599
	Sulphide	mg/L																
	Bromide	mg/L																
	Chloride	mg/L														146,258	45,307	224,002
	Cyanide	mg/L																
	Flouride	mg/L	1,5															
Cations	Barium	mg/L	0,34	0,002	<0,000003	0,337	0,001	<0,000005	0,173	0,000	0,000	0,003				0,027	0,000	0,216
	Calcium	mg/L														134,702	134,702	134,702
	Lithium	mg/L																
	Magnesium	ppm														49,402	49,402	49,402
	Potassium	mg/L		343,393	35,200	4 471,000	293,625	14,400	1 697,000	313,921	20,200	4 390,000				36,354	12,961	62,174
	Sodium	mg/L		1 885,892	198,000	16 760,000	1 860,344	0,360	10 470,000	1 769,631	173,000	16 090,000				444,074	115,380	726,941
Base metals	Aluminium	mg/L	5,0															
	Cadmium	mg/L	0															
	Chromium	mg/L	0,01															
	Chromium (vi)	mg/L																
	Cobalt	mg/L																
	Copper	mg/L	0,06													0,001	0,001	0,001
	Iron	mg/L	0	0,735	0,004	29,000	0,449	0,004	9,900	0,623	0,001	7,200				0,001	0,000	0,008
	Lead	mg/L																
	Manganese	mg/L	0	0,000	0,000	0,002	0,002	0,000	0,500	0,000	0,000	0,005				0,000	0,000	0,003
	Nickel	mg/L																
	Zinc	mg/L																
Heavy metals	Arsenic	mg/L																
	Mercury	mg/L																
	Molybdenum	mg/L																
	Strontium	mg/L	1,55													0,070	0,000	0,555
	Uranium	mg/L																
	Vanadium	mg/L																
Non metals	Boron	mg/L																
	Chlorine	mg/L	125,94															
	Total chlorine (Cl_2)	mg/L																
	Free chlorine (Cl_2)	mg/L																
	Flourine	mg/L		15,160	0,010	950,000	37,200	0,010	2 587,000	1,640	0,000	15,000				5,085	2,215	18,031
	Phosphorus	mg/L																
	Total phosphorus	mg/L																
	Selenium	mg/L																
	Silica	ppm														4,154	0,664	5,704
	Silica dioxide (SiO_2)	ppm		73,536	7,000	1 046,000	66,046	0,000	2 404,000	67,439	0,385	1 025,000						
	Sodium absorbtion ratio																	

Table 15: Characterisation of effluent streams from the power generation industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (3 of 6)

			Company records, Tutuka			Company records, Tutuka			Company records, Tutuka			Company records, Tutuka			Company records, Tutuka		
			Average (SRO1 brine)	Minimum (SRO1 brine)	Maximum (SRO1 brine)	Average (SRO2 brine)	Minimum (SRO2 brine)	Maximum (SRO2 brine)	Average (SRO3 brine)	Minimum (SRO3 brine)	Maximum (SRO3 brine)	Average (SRO4 brine)	Minimum (SRO4 brine)	Maximum (SRO4 brine)	Average (SRO5 brine)	Minimum (SRO5 brine)	Maximum (SRO5 brine)
Stream details	Discharge volume	m^3/annum															
	Discharge volume	m^3/day															
	Discharge volume	m^3/hour															
	Specific effluent volume (SEV)	m^3/t product															
	Pressure	kPa															
	Temperature	°C															
General parameters	pH		8,844	0,360	794,000	7,401	2,850	10,730	7,431	2,920	10,710	8,077	2,560	655,000	8,370	2,970	987,000
	Electrical conducitivity	mS/m	2 132,120	185,300	18 222,000	2 231,034	0,100	4 478,200	2 168,727	3,520	5 164,400	2 000,754	12,200	30 363,000	2 012,103	0,000	4 462,600
	Turbidity	NTU	1,147	0,130	717,000	0,724	0,063	279,000	0,393	0,000	8,350	1,186	0,026	651,000	1,430	0,060	558,000
	Total suspended solids	mg/L															
	Total dissolved solids	mg/L	18 748,878	1 631,000	160 354,000	19 646,391	0,880	39 408,000	19 079,330	31,000	45 447,000	17 611,550	107,000	267 194,000	17 692,972	0,000	39 271,000
	Acidity	mg/L															
	Alkalinity	mg/L															
	m-Alkalinity	mg/L															
	p-Alkalinity	mg/L															
	Salinity	mg/L															
	Salinity	psu (g/kg)															
Hardness	Total Hardness CaCO3	ppm															
	Ca Hardness as CaCO3	ppm	669,929	60,000	22 137,000	740,942	64,400	12 613,000	630,203	6,700	2 172,000	755,329	0,300	7 523,000	681,105	0,300	8 661,000
	Mg Hardness as CaCO3	ppm	708,303	44,500	2 459,000	903,697	11,000	9 740,000	827,504	0,830	3 210,000	802,836	1,100	10 141,000	743,757	0,200	2 660,000
	Precipitation potential	ppm															
Organic parameters	Total organic carbon	ppm															
	Chemical oxygen demand	mg/L	748,917	2,330	16 500,000	690,128	2,270	1 650,000	640,935	205,000	1 650,000	563,530	0,000	1 842,000	616,252	95,000	1 680,000
	Lignin	mg/L															
	Colour	hazen units															
	Oxygen absorbed	mg/kg	103,430	0,930	386,000	158,045	0,630	2 761,000	155,905	0,740	3 011,000	122,545	0,860	810,000	143,488	0,200	2 511,000
	Total (petroleum) hydrocarbons	mg/L															
	Soap, oil and grease	mg/L															
	Benzene	mg/L															
	Chloroform	mg/L															
	mp-Xylene	mg/L															
	o-Xylene	mg/L															
	Phenol	mg/L															
	Phenolic compounds (QOH)	mg/L															
	Toluene	mg/L															
	Vinyl chloride	mg/L															
	E.coli	count/100ml															
	Faecal coliform	count/100ml															
Nitrogen systems	Nitrogen (N)	mg/L															
	Total nitrogen	mg/L															
	Total organic nitrogen (TKN)	mg/L															
	Total ammonia nitrogen (TAN)	mg/L															
	Ammonia	mg/L															
	Ammonia (as N)	mg/L	0,002	0,000	0,083	0,002	0,000	0,074	0,002	0,000	0,066	0,001	0,000	0,008	0,002	0,000	0,074
	Nitrate	mg/L															
	Nitrate (as N)	mg/L															
	Nitrate/Nitrite as Nitrogen	mg/L															

Table 16: Characterisation of effluent streams from the power generation industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (4 of 6)

			Company records, Tutuka			Company records, Tutuka			Company records, Tutuka			Company records, Tutuka			Company records, Tutuka		
			Average (SRO1 brine)	Minimum (SRO1 brine)	Maximum (SRO1 brine)	Average (SRO2 brine)	Minimum (SRO2 brine)	Maximum (SRO2 brine)	Average (SRO3 brine)	Minimum (SRO3 brine)	Maximum (SRO3 brine)	Average (SRO4 brine)	Minimum (SRO4 brine)	Maximum (SRO4 brine)	Average (SRO5 brine)	Minimum (SRO5 brine)	Maximum (SRO5 brine)
Anions	Phosphate (PO_4)	mg/L															
	Orthophosphate	mg/L															
	Sulphate	mg/L	9,151	0,000	29,120	10,098	0,000	37,280	9,935	0,082	36,860	9,320	0,001	46,855	9,119	0,001	23,460
	Sulphide	mg/L															
	Bromide	mg/L															
	Chloride	mg/L															
	Cyanide	mg/L															
	Flouride	mg/L															
Cations	Barium	mg/L															
	Calcium	mg/L															
	Lithium	mg/L															
	Magnesium	ppm															
	Potassium	mg/L	188,544	18,8	2 978	185,302	5	623	174,210	5,510	649	168,419	0,30	1 165	166,109	19,8	593
	Sodium	mg/L	5 227,869	0,010	11 572	5 872,222	0,010	17 870	5 749,022	115	12 030	4 751,807	0,01	25 700	5 096,042	23,6	11 160
Base metals	Aluminium	mg/L															
	Cadmium	mg/L															
	Chromium	mg/L															
	Chromium (vi)	mg/L															
	Cobalt	mg/L															
	Copper	mg/L															
	Iron	mg/L															
	Lead	mg/L															
	Manganese	mg/L															
	Nickel	mg/L															
	Zinc	mg/L															
Heavy metals	Arsenic	mg/L															
	Mercury	mg/L															
	Molybdenum	mg/L															
	Strontium	mg/L															
	Uranium	mg/L															
	Vanadium	mg/L															
Non metals	Boron	mg/L															
	Chlorine	mg/L	2,543	0,000	24,600	2,548	0,015	6,517	2,857	0,003	37,790	2,461	0,014	33,860	4,517	0,001	398,500
	Total chlorine (Cl_2)	mg/L	0,113	0,000	1,520	0,137	0,000	14,300	0,119	0,000	1,720	0,114	0,010	0,860	0,125	0,000	1,280
	Free chlorine (Cl_2)	mg/L	0,074	0,000	0,680	2,092	0,000	2 073	0,078	0,000	1,350	0,074	0,000	0,470	0,081	0,000	0,590
	Flourine	mg/L															
	Phosphorus	mg/L															
	Total phosphorus	mg/L															
	Selenium	mg/L															
	Silica	ppm															
	Silica dioxide (SiO_2)	ppm															
	Sodium absorbtion ratio																

Table 17: Characterisation of effluent streams from the power generation industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (5 of 6)

			WUL	WUL	WUL	WUL	WUL	WUL	WUL	WUL
			Max. limits for wastewater used for irrigation	Max. limits for wastewater disposed to environment	Max. limits for waste water disposed to upper dams	Max. limits for wastewater disposed to dams	Max. limits for wastewater disposed to dams	Max. limits for waste water used for irrigate	Max. limits for wastewater disposed to dams	Max. limits for waste water used for irrigation
Stream details	Discharge volume	m^3/annum	730 000	62 000	788 000	788 000	788 000	720 968		732 000
	Discharge volume	m^3/day								
	Discharge volume	m^3/hour								
	Specific effluent volume (SEV)	m^3/t product								
	Pressure	kPa								
	Temperature	°C								
General parameters	pH		6 - 9,0	6,0 - 9,0	12,370	12,470	12,470		8,03	8,34
	Electrical conducitivity	mS/m	70	70						37,51
	Turbidity	NTU								
	Total suspended solids	mg/L								
	Total dissolved solids	mg/L	450	450	2 012	2 272	2 486	80	2 873	
	Acidity	mg/L								
	Alkalinity	mg/L			825	987	1 208		164	
	m-Alkalinity	mg/L								
	p-Alkalinity	mg/L								
	Salinity	mg/L								
	Salinity	psu (g/kg)								
Hardness	Total Hardness CaCO3	ppm								
	Ca Hardness as CaCO3	ppm								
	Mg Hardness as CaCO3	ppm								
	Precipitation potential	ppm								
Organic parameters	Total organic carbon	ppm								
	Chemical oxygen demand	mg/L								
	Lignin	mg/L								
	Colour	hazen units								
	Oxygen absorbed	mg/kg								
	Total (petroleum) hydrocarbons	mg/L								
	Soap, oil and grease	mg/L	2,5	2,5						
	Benzene	mg/L								
	Chloroform	mg/L								
	mp-Xylene	mg/L								
	o-Xylene	mg/L								
	Phenol	mg/L								
	Phenolic compounds (QOH)	mg/L								
	Toluene	mg/L								
	Vinyl chloride	mg/L								
	E.coli	count/100ml	0,0	0,0						
	Faecal coliform	count/100ml	150	150						
Nitrogen systems	Nitrogen (N)	mg/L								
	Total nitrogen	mg/L								
	Total organic nitrogen (TKN)	mg/L								
	Total ammonia nitrogen (TAN)	mg/L								
	Ammonia	mg/L								
	Ammonia (as N)	mg/L								
	Nitrate	mg/L	15	15						0,48
	Nitrate (as N)	mg/L								
	Nitrate/Nitrite as Nitrogen	mg/L								

Table 18: Characterisation of effluent streams from the power generation industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (6 of 6)

			WUL	WUL	WUL	WUL	WUL	WUL	WUL	WUL
			Max. limits for wastewater used for irrigation	Max. limits for wastewater disposed to environment	Max. limits for waste water disposed to upper dams	Max. limits for wastewater disposed to dams	Max. limits for wastewater disposed to dams	Max. limits for waste water used for irrigate	Max. limits for wastewater disposed to dams	Max. limits for waste water used for irrigation
Anions	Phosphate (PO_4)	mg/L								
	Orthophosphate	mg/L								
	Sulphate	mg/L	200	200,000	554,000	606,000	635	36	1 970	15
	Sulphide	mg/L								
	Bromide	mg/L								
	Chloride	mg/L	30	50,000	77,000	87,000	87,000	<5	6,690	8,800
	Cyanide	mg/L								
	Flouride	mg/L	7	5,000	1,100	1,300	1,300			
Cations	Barium	mg/L						0,044		
	Calcium	mg/L	200	200,000	512,000				404,000	20,680
	Lithium	mg/L								
	Magnesium	ppm			<0,01	<0,01	<0,01			5,61
	Potassium	mg/L							14	
	Sodium	mg/L	100	100,000	108,000	118,000	118,000		141,000	10,450
Base metals	Aluminium	mg/L			<0,01	<0,01	0,200			
	Cadmium	mg/L						<0,005		
	Chromium	mg/L						<0,025		
	Chromium (vi)	mg/L						0,028		
	Cobalt	mg/L								
	Copper	mg/L								
	Iron	mg/L	1,0	1,0	<0,01	<0,01	<0,01		< 0,003	
	Lead	mg/L								
	Manganese	mg/L	0,5	0,5	<0,01	<0,01	<0,01			
	Nickel	mg/L								
	Zinc	mg/L								
Heavy metals	Arsenic	mg/L						<0,01		
	Mercury	mg/L								
	Molybdenum	mg/L								
	Strontium	mg/L								
	Uranium	mg/L								
	Vanadium	mg/L						0,049		
Non metals	Boron	mg/L						0,733	0,465	
	Chlorine	mg/L								
	Total chlorine (Cl_2)	mg/L								
	Free chlorine (Cl_2)	mg/L								
	Flourine	mg/L								
	Phosphorus	mg/L								
	Total phosphorus	mg/L			<0,1	<0,1	<0,01			
	Selenium	mg/L								
	Silica	ppm								
	Silica dioxide (SiO_2)	ppm								
	Sodium absorbtion ratio									

Table 19: Characterisation of effluent streams from the mining industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (1 of 2)

			WUL	WUL	WUL	WUL	Compliance report		Compliance report					WUL			WUL		WUL
			Limits for treated seweage for irrigation	Wastewater to the wastewater facilities	Treated effluent dischraged into river	Max. limits for decant into river	Water quality prior to seepage	Current water quality, after seepage	WUL discharge standards	Discharge 1, 50th percentile	Discharge 1, 95th percentile	Discharge 2, 50th percentile	Discharge 2, 95th percentile	Treated waste water from sewage works	Wastewater disposed to waste facility	Discharge of treated mine water into river	Water quality limits for mine feed water dam	Water quality limits for emergency brine pond	Limits for wastewater to waste facility
Stream details	Discharge volume	m^3/annum	980676		730000	1825000								66576	729708	12960000	16200000	2917,6	
	Discharge volume	m^3/day																	
	Discharge volume	m^3/hour																	
	Specific effluent volume (SEV)	m^3/t product																	
	Pressure	kPa																	
	Temperature	°C																20	
General parameters	pH		5.0 - 9.5	6,6	6,5 - 9,5	5 - 9,7	7,8	6,4	5,5-9,5	8,07	9,107	7,705	9,872	5,5 - 7,5	5,0 - 9,5	6,5 - 9,0	7,5	7,5	5,0 - 9,5
	Electrical conductivity	mS/m	200		70	170	217	390	115	191	218,7	139	157,13		< 150	70			
	Turbidity	NTU																	
	Total suspended solids	mg/L			25	25	9,7	26,4	55	39,6	191,6	45	190,8	10					
	Total dissolved solids	mg/L	30	2927	11				750	1590	1694	1150	1264				1543		1800
	Acidity	mg/L																	
	Alkalinity	mg/L		84,95													121		
	m-Alkalinity	mg/L																	
	p-Alkalinity	mg/L																	
	Salinity	mg/L																	
	Salinity	psu (g/kg)																	
Hardness	Total Hardness CaCO3	ppm																	
	Ca Hardness as CaCO3	ppm	25																
	Mg Hardness as CaCO3	ppm																	
	Precipitation potential	ppm																	
Organic parameters	Total organic carbon	ppm																	
	Chemical oxygen demand	mg/L	5000		75									30					
	Lignin	mg/L																	
	Colour	hazen units																	
	Oxygen absorbed	mg/kg																	
	Total (petroleum) hydrocarbons	mg/L																	
	Soap, oil and grease	mg/L																	
	Benzene	mg/L																	
	Chloroform	mg/L																	
	mp-Xylene	mg/L																	
	o-Xylene	mg/L																	
	Phenol	mg/L																	
	Phenolic compounds (QOH)	mg/L																	
	Toluene	mg/L																	
	Vinyl chloride	mg/L																	
	E.coli	count/100ml	0											0					
	Faecal coliform	count/100ml	250		500									0					
Nitrogen systems	Nitrogen (N)	mg/L																	
	Total nitrogen	mg/L		7,8															
	Total organic nitrogen (TKN)	mg/L																	
	Total ammonia nitrogen (TAN)	mg/L																	
	Ammonia	mg/L		0	6									1					
	Ammonia (as N)	mg/L			6														
	Nitrate	mg/L												1,5	3				
	Nitrate (as N)	mg/L	5		15											6			
	Nitrate/Nitrite as Nitrogen	mg/L																	

Table 20: Characterisation of effluent streams from the mining industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (2 of 2)

			WUL	WUL	WUL	WUL	Compliance report		Compliance report					WUL		WUL			WUL
			Limits for treated seweage for irrigation	Wastewater to the wastewater facilities	Treated effleunt dischraged into river	Max. limits for decant into river	Water quality prior to seepage	Current water quality, after seepage	WUL discharge standards	Discharge 1, 50th percentile	Discharge 1, 95th percentile	Discharge 2, 50th percentile	Discharge 2, 95th percentile	Treated waste water from sewage works	Wastewater disposed to waste facility	Discharge of treated mine water into river	Water quality limits for mine feed water dam	Water quality limits for emergency brine pond	Limits for wastewater to waste facility
Anions	Phosphate (PO_4)	mg/L			10	1		<0,05											
	Orthophosphate	mg/L												1					
	Sulphate	mg/L		1143,5		500	628	1980	600	918	972,2	721	812		400	380	1036		1000
	Sulphide	mg/L																	
	Bromide	mg/L																	
	Chloride	mg/L			70	300	134	212		96,4	104,4756	33,6	40,22	0,1	38,6	25	18	15415,1	40
	Cyanide	mg/L				0,2													
	Flouride	mg/L							0,1	0,108	0,7	0,346	0,84		0,44	1	1,2		0,6
Cations	Barium	mg/L															0,081	0,4	
	Calcium	mg/L		153,3		100			90	194	225	192	235			150	216	844,4	150
	Lithium	mg/L															0,2		
	Magnesium	ppm		433,8		70	49	158	70	69,4	81,7	32	45,44		50,6	70	112		100
	Potassium	mg/L															7,1		
	Sodium	mg/L		0		200	125	414,3	70	177	202	99,476	113		59,9	70	100		200
Base metals	Aluminium	mg/L				0,3	0,0075	0,012	0,5	0,028	0,239	0,101	0,835				6,4	0,2	
	Cadmium	mg/L				0,003	0,008	<0,05	0,01	0,001	0,05	0	0,05				< 0,001		
	Chromium	mg/L															0,078		
	Chromium (vi)	mg/L																	
	Cobalt	mg/L															0,048		
	Copper	mg/L				2	0,008	0,1024	0,1	0,002	0,05	0,009	0,05				0,065		
	Iron	mg/L				0,3	0,05	5,8	0,2	0,029	0,222	0,019	0,204			1	4,8		
	Lead	mg/L				0,01	0,05	<0,01	0,1	0,001	0,05	0,001	0,05				0,07		
	Manganese	mg/L				0,1	0,07	3,6	0,1	0,5	1,354	0,148	0,542			0,4	9,7		
	Nickel	mg/L		7,8					0,2	0,11	0,444	0,166	1,054				0,072		
	Zinc	mg/L				5	0,018	0,177	0,08	0,026	0,238	0,03	1,084				0,0077		
Heavy metals	Arsenic	mg/L															< 0,023		
	Mercury	mg/L																	
	Molybdenum	mg/L															0,017		
	Strontium	mg/L																	
	Uranium	mg/L				0,03	0,095	<0,03	70	271	479,8	100	476,2				< 0,01		
	Vanadium	mg/L															0,11		
Non metals	Boron	mg/L				2,4	0,08	0,218	0,5	0,099	0,2	0,121	0,229				0,34	0,1	
	Chlorine	mg/L																	
	Total chlorine (Cl_2)	mg/L																	
	Free chlorine (Cl_2)	mg/L	0,5																
	Flourine	mg/L																	
	Phosphorus	mg/L																	
	Total phosphorus	mg/L																	
	Selenium	mg/L																	
	Silica	ppm		4,8															
	Silica dioxide (SiO_2)	ppm																	
	Sodium absorbtion ratio																		

Table 21: Characterisation of effluent streams from the petroleum industry in terms of stream details and general, hardness, organic, biological, and nitrogen system parameters (2 of 2)

			CWDP	CWDP	WUL			WUL			WUL			WUL	
			Maximum discharge standard	Maximum discharge standard	95th % limit (for 18 month); wastewater A to river	Max. limit (for 18 months); wastewater A to river	Max. limit (after 18 months); wastewater A to river	95th % limit (for 18 month); wastewater B to river	Max. limit (for 18 months); wastewater B to river	Max. limit (after 18 months); wastewater B to river	Maximum limits for treated sewerage water for irrigation	Max. limits for treated sewerage water discharged into river	Current quality of underground mine water to dams	Max. limits for sludge from dams to be used for irrigation	Max. limits for domestic wastewater to river
Stream details	Discharge volume	m^3/annum			16060000	16060000	16060000	2701000	2701000	2701000	9000	18000	3200000	34200	6200000
	Discharge volume	m^3/day	12 624	8 680											
	Discharge volume	m^3/hour	93												
	Specific effluent volume (SEV)	m^3/t product													
	Pressure	kPa													
	Temperature	°C	35	25											
General parameters	pH		5,5 - 9,0	6,0 - 7,5		5,5 - 9,5	5,5 - 9,5		5,5 - 9,5	5,5 - 9,5	5,5 - 9,5	5,5 - 9,5	8,1	7,9	5,5 - 9,5
	Electrical conducitivity	mS/m	5 000	5000	180	200	170	980	150	120	150	100		380	
	Turbidity	NTU	19	9											
	Total suspended solids	mg/L	70	25		25	25		25	25	25	25		880	
	Total dissolved solids	mg/L									750	750	484		<= 25
	Acidity	mg/L													
	Alkalinity	mg/L													
	m-Alkalinity	mg/L			220	400	400	222	250	235					
	p-Alkalinity	mg/L													
	Salinity	mg/L													
	Salinity	psu (g/kg)													
Hardness	Total Hardness CaCO3	ppm			400	500	500		400	400					
	Ca Hardness as CaCO3	ppm													
	Mg Hardness as CaCO3	ppm													
	Precipitation potential	ppm													
Organic parameters	Total organic carbon	ppm												240	
	Chemical oxygen demand	mg/L	3 500	200		75	75		75	75	75	75	16	800	<= 75
	Lignin	mg/L													
	Colour	hazen units													
	Oxygen absorbed	mg/kg													
	Total (petroleum) hydrocarbons	mg/L	10	10											
	Soap, oil and grease	mg/L	5	19	2,5	3,5	3,5		2,5	2,5					
	Benzene	mg/L	0,95	0,95											
	Chloroform	mg/L		0,95											
	mp-Xylene	mg/L		1,95											
	o-Xylene	mg/L		0,95											
	Phenol	mg/L	0,95	2,5											
	Phenolic compounds (QOH)	mg/L			0,5	1	1	0,1	0,5	0,5					
	Toluene	mg/L		0,95											
	Vinyl chloride	mg/L							1	1					
	E.coli	count/100ml				400	400	400	2000	400					
	Faecal coliform	count/100ml									1000	1000		1000	0
Nitrogen systems	Nitrogen (N)	mg/L													
	Total nitrogen	mg/L													
	Total organic nitrogen (TKN)	mg/L												258	
	Total ammonia nitrogen (TAN)	mg/L													
	Ammonia	mg/L												220	
	Ammonia (as N)	mg/L	27	17		10	10			10	6	6			<= 6
	Nitrate	mg/L												25	
	Nitrate (as N)	mg/L													<= 15
	Nitrate/Nitrite as Nitrogen	mg/L			16	18	16	16	18	1	15	15			

Table 22: Characterisation of effluent streams from the petroleum industry in terms of anions, cations, base metals, heavy metals, non metals and other parameters (2 of 2)

			CWDP	CWDP	WUL			WUL			WUL			WUL	
			Maximum discharge standard	Maximum discharge standard	95th % limit (for 18 month); wastewater A to river	Max. limit (for 18 months); wastewater A to river	Max. limit (after 18 months); wastewater A to river	95th % limit (for 18 month); wastewater B to river	Max. limit (for 18 months); wastewater B to river	Max. limit (after 18 months); wastewater B to river	Maximum limits for treated sewerage water for irrigation	Max. limits for treated sewerage water discharged into river	Current quality of underground mine water to dams	Max. limits for sludge from dams to be used for irrigation	Max. limits for domestic wastewater to river
Anions	Phosphate (PO_4)	mg/L													
	Orthophosphate	mg/L				0,5	0,5		0,5	0,5	10	10		62,5	<= 10
	Sulphate	mg/L			500	750	500	150	200	200			31,25	2100	
	Sulphide	mg/L	0,9	5											
	Bromide	mg/L													
	Chloride	mg/L			240	300	300	200	400	300				230	
	Cyanide	mg/L	1	1	0,25	0,39	0,39		0,1	0,1					
	Flouride	mg/L	5		2	3	3	1	2	1,5	1		0,7	81,6	<= 1
Cations	Barium	mg/L													
	Calcium	mg/L			140	160	160		140	140				354	
	Lithium	mg/L													
	Magnesium	ppm				25	25	40	75	75			18	650	
	Potassium	mg/L													
	Sodium	mg/L			300	320	280	90	115	115			159	298	
Base metals	Aluminium	mg/L													
	Cadmium	mg/L				0,01	0,01		0,01	0,01					
	Chromium	mg/L	0,5	0,5		0,5	0,5		0,5	0,5					
	Chromium (vi)	mg/L			0,05	0,06	0,06		0,05	0,05					
	Cobalt	mg/L													
	Copper	mg/L	0,9	0,9		0,7	0,7		0,7	0,7					
	Iron	mg/L											5,9		
	Lead	mg/L	0,9	0,1		0,5	0,05		0,05	0,05					
	Manganese	mg/L				0,4	0,4		0,4	0,4					
	Nickel	mg/L						0,03	0,05	0,05					
	Zinc	mg/L	1,4	1,4	0,5	0,8	0,8	0,5	0,8	0,8					
Heavy metals	Arsenic	mg/L				0,05	0,05		0,05	0,05					
	Mercury	mg/L	0,1	0,1		0,002	0,002	0,002	0,005	0,005					
	Molybdenum	mg/L													
	Strontium	mg/L													
	Uranium	mg/L													
	Vanadium	mg/L													
Non metals	Boron	mg/L			4	5	5		1	1					
	Chlorine	mg/L													
	Total chlorine (Cl_2)	mg/L													
	Free chlorine (Cl_2)	mg/L									0,25	0,25			
	Flourine	mg/L													
	Phosphorus	mg/L													
	Total phosphorus	mg/L													
	Selenium	mg/L				0,05	0,05		0,05	0,05					
	Silica	ppm													
	Silica dioxide (SiO_2)	ppm													
	Sodium absorbtion ratio														