*A framework to determine the true cost of centralised waste water systems on the economies of South African Cities.*

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# Declaration

I, **Cleo Forster** declare that this research report is my own unaided work except where otherwise acknowledged. It is submitted for the degree of Master of Architecture at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any university.

Signature of candidate

On the 22 day of Sepember 2017

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# Abstract

Green Drop data indicates that South African metropolitan areas are particularly poor at ensuring that the effluent quality released by their wastewater treatment plants meets the required national standards. The impact of the poor performance of wastewater plants, although known, is not quantified in terms of real impact on the South African economy. This research report identifies the health, environmental and economic externalities associated with the pollution of water bodies by untreated or partially treated wastewater, and determines economic methods through which these externalities can be monetised. As these methodologies should ideally be incorporated into existing wastewater evaluation approaches, the feasibility and method in which to incorporate externality evaluation into the existing Green Drop system is investigated and through key informant interviews the resulting recommendations contextualised. The research report concludes with recommendations as to how the approach to South African wastewater treatment evaluations can be improved through the incorporation of economic externalities

Key words: *Ineffective wastewater treatment, water pollution, externalities, economic impact, Green Drop SA*

## List of abbreviations and acronyms

COD – Chemical Oxygen Demand

BOD – Biochemical Oxygen Demand

CRR – Cumulative Risk Ratio

W2RAP – Wastewater Risk-Abatement Plan

CBA – Cost-Benefit Analysis

NPV – Net Present Value

DWS – Department of Water Affairs and Sanitation

PAT – Progress Assessment Tool

## Glossary of terms

**Wastewater** – spent or used water with dissolved or suspended solids, discharged from homes, commercial establishments, farms, and industries

**Greywater** – any domestic wastewater produced, excluding sewage

**Blackwater** – wastewater containing bodily or other biological wastes

**Sludge** – thick, soft, wet mud or a similar viscous mixture of liquid and solid components

**Wastewater Treatment System/Works/Plant** – process or combination of processes undertaken to render wastewater/sewerage acceptable for discharge to the environment or reuse

**Effluent** - liquid waste or sewage discharged into a river or the sea

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# Chapter 1

# Introduction and background to the study

## 1.1 Background

### 1.1.1 Introduction

South Africa is a water-scarce country with a rapidly growing urban population, resulting in an ever-increasing demand for water supply and high consumption rates. This makes the close management of the existing and future water infrastructure systems a top priority (Ruiters & Matji, 2015).

The typical urban water cycle takes water from a natural source, mostly rivers, treats it to the point at which it is safe for human consumption and then distributes it to consumers for use. Thereafter, the wastewater that results (a combination of both greywater and blackwater) is collected and treated prior to releasing it back into the natural watercourse for the process to be repeated downstream. Alternatively, the effluent may be released into the ocean, as is often the case in coastal cities.

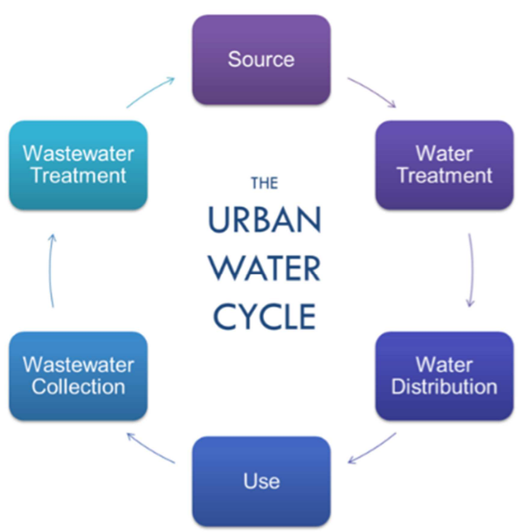


*Figure 1: The urban water cycle (source: National Geographic, 2014)*

As downstream communities and activities are directly affected by the quality of water discharged from upstream urban wastewater treatment facilities, the importance of effective wastewater treatment in the protection of South African water resources is highlighted. However, this expectation is often not met and the majority of South African wastewater treatment facilities are failing to treat water to an acceptable quality before releasing it back into the water cycle (Department of Water and Sanitation, 2014). Although the need for action appears obvious, there is little momentum for change in the sector. Research indicates that performance is, in fact, worsening with time, and that this has substantial knock-on impacts on the economies of municipalities. In the context of poor wastewater management practices in South Africa, the need for alternative more effective and efficient systems is dire, which calls for an enabling policy environment to guide and expedite the changes.

### 1.1.2 Problem statement

> "The economy is a wholly owned subsidiary of the ecology. Without the environment, there is no economy!" – Greater Cape Town Civic Alliance slogan

According to a report on South Africa's wastewater treatment facilities released by the Department of Water Affairs and Forestry in 2008, 96% of the wastewater treatment facilities surveyed were not operating in terms of the stipulated performance criteria (Snyman, Van Niekerk & Rajasakran, 2008). The poorly treated effluent resulting from these plants is then released into the natural watercourses, thus polluting and contaminating rivers for downstream uses. This contamination has numerous effects that may not be felt directly by the polluting municipality and are therefore deemed to be external impacts of the failing infrastructure. As there is no market feedback to the polluter itself (the underperforming wastewater facility), there is little economic incentive to change.

As South African wastewater treatment facilities in urban centres are primarily highly centralised systems, dealing with bulk quantities using complex engineering systems, the inefficiencies are largely due to poor maintenance and a shortage of qualified operational staff who can manage such complex systems (Snyman et al., 2008). In addition, these facilities have been found to consume large quantities of energy in their ineffective processing of waste, with an average of 16 MWh per m3 of waste water (Morrison et al., 2001). On the other hand, there are alternative treatment methodologies available that would enable wastewater treatment to be a net producer of energy. These alternatives are often not considered during the feasibility stage of system selection. Larson et al. (2009) attributes this inability to overcome the inertia of the current systems to three main factors as follows:

- Perceived risks of alternative treatment methodologies by the public, policy makers and professionals, due to unfamiliarity.
- Reluctance on the part of water professionals currently operating in South Africa to explore alternative possibilities in place of traditional approaches.
- The lack of enabling policy and political environment, as norms and standards fall behind technological innovations.

### 1.1.3 Reason for the study

Centralised wastewater treatment facilities in South Africa are not only functioning ineffectively and inefficiently, but in addition, the poor operations of the systems have a number of knock-on effects that have significant health, economic and environmental impacts (Hernández-Sancho et al., 2015); these are deemed to be the externalities of poor effluent quality. Although case studies exist that evaluate the energy consumption and carbon emissions of these systems, a framework to investigate the true economic impact of wastewater treatment inefficiencies has not been developed in South Africa.

Clearly, due to the combination of the water scarcity, rapidly rising energy costs, skills shortages and mismanagement (Snyman et al., 2008), the sustainability of the existing systems is questionable at best, and alternatives should be considered at a municipal governance level, given the public nature of water resources. While the impacts of the poor functioning of these systems is well acknowledged and researched (Hussain et al., 2001), they do not seem motivation enough for municipalities or professionals to look to alternative methodologies that will enable the realisation of the energy potential of waste, and therefore it is believed that a more convincing argument, supported by an economic analysis, is needed to encourage change.

### 1.1.4 Aim

This research report aimed to make recommendations as to how a framework could be developed that would allow municipalities to evaluate the true economic impact of poorly functioning wastewater treatment plants and to establish potential methodologies through which this can be understood. This can only be achieved through quantifying, not only the well-understood consumption and operations costs, but also taking into account the environmental, health and economic impact, and their associated costs.

### 1.1.5 Objectives

1) Review the relevant health, environmental and economic impacts of the existing operation of ineffective wastewater treatment systems and methods through which these impacts can be quantified.
2) Identify the toolsets currently used by local government to quantify waste water performance and efficiency.
3) Determine methods to inform a framework in order to provide a means by which to understand the true cost of wastewater treatment practices for the South African economy.

### 1.1.6 Research questions

Main question:

How can the impact of ineffective wastewater treatment systems on the economies of South African municipalities be evaluated and monetised, in order to encourage improvement in the performance of these systems?

Sub-questions:

1. What are the health, environmental and economic attributes which are impacted by ineffective wastewater treatment processes and how can these be measured financially?
2. What are the methods currently used to evaluate waste water system effectiveness and what parameters are considered? Are these parameters inclusive of all the associated impacts?

3. How can these methodologies be utilised to develop a framework that will enable municipalities to evaluate the true cost of these systems to the local economy?

## 1.2 Theoretical framework

The primary theoretical framework that will be utilised in this research is that of the economic theory of externalities. An externality cost is defined as a "a cost imposed on society due to the activities of a third party, resulting in social, health, environmental, degradation or other costs" (Integrated Energy Plan (IEP), 2016, 66). As the externalities of ineffective wastewater treatment span a number of sectors, aspects of environmental, health and market economics are used throughout the report to gain an understanding of how associated impacts of infrastructure failure can affect the economies of South African cities.

## 1.3 Existing research

There is a substantial body of existing research with regard to the indirect impacts of ineffective wastewater treatment on local communities and the environments that surround them. However, there has been very little research done locally that looks at valuing these impacts through economic theory. This research attempted to address this gap in knowledge by determining economic methods by which these externalities can be evaluated. Likewise, although the recipient of much criticism, the methodology by which South Africa has selected to evaluate the performance of its wastewater treatment plants, namely the Green Drop report, has not been subject to a public critical evaluation that looks to incorporate the external impacts of wastewater plants' resulting effluent. This research therefore aimed to address this gap and makes recommendations as to how national wastewater evaluation and policy can be adjusted for the benefit of all.

## 1.4 Conceptual framework

Figure 1 below provides a framework for the key concepts explored in this research report. The flow diagram is a visual representation of the main concepts that are discussed; it groups the externalities to wastewater treatment into those included in current evaluation tools and those that require further investigation.

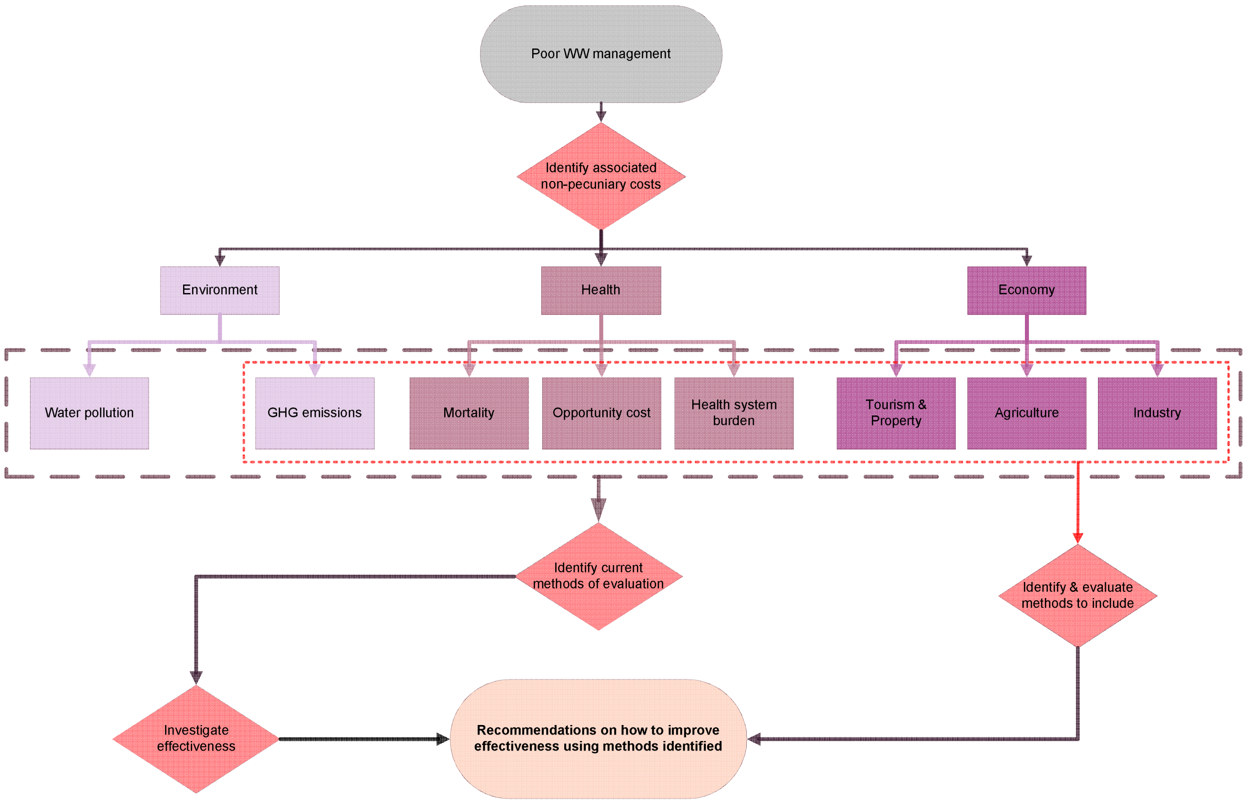


*Figure 2: Conceptual layout of the report (source: researcher)*

## 1.5 Working hypothesis

It is assumed that there is a lack of regard for the existing performance results issued to municipal employees due to a lack of technical knowledge by the decision makers within the municipality. It is hypothesised that because rands and cents are values that, regardless of training and educational background, South Africans understand, valuing the externalities of the poorly performing wastewater systems will enable the quantification of economic impact. It is hoped that this will drive a shift in the way that wastewater plant performance is managed and addressed nationally.

## 1.6 Structure and organisation of the report

This report will start by giving context to the South African water sector, highlighting the importance of preserving the country's existing water resources. Once the link between wastewater and water security has been defined, the report will move on to exploring the associated impacts of ineffective waste water treatment, thereafter deemed to be the externalities. The associated economic impact of these externalities on local communities will then be discussed and will result in the development of a checklist that can be used to evaluate the completeness of existing wastewater treatment evaluation tools.

This checklist will then be used on a sample of the current evaluation tools used to manage South African wastewater plants, alongside an evaluation of the evaluation tools to date. This performance evaluation, combined with the outcomes of the externality evaluation checklist, will identify a number of gaps and opportunities for improvement. Finally, given the gaps identified, methodologies as to how address these aspects in a way best suited to the context of wastewater will be discussed. As this is a tool to be utilised at a municipal governance level, the operational context of the tool will be framed. This research will conclude with a discussion and recommendations of how the methods by which wastewater treatment is currently managed and evaluated could be improved in the context of South African municipal structures.

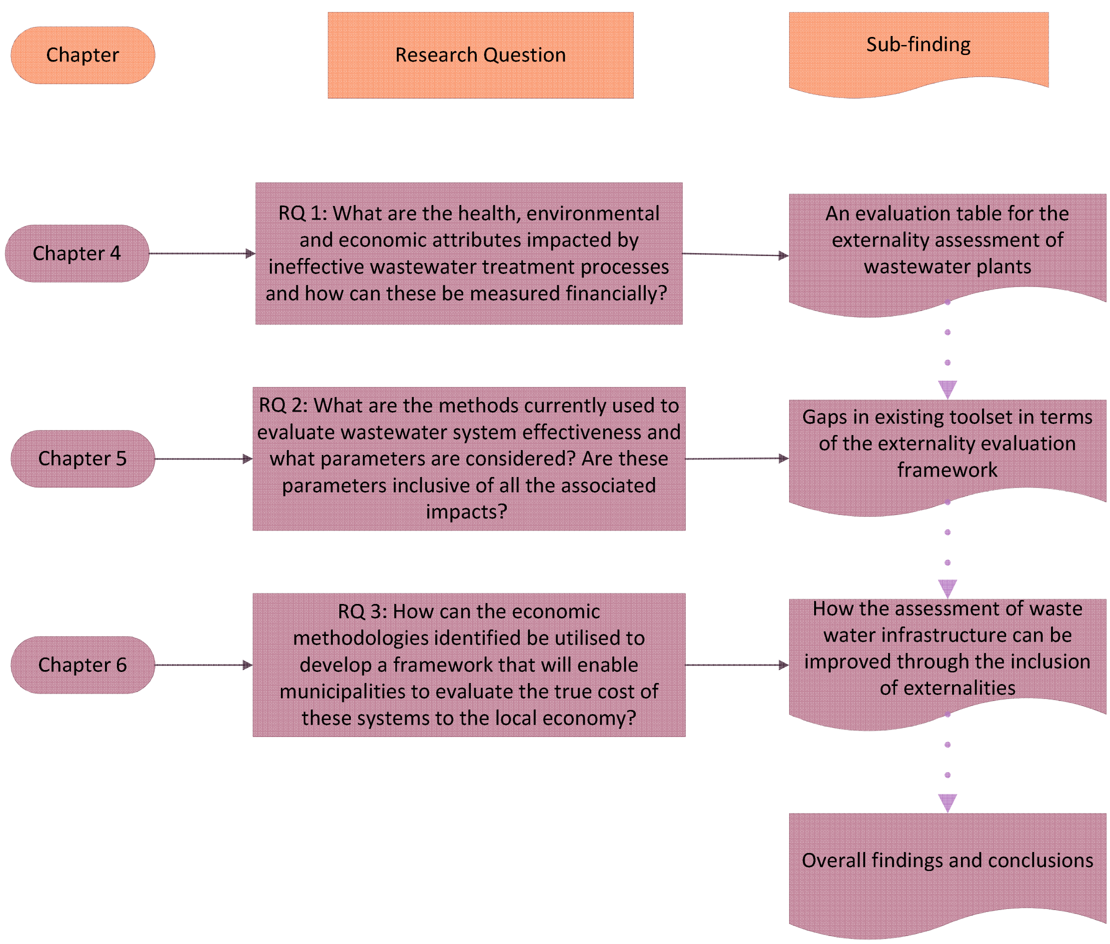


*Figure 3: Structure of the report (source: researcher)*

# Chapter 2

# Literature review

## 2.1 Global water context

Water is one of the essential elements of life on Earth. As the effects of climate change and rapidly rising global populations impact on water resources globally, international and local bodies are acknowledging that greater attention needs to be paid to preserving these water resources. Although not stipulated explicitly, access to safe drinking water is obligated under international human rights laws (United Nations, 2010), and the relevance of access to a safe, reliable water supply to human and economic health continues to gain international attention. This global drive to provide access to water for a greater proportion of the population amidst dwindling global water resources (Corcoran et al., 2010) emphasises the importance of careful management of the resources still available globally, regionally and locally. The critical significance of the challenge is captured best by those who postulate that the next worldwide conflict will not be over mineral or land rights, such as have characterised those of the past, but that the next global war will be over water (Erikson, n.d.).

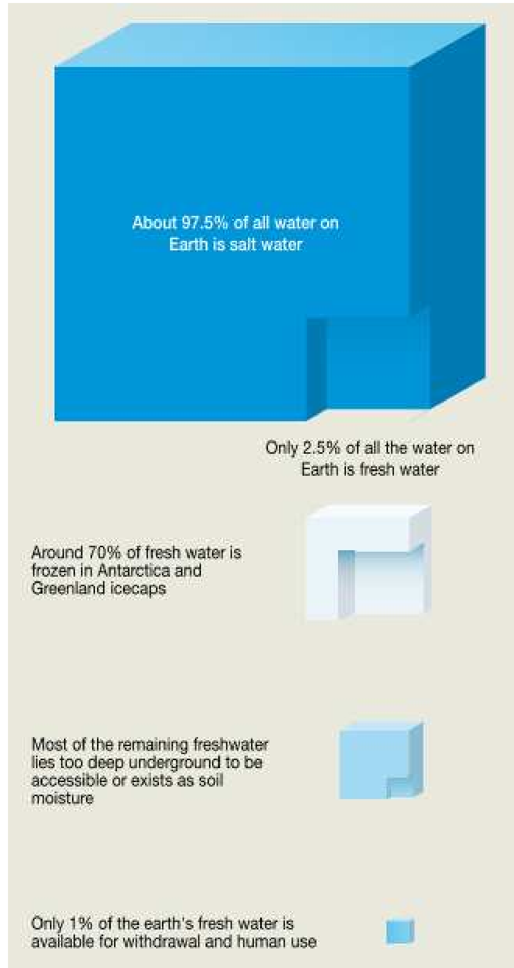


*Figure 4: Global water availability (Corcoran et al., 2010)*

As a semi-arid country, South Africa is an example of a developing country that faces a water scarcity risk in the face of a rapidly growing population. When compared to other countries globally in terms of average 'total actual renewable water resources' (TARWR) per person, South Africa is listed as the 29th driest country worldwide (Muller et al., 2009). The Second National Water Resource Strategy (NWRS2) highlights the importance of access to safe water for the growth and development of the economy and for the health and well-being of South African citizens (IEP, 2016). Yet, due to the misperceptions that there is an abundance of water supply and well-developed infrastructure and management plans (IEP, 2016), the resource continues to be undervalued as indicated by inefficient use and abuse. Even though the South African government has commited to ensuring that all South Africans have access to sufficient quanities of safe drinking water, 98% of the country's water resources have already been committed (Turton, 2016) prior to planning for growth and economic expansion in the future. This does not even include the estimated 37% of water that is lost within the urban water cycle due to inefficiencies in the aging systems, with further losses incurred through the impacts of pollution and degradation (IEP, 2016).

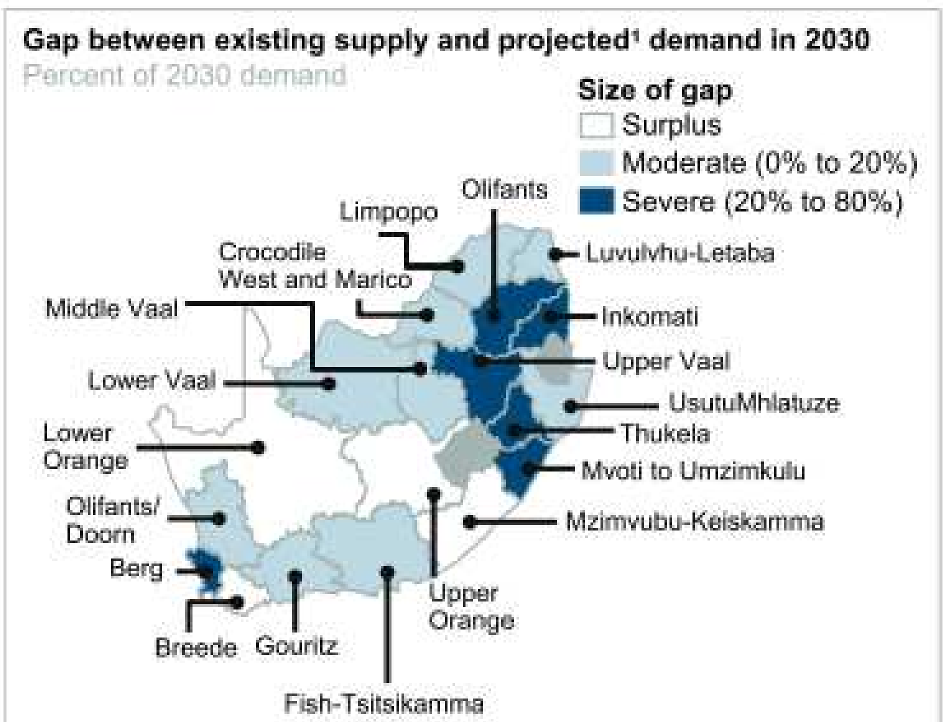


*Figure 5: The South African catchment water projections for 2030* (McKinsey & Company et al., 2009)

The Department of Water Affairs and Forestry states that, currently, 11 of the 19 water catchment areas in South Africa are in a state of water deficit and anticipates that by 2025, this number will have increased to a point at which water security will be questionable (Otieno & Ochieng, 1998). There are three main consumers of water in South Africa, with the agricultural sector being the major consumer at an estimated 60%, with industry and urban consumption making up the remaining 40% (Otieno & Ochieng, 1998). By 2030, it is estimated that demand will exceed supply by 17% (McKinsey & Company et al., 2009), meaning that the time for action in terms of water quality reliability and infrastructure improvements is now. This study arises from this insight but focuses on urban wastewater treatment systems as part of the urban water cycle.

### 2.1.1 The urban water cycle

Traditionally the urban water process is considered to be a linear system that takes water from the source, purifies and delivers it for human consumption, collects any waste and treats the effluent prior to discharge into a water body. In reality, however, this is a far more cyclic system as the wastewater is directed back to natural watercourses where, in many cases, the cycle is repeated downstream. This means that the quality of the effluent discharged into a water body will have direct consequences on the water availability and quality for any downstream industries or communities.

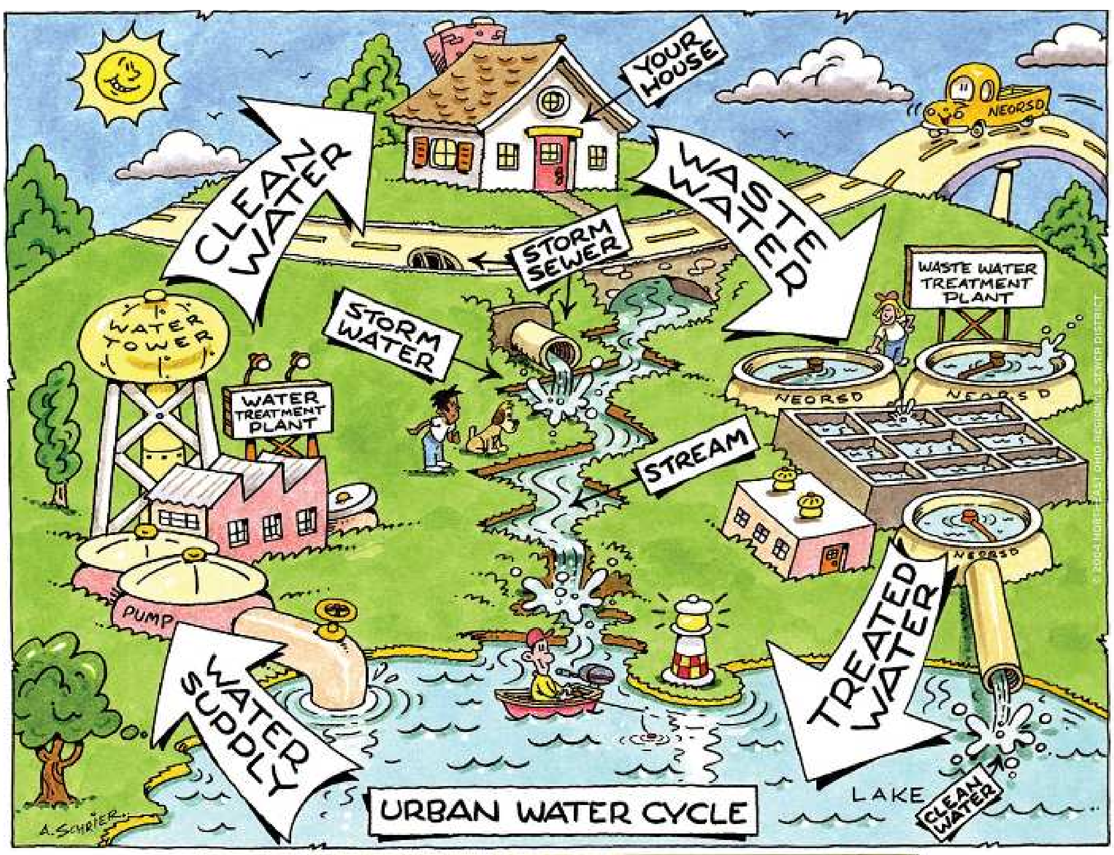


*Figure 6: The urban water cycle (image source: WATER: It's called a "cycle" for a reason right?, 2013)*

The South African government has a responsibility to provide its citizens with safe and sufficient water for consumption; to date, the delivery on this commitment has seen a rapid growth in supply of water infrastructure, with an increase of 42% of households with access to piped water and sewerage since 2005 (Turton, 2016). However, water scarcity is a real and looming risk in South Africa, especially when one factors in climate change impacts which are likely to escalate the problem. Pollution from wastewater treatment facilities in the form of untreated effluent contributes further to the water shortages through aquifer contamination and watercourse pollution (Winpenny, Heinz & Koo-Oshima, n.d.). Water quality and wastewater are inextricably linked, with the ongoing failure of wastewater infrastructure only contributing further towards contamination of the precious water sources that remain.

In essence, “the future demands for water cannot be met unless wastewater treatment is revolutionised” (Corcoran et al., 2010, 9). This emphasises the impact that wastewater treatment can have on water security, as the quality of the water discharged from treatment facilities impacts the usability of the entire watercourse (Mema, 2010). If not correctly managed, the end-of-pipe solution relied upon in many urban centres can create risk factors for the water quality of an entire country (Pahlow et al., 2015). Poor or polluted water sources have major implications for food security, health and environmental management (Corcoran et al., 2010, 9).

## 2.2. Wastewater in South Africa

Urban wastewater in South Africa is generally directed towards a regional or local wastewater treatment plant for processing prior to discharge into a local water body. These plants may vary in their procedure for treating the waste but a majority of them are owned and operated by either the Department of Public Works or the local municipality. Usually, the wastewater treatment facilities in urban areas are highly centralised systems, with the capacity to deal with large quantities of waste; however, high levels of runoff and cross-contamination from illegal connections provide significant challenges to this kind of system. This results in the pipe network and treatment facilities requiring design specifications which can deal with highly irregular flows (Corcoran et al., 2010). These irregular design requirements exclude the contribution of the increased rate of occurrence of extreme weather events, such as flooding, high intensity rainfall and drought, occurring due to the impact of global warming (Hernández-Sancho et al., 2015). Even without accounting for future fluctuations and additions, these plants already have to deal with massive volumes of wastewater, often beyond their design capacity. For example, in 2016, it was estimated that a total of 5.13 billion litres of effluent was treated daily by South African wastewater plants (Turton, 2016).

From an engineering perspective, wastewater treatment system design is a complex challenge and the primary approach from a design and management perspective has been to continue with the design methodologies dating back to those used by water professionals 100 years ago, despite the vastly different challenges of that time such as rapid industrialisation and far lower population numbers. Centralised wastewater treatment in South Africa generally constitutes a process entailing a form of liquid treatment followed by sludge processing. Figure 7 below depicts the typical South African wastewater treatment process; most treatment plants will neglect the extensive sludge processing and possible energy extraction from the solid waste that results, as indicated by the dotted line edited onto the image.

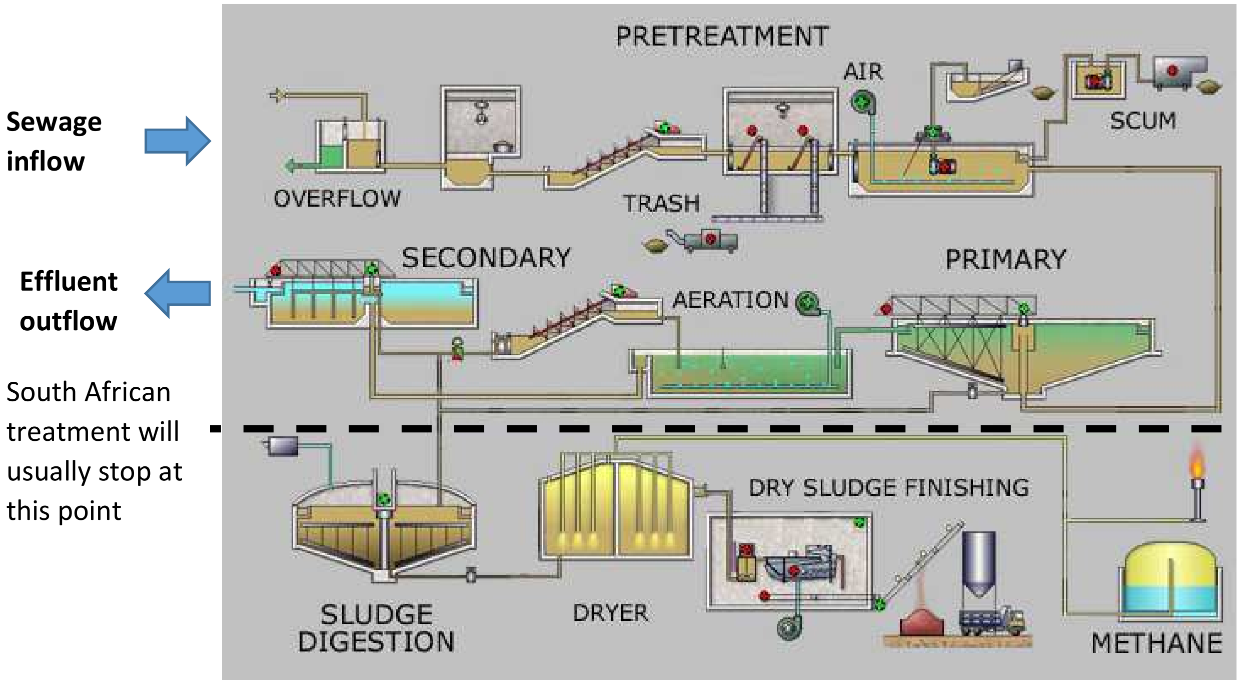


*Figure 7: A schematic of the basic centralised wastewater processing in South Africa, adapted by the researcher (source: Sewage Treatment, n.d.)*

The most common methodology for South African plants is activated sludge treatment with aerobic digestion, this notwithstanding the fact that anaerobic digestion enables energy generation through the production of methane gas without requiring any energy input. Anaerobic digestion, however, takes longer and requires significantly greater attention to the pre-processing of the effluent. The energy potential of anaerobic digestion versus aerobic digestion can be seen in Figure 8 below from Chetty and Pillay (2005), in which the same quantity of wastewater (measured in Carbon Oxygen Demand (COD)) can result in two very different energy patterns. Aerobic digestion can be seen to be in an energy deficit with a large potential of greenhouse gas (GHG) emission in the form of carbon dioxide, and a greater quantity of potentially toxic sludge to dispose of; in contrast, the anaerobic digestion can be seen to have no external energy input but resulting in an energy surplus of 280kWh/100kg COD, and a far smaller quantity of sludge for further processing and disposal.

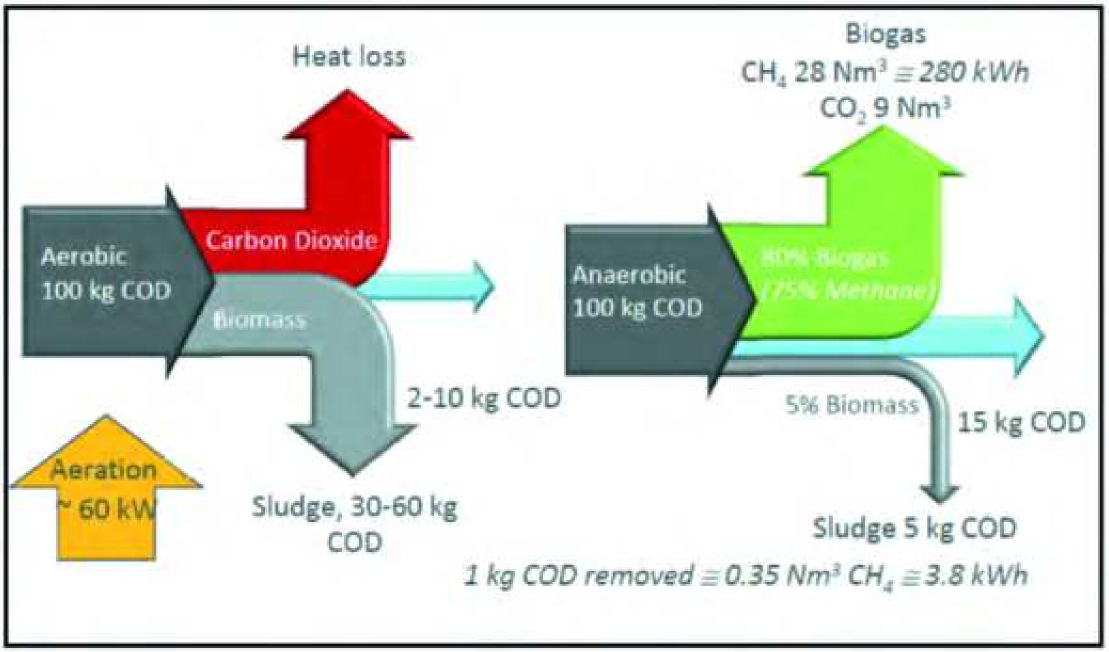


*Figure 8: The energy savings possible through the use of anaerobic digestion over aerobic digestion* (Chetty & Pillay, 2015)

The pollution potential of the effluent will vary depending on the disposal method for the sludge and the type of liquid effluent disposal utilised. Deep sea outfalls would likely have a far lower pollution potential due to the dilution possible given the size of the receiving water body. Although allowance is made within the tool for irrigation use and recycling of water, this is not common currently due to policy surrounding wastewater effluent which only allows reuse if the water quality reaches standards comparable with those imposed on treatment plants for the Green Drop assessment (Department of Water and Environmental Affairs, 2013). This is outlined in Section 37 (1) (a) of the National Water Act (36) of 1998.

This means that all plants that are not located within coastal regions are likely to be discharging into local rivers and streams, with a far smaller dilution potential than that of the ocean. This, combined with the performance of these aging systems and designs, has developed into a serious cause for alarm. According to a report released by the Department of Water Affairs and Forestry in 2008, 96% of the wastewater treatment facilities surveyed in South Africa were not fully compliant with the performance criteria stipulated (Snyman et al., 2008). By 2016, the results had not improved, and the inadequacies at these plants resulted in only 16% of the treated effluent considered to be safe for discharge. The remaining 4.3 billion litres of partially or untreated effluent is discharged into the receiving water bodies (Turton, 2016). Clearly “we now rely on infrastructure and [operational] management strategies that are not sustainable in the 21st century” (Larsen et al., 2009, 6129). As our current economic reality is no longer that of the 20th century, many South African cities now face multiple water security risks, to which the urban water cycle currently contributes substantially.

2.2.1 How South Africa manages wastewater systems

South Africa has developed a review process called the Green Drop report (see Figure 9) in order to manage and mitigate the risks of non-compliance to the stringent standards of wastewater quality. The Green Drop report is orchestrated and managed by the Department of Water and Sanitation and used as an incentive-based model through which to encourage compliance (Department of Water Affairs, 2011). The report provides feedback on the status and historical trends of municipal treatment works, Department of Public Works treatment works and privately owned and operated treatment works across South Africa. The information is then grouped according to provincial location, in order to enable action on a local governance level. In addition, this helps in identifying areas in which the cumulative impact of multiple problematic plants may become of  key concern (Department of Water and Sanitation, 2014).


*Figure 9: Provincial split of average compliance percentage* (source: Department of Water and Sanitation, 2014)

Wastewater treatment in South Africa is primarily managed at a municipal or national governance level with only five privately owned systems assessed in the Green Drop report of 2014. Interestingly, four of these five privately managed systems (80%) achieved Green Drop certification, while only 60 of the 824 publicly managed systems (7%) achieved this certification, whereas 86% of the systems operated by the Department of Public Works were listed as being in a "critical state" (Department of Water and Sanitation, 2014). Although the Green Drop annual progress report has been in place since 2009, and although it has to be credited for some improvements, it is clear that the problems still remain despite all of the efforts made to date. In fact, the latest report, 2014, suggests that the performance of the majority of the plants has deteriorated rather than improved, as is highlighted in Figure 10 below.

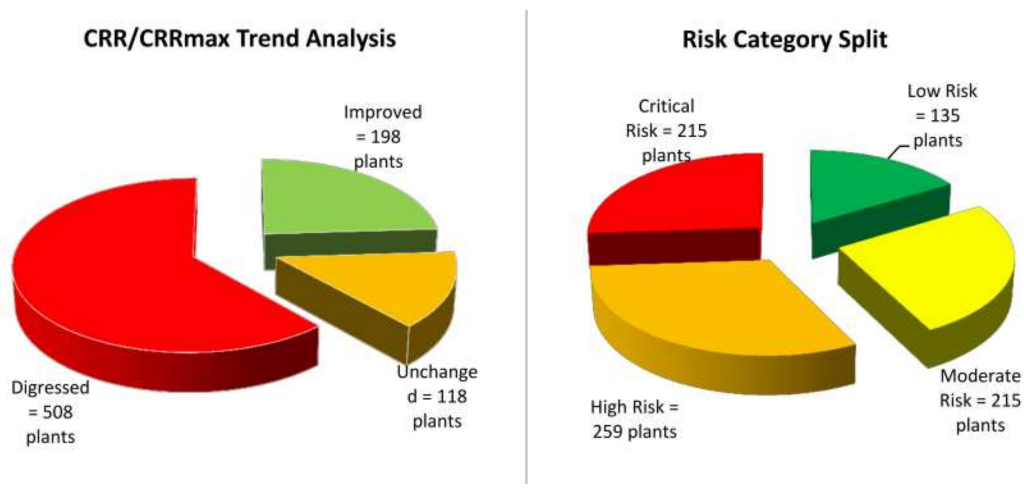


*Figure 10: Extract from the 2014 Green Drop progress report* (source: Department of Water and Sanitation, 2014, 19)

The Green Drop certification process uses the Progress Assessment Tool (PAT) to determine the risk rating for each facility. This tool makes assumptions based on the effluent and sludge treatment methodology, in addition to using information regarding the volumes and outputs of the plant; it will be discussed in more detail in Chapter 5 of this report. Although the reports highlight the specific plants which require the greatest intervention and the areas in which they are having the greatest inadequacies, the high-level concerns surrounding the systemic issues with South African plants are not clear in the results issued to the plant managers.

Mema (2010) conducted a study in which four South African wastewater facilities were compared across a number of attributes. His findings (see Table 1) indicate that the primary reasons for the problems in the functioning of these plants were due to the following (Mema, 2010, 11):

- Poor planning of the treatment works, often resulting in under- or over-design of the systems.
- Inefficient operation of the treatment works leading to poor operational efficiencies.
- Limited skills of the operations staff, resulting in poor management of the works and inability to identify and rectify any issues that may be encountered.
- Poor enforcement of operations procedures, resulting in degrading operations practices.

| | | Case studies | | | | Frequency of the causes of the problems across the case studies (Tally marks) |
|---|---|---|---|---|---|---|
| **Name of Case study** | | Inadequate water-borne sanitation in Keiskammahoek | Buffalo City and Nkonkobe Municipalities | Cape Flats ad Zandvliet (WWTP) | Pollution of water resource by industrial effluents in KwaZulu Natal | |
| **Problem reflected in the case study** | | Untreated sewage and wastewater discharge | - Inadequate removal of nutrients - Chlorine overdose | Groundwater pollution by wastewater and phosphate discharge | High coliform count in the water catchments | |
| **Causes of the problem as reflected in each case study** | Poor design | I | I | | | II |
| | Poor planning | I | I | I | | III |
| | Inefficient treatment works | I | I | | I | III |
| | Inadequate waterborne sanitation | I | | | | I |
| | Limited skilled personnel | I | I | | I | III |
| | Limited financial resources | I | I | | | II |
| | Poor law enforcement | | I | I | I | III |
| | Lack of Training | | I | | | I |
| | Population growth | | | I | | I |
| | Economic growth | | | I | | I |
| | Industrial Growth | | | I | | I |

*Table 1: The primary Influencing factors of poor wastewater plant functioning across four South African case studies (Mema 2010, 11)*

According to the CSIR's water sustainability flagship committee, the approach within the South African water sector continues to be fragmented and operating in silos, when responding to the current water concerns and challenges. This results in “ineffective solutions at the national level, despite genuine efforts by the Department of Water Affairs (as water sector leader) to realise a more holistic response to these challenges” (Pienaar et al., 2014, 1)

## 2.3 Wastewater as a risk

The reality is that the poor performance of these systems cannot simply be ignored. Friedrich and Pillay (2009) studied the various pollution potentials of each urban water supply aspect and the associated impact in terms of percentage contribution (see Figure 11). Clearly, the treatment of wastewater is the major polluter across all pollution types, with the contribution percentage exceeding 35% across human toxicity, terrestrial ecotoxicity, aquatic ecotoxicity, photo-oxidant formation, eutrophication, acidification, ozone depletion and global warming (Friedrich & Pillay, 2009).

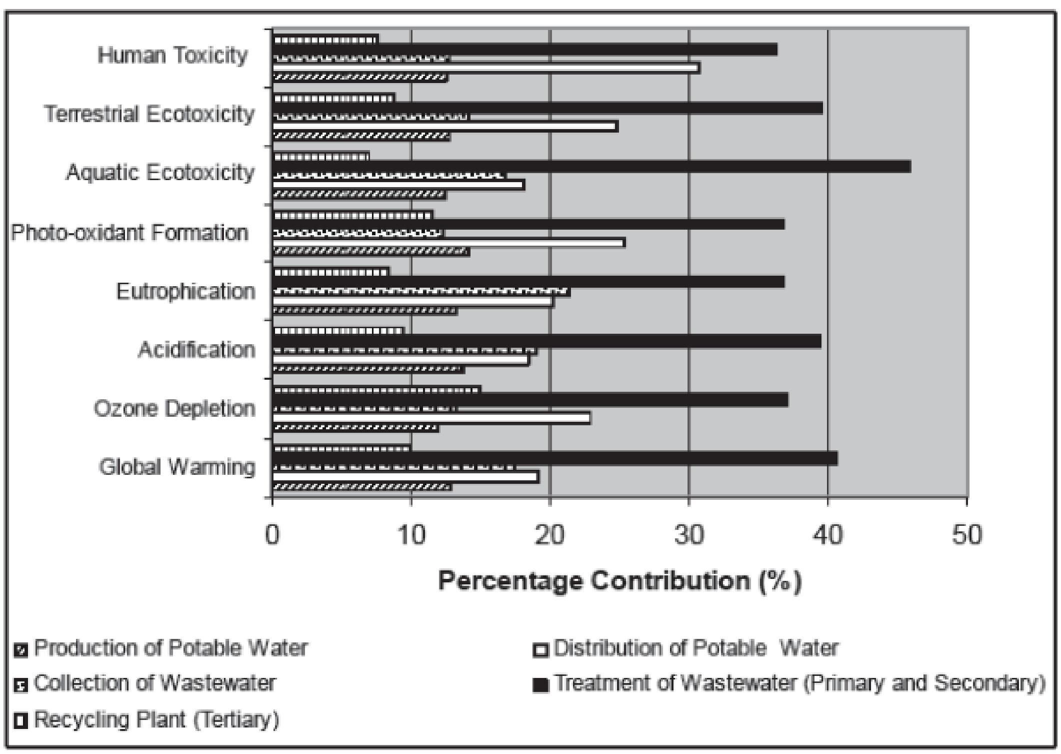


*Figure 11: Pollution potential of each aspect of the urban water cycle* (Friedrich & Pillay, 2009)

Each of these pollution potentials has an impact; these impacts are often not quantified, but economics has developed a term, externalities, as well as methodologies through which to account for them. Thus, “an externality cost is a cost imposed on society due to the activities of a third party, resulting in social, health, environmental, degradation or other costs” (IEP, 2016, 66). As there is no market feedback from the cost bearer to the externality creator (Young, 2000), these costs often go unaccounted. This is not to say that externalities are solely a negative influence; positive externalities exist when at least one person’s welfare increases and there is no detraction from any others’ (Young, 2000).

The concept of ‘duty of care’ allows for some environmental degradation with certain practices but within the boundaries of social acceptance (Young, 2000). In the case of water, the water use guidelines would be an example of duty of care as these are less stringent regulations, without penalty, unlike the legislation. However, as with the case of water pollution, without market and price signals to keep water users within the bounds of responsible water use, the standards indicated in the water use guidelines can continue to be unmet, without consequence.

Unfortunately, ineffective wastewater treatment can result in a number of human, environmental and economic externalities. As the methodology of effluent disposal and level of treatment will vary from plant to plant, a blanket interpretation of these risks is difficult to establish (Young, 2000). An ocean outfall will have different effects and levels of intensity to that of poorly treated effluent being directed towards a local river or stream that will pass through areas of human activity; this is due not only to the variation of environment, but also to the dilution potential of the receiving water body (Young, 2000). This effectively means that systems that are sequential in nature, and whose outputs will have downstream impacts, will have a higher number of externalities to consider than those of a nodal system which will discharge the water post consumption directly into the ocean (Young, 2000).

An awareness of the need to incorporate externality costs into the modelling of costing scenarios is becoming more prevalent, with the externality costs of pollution from energy generation methodologies being used as a major component in the determination of the various scenarios in the new Integrated Energy Plan, 2016 (IEP, 2016). This indicates a shift by local policy makers towards acknowledging these previously unaccounted-for impacts resulting from energy generation methodologies. These include "the effect of carbon emissions on the climate; deterioration of health and mortality due to fires and inhalation of poisonous fumes from the combustion of harmful fuels; waste handling of spent nuclear fuels; and disaster management in the event of leaks or spills" (IEP, 2016, 119). A similar approach could be taken with the planning of South Africa's water resources. The externalities relating to ineffective wastewater treatment could then be divided into three main categories: health, environmental and economic factors some of the details of which can be seen in Table 2 below.

| IMPACTS ON | EXAMPLES OF IMPACTS |
|---|---|
| **Health** | • Increased burden of disease due to reduced drinking water quality<br>• Increased burden of disease due to reduced bathing water quality<br>• Increased burden of disease due to unsafe food (*contaminated fish, vegetables and other farm produce*)<br>• Increased risk of diseases when working or playing in wastewater-irrigated area<br>• Increased financial burden on health care |
| **Environment** | • Decreased biodiversity<br>• Degraded ecosystems (*e.g. eutrophication and dead zones*)<br>• Bad odours<br>• Diminished recreational opportunities<br>• Increased GHG emissions |
| **Productive activities** | • Reduced industrial productivity<br>• Reduced agricultural productivity<br>• Reduced market value of harvested crops, if unsafe wastewater irrigation<br>• Reduced number of tourists, or reduced willingness to pay for recreational services<br>• Reduced fish and shellfish catches, or reduced market value of fish and shellfish |

*Table 2: List of associated impacts of wastewater (Hernández-Sancho et al., 2015, 15)*

### 2.3.1 Health

Wastewater contains a concentrated amount of nutrients and pathogens that, when humans come into contact with them, can cause a number of serious diseases. Various viruses carried in sewerage include but are not limited to: adenovirus, astrovirus, coxsackievirus, enterovirus, norovirus, rotavirus, and cyclovirus (Turton 2016) (see Table 3).

| VIRUS | RISK |
|---|---|
| Adenovirus | Causes colds, but poses a specific risk to children and adults with compromised immune systems. |
| Astrovirus | Typically manifests as viral gastroenteritis. All persons are at risk, but children, the elderly and those with compromised immune systems are the typical targets. This has particular relevance to the poor who carry a disproportionally high burden of disease. |
| Coxsackievirus | May cause mumps, aseptic meningitis and hand, foot and mouth disease, which usually occurs in children. A more dangerous subset damages the heart, pancreas and liver, with some evidence that insulin-dependent diabetes is associated with Coxsackievirus B pancreatitis. |
| Enterovirus | Spread through the faecal-oral pathway, includes polio, currently under control in all but a few undeveloped countries. Infections include conjunctivitis, aseptic meningitis, myocarditis, neonatal sepsis and flaccid paralysis. |
| Norovirus | Causes gastroenteritis. |
| Rotavirus | Directly associated with diarrheal risk to infants below the age of five, and is a known risk to the poor. |
| Cyclovirus | Not yet fully understood by scientists, but currently manifesting as a neurological disease among children in Asia. This includes a form of non-trauma related paraplegia, manifesting mostly among the poor that rely on untreated water for survival. |

*Table 3: Viruses and health impacts (Turton, 2016, 6)*

At any one time, half of the occupied hospital beds globally are filled with those suffering from waterborne diseases, directly correlated to water quality (Corcoran et al., 2010). The discharge of raw or untreated wastewater poses a risk to human health as it contains many harmful bacteria that can cause a multitude of diseases if the water is later consumed untreated (Mema, 2010). Inadequate infrastructure in rural areas means that, currently, many households rely on natural water bodies as their source of water for drinking, bathing and washing clothes (Turton, 2016); due to inefficiencies at the treatment plants, these water sources are often contaminated, leading to the spread to disease.

Wastewater treatment is therefore the essential link between access to safe drinking water and access to sanitation, making it a vital component of all developing countries attempting to meet the millennium development goals (Corcoran et al., 2010). According to Corcoran et al. (2010, 9), “contaminated water from inadequate wastewater management provides one the greatest health challenges restricting development and increasing poverty through costs to health care and lost labour productivity”. The Global Burden of Disease (GBD) Study 2013

(GBD, 2013) for South Africa indicates that HIV/AIDS, diarrhoeal diseases and cardiovascular disease were the highest ranking causes of years of life lost in 2013. This indicates that diarrhoeal diseases contribute only second to HIV in the burden of disease in South Africa.

In addition, many households grow food using contaminated water for irrigation and new research indicates that there may be a link between consumption of food and water contaminated by microcystin and cognitive disabilities (Turton, 2016). Given recent concerns surrounding the impact of drug-resistant strains of viruses placing additional pressure on the South African health care system, the results of a study conducted by the Irish Environmental Protection Agency that links the effective treatment of wastewater to a reduction in the presence of drug-resistant bacteria (Turton, 2016) should serve as greater motivation for the need to relook at the way in which wastewater is addressed.

### 2.3.2 Environmental management

Wastewater has a number of significant environmental impacts, the severity of which is largely determined by the treatment process selected.

#### *2.3.2.1 Greenhouse gas emissions*

Wastewater treatment plants are responsible for greenhouse gas emissions in the form of methane ($CH_4$), carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$) (Chetty & Pillay, 2015), all by-products of the treatment process (see Table 4). The quantity of emissions will vary dependent on the treatment methodology adopted. Although the contribution in terms of global proportions is low, this is anticipated to rise as other sectors attempt to mitigate their greenhouse gas contributions (Corcoran et al., 2010).

| TABLE 3<br>Emission factors for wastewater treatment | | | | |
|---|---|---|---|---|
| **Emissions related to wastewater treatment processes** | **Unit** | **$N_2O$** | **$CH_4$** | **$CO_2$ eq. factor** |
| Nitrogen treatment | kg TKN | 0.01 | | 298 |
| Carbon treatment | kg COD | | 0.0085 | 25 |
| Nitrogen treatment | kg N total | 0.015714 | | 298 |
| Biogas | $m^3/d$ | 0.0023 | 0.0233 | |
| Transportation of chemicals | kg/d | | | 0.013 |
| Incineration of waste | kg/ton dry solids | 0.99 | | 298 |
| | kg/ton dry solids | | 1.1 | 25 |
| Transportation of waste to hazardous waste disposal site | kg/d | | | 0.0011 |
| Transportation of waste to general disposal site | kg/d | | | 0.0011 |

*Table 4: Emissions from wastewater treatment plants (Chetty & Pillay, 2015)*

In terms of the urban water system, wastewater treatment is the highest energy consumer throughout the system, with the collection of wastewater and associated pumping listed as another major consumer (Friedrich & Pillay, 2009) (see Figure 12). This is despite the fact that wastewater treatment has the potential to produce ten times the amount of energy that it consumes (Chetty & Pillay, 2015). Friedrich et al. (2007) go as far as to ascertain that the low price of electricity has made many of the plant managers choose the easy route and discharge directly into the receiving water body rather than use the available anaerobic digesters to produce methane gas, causing them to be 'mothballed' (Friedrich et al., 2007).

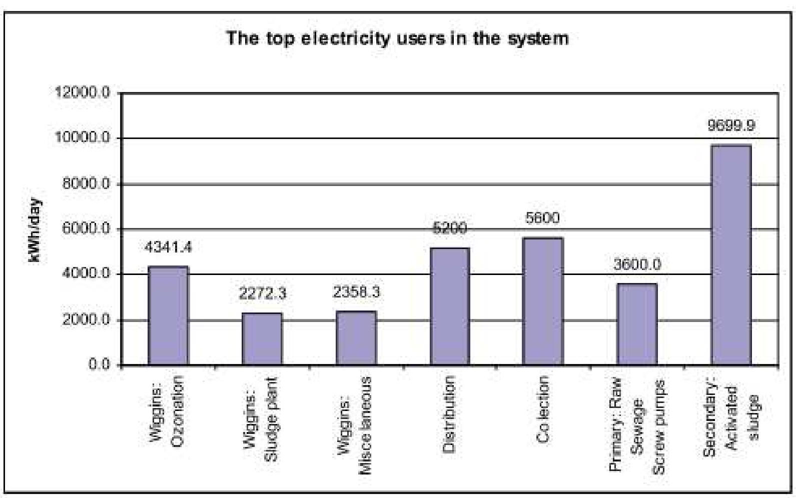


*Figure 12: Energy consumption per activity (Friedrich & Pillay, 2009)*

With the imminent introduction of carbon taxes in South Africa in order to meet the carbon reductions agreed upon in the Paris Accord, the need to quantify the emissions from infrastructure services is of growing importance. Although the proposed carbon tax does not set an actual limit on GHG emissions, the intention behind the imposed tax would be to act as a market regulator that, over time, brings the cost of goods and services with a lower emission potential to below that of their higher-emitting counterparts (IEP, 2016). In South Africa, most electrical generation comes from coal, with the energy sector accounting for more than 80% of the country's carbon emissions in 2010 (IEP, 2016). Therefore, any energy consumed in the operation of the wastewater treatment process has the additional associated greenhouse emissions from using 'dirty energy' (Friedrich & Pillay, 2009).

This will mean that the emissions of these waste water treatment systems will start to create additional costs in the operations of the systems on top of the already costly energy cost contribution, which can account for up to 25% of the treatment operations (Chetty & Pillay, 2015).

#### 2.3.2.2 Eutrophication

The effluent discharged from treatment plants into South African water bodies, even post processing, is high in the nutrients phosphorous and nitrogen; this combined with runoff from fertilised fields, can contribute to the eutrophication of water bodies (Corcoran et al., 2010). Eutrophication, "defined as enrichment by nutrients, and toxin-producing cyanobacteria (blue-green algae) blooms" (Matthews & Bernard, 2015, 1), is a water system's response to excess nutrients, leading to algae blooms and a limited amount of oxygen available in the water to sustain other life forms. Two-thirds of South African dams are affected by eutrophication (Turton, 2016). In 2015, Matthews and Bernard (2015) conducted a study of 50 South African water bodies; their findings indicate that 62% of the water bodies investigated were highly nutrient enriched or hypertrophic, with 52% of them containing cyanobacterial blooms, whose surface scums posed a dangerous health risk to humans (Matthews & Bernard, 2015).

The concern about eutrophication is not only from the health hazards of surface scum, but also from a number of issues such as "increased phytoplankton blooms, turbid water conditions, increased cyanobacteria (blue-green algae), taste and odour problems, oxygen depletion (anoxia), increased incidence of fish kills, loss of biodiversity and decreased aesthetic value" (Matthews & Bernard, 2015, 5). Cyanobacteria is of primary concern as this can cause a bio-accumulation of toxins, chemicals and hormones within an organism, which may be fatal when consumed by humans or other animals (Bay of Sewage, 2016). This can potentially lead to decreased biodiversity in the ecosystem, proliferation of alien invasive species (Matthews & Bernard 2015) and the dying out of species. Without the proper functioning of aquatic ecosystems, the safe drinking water supply of South Africa is at risk. Research done by the CSIR in the Sekhukhune district by taking samples upstream and downstream of the plant confirmed that the treatment plant was contributing to the eutrophication of the water course, thereby rendering the water unsafe for consumption (Pienaar et al., 2014).

It is not only the above-ground water sources that face the risk of pollution but if the polluted water is used to irrigate, there is the additional risk of subterranean water contamination (Hussain, Raschid & Hanjra, 2001). The positive impact of the recharge of the ground water table from irrigation from wastewater can be counteracted by the addition of excess nutrients, pathogens and salts, where wastewater or contaminated water is used for irrigation (Hussain, Raschid & Hanjra, 2001), leading to the contamination of aquifers. This will largely depend on the soil quality and composition and will vary from region to region as the thresholds differ. Like the aquifers, there is the danger of soil contamination from irrigation as the build-up of nutrients, salts and heavy metals continues over time (Hussain, Raschid & Hanjra, 2001). The danger is that prolonged irrigation use results in waterlogged soils, soil salinity, alteration of soil structure and, ultimately, a reduced soil capacity and lower agricultural yields (Hussain, Raschid & Hanjra, 2001)

### 2.3.2 Economic factors

Poor water quality will have impacts that reach further into the economies of countries than simply the economic effect of the numerous health impacts. Water is crucial to the growth and development of the South African economy, including the industrial and agricultural sectors. The impact on the agricultural sector can be significant, in terms of decreasing crop yields and marketability (Winpenny et al., n.d.); this is despite the fact that "each year, 330km$^3$ of municipal wastewater [is] generated globally capable of irrigating and fertilising millions of hectares of crops and producing biogas to support millions of households" (Hernández-Sancho et al., 2015, 11). In addition, cyanobacterial toxins can lead to poisoning of domestic animals (Matthews & Bernard, 2015) and therefore the loss of livestock and income for farmers.

The deterioration of South African water bodies can also result in the loss of recreational facilities and business opportunities due to the health risks for the users, which would in turn impact on tourism (Matthews & Bernard, 2015). A decrease in property values along the water's edge, reduced amenity values and additional costs may also be incurred in order to protect the property from the risks posed by a polluted water body (Young, 2000). These costs have not begun to include the additional costs of water purification and management of the polluted water body.

As Matthews and Bernard (2015) observe, "the economic cost of eutrophication is likely to extend to hundreds of millions of rands per year, being borne across all levels of society, but particularly affecting the livelihoods and health of the poor and vulnerable" (Matthews & Bernard, 2015, 2).

## 2.4 Wastewater as a resource producer

The recoverable resources available from wastewater fall into three main categories: water, materials and energy (Larsen et al., 2009). The 2016 Africa Futures report (Hedden, 2016) targets the increase in use of treated wastewater in seven of its large-scale reconciliation strategies in order to increase the yield of available water resources in the future (Hedden, 2016).

### 2.4.1 Water

The recycling of wastewater has the least impact in terms of carbon dioxide emissions per litre (Friedrich & Pillay, 2009) making it in effect a better environmental option than extraction and purification of water for domestic use. However, there are many negative perceptions of the reuse of wastewater as potable water, thus warranting the possibility of developing different supply chains for different consumption sectors (Otieno & Ochieng, 1998). Dual reticulation water systems (potable and non-potable) are a commonplace design internationally and the implementation of these would allow for wastewater to be recycled for non-potable uses. The water savings possible through wastewater reuse are indicated in Table 5 below.

**Environmental savings from replacing virgin water with recycled water**

| Impact category | Provision of virgin water (treatment and distribution) | Recycling of waste-water | Environmental saving % |
|---|---|---|---|
| Global warming potential (kg $CO_2$ equivalents) | 4.81E-01 | 1.01E-01 | **79** |
| Ozone depletion potential (kg CFC-11 equivalents) | 1.10E-08 | 3.19E-09 | **68** |
| Acidification potential (kg $SO_2$ equivalents) | 2.85E-03 | 5.68E-04 | **72** |
| Eutrophication potential (kg Phosphate equivalents) | 2.05E-04 | 3.51E-05 | **83** |
| Photo-oxidant formation potential (kg ethene equivalents) | 5.28E-05 | 1.05E-05 | **80** |
| Aquatic ecotoxicity potential (kg DCB* equivalents) | 6.45E-03 | 1.00E-03 | **84** |
| Terrestrial ecotoxicity potential (kg DCB* equivalents) | 7.88E-01 | 1.25E-01 | **84** |
| Human toxicity potential (kg DCB* equivalents) | 1.49E-02 | 1.77E-03 | **88** |

**All toxicity scores are expressed in kg DCB (1, 4 dichlorobenzene) equivalents*

*Table 5: Environmental saving of using recycled water instead of virgin water (Friedrich & Pillay 2009)*

### 2.4.2 Materials

The reuse of solid waste by-products, such as those found in the agricultural sector, is well understood and practised internationally (Larsen et al., 2009). The main nutrients found in the waste products of wastewater treatment are phosphorus and nitrogen (Corcoran et al., 2010), exactly those used in traditional fertilisers, and therefore wastewater by-products can be used as an alternative to chemical fertilisers for food production. However, the reuse of wastewater by-products for food production calls for careful monitoring, as the combination with traditional fertilisers may result in over-provision of nutrients and therefore further pollution (Corcoran et al., 2010). It also poses potential health risks during handling if proper training is not simultaneously provided.

### 2.4.3 Energy

The extraction of the methane gas from solid waste produced during anaerobic digestion is a well-documented and understood process (Corcoran et al., 2010). The methane gas can be burned directly and used to operate the treatment plant, or cleaned and sold to local gas providers or even cleaned and used as fuel for vehicles (Larsen et al., 2009). By utilising methods of energy extraction from waste, the processes in wastewater systems would no longer have to be consumers of massive amounts of energy, and could instead be transformed to be energy positive, making them a net producer of energy. Internationally, there is precedent for this, with wastewater treatment plants in Austria and Switzerland being energy neutral or in some cases energy positive (see Table 6).

| | Sweden (Average of all WWTPs) | Czech Republic (Centre WWTP, Prague) | Singapore (Jurong WWTP) | UK (Average of the WWTPs) | Switzerland (Werdhölzli WWTP, Zurich) | Austria (Strass WWTP) |
|---|---|---|---|---|---|---|
| Energy Efficiency (%) | 9% | 83,5% | 40% | 50% | 100% | 108% |

*Table 6: International wastewater plant energy efficiencies (Scheepers & Merwe-Botha, 2013, 14)*

## 2.5 Why do we need an economic analysis of externalities?

The economics of water resource management is a poorly understood and explored sector of economics. This results in many countries having difficulties preparing fact-based policies and viable business cases for investment in water infrastructure (McKinsey & Company et al., 2009). Indeed, “the lack of clarity on the true financial cost of water exacerbates the problem in a further, important way: businesses, farmers, and households lack sufficiently strong signals and incentives to prompt them to use water more efficiently and productively” (McKinsey & Company et al. 2009, 34). Although it is up to governments to intervene and ensure that the externality cost is imposed on the firms and individuals responsible (Riegels et al., 2015), decision makers often struggle to interpret the non-financial implications related to their decisions and thus find it preferable to use monetary values to guide their choices and decisions (Brouwer & Stavros, 2012). Despite the impacts of wastewater, both negative and positive, being widely acknowledged, a succinct valuation of the externalities has not been systematically attempted in South Africa (Hussain et al.

2001). As a result, possible interventions to improve the wastewater situation, as well as their social, economic and environmental implications, have not been accurately conceptualised or developed for implementation.

Despite there being a clear concern regarding the impact of poor wastewater management in South Africa, the motivation for additional expenditure and policy adjustment remains as possibly the most critical stumbling block towards interventions for improved performance. The use of economic principles provides a methodology for this motivation; “economic evaluation is thus about determining whether an intervention is an efficient use of society’s resources and can be defined as the comparative analysis of alternative courses of action in terms of both their costs and consequences” (Drummond et al., 1987, 124).

As policy decisions are made from the perspective of society as a whole, policy adjustment regarding public goods (such as water) requires that a broad net of societal impacts be considered (Brouwer & Stavros, 2012). This ultimately calls for the economic evaluation of the externalities associated with poor wastewater management. This economic evaluation requires the “identification, measurement, valuation and comparison of the costs and consequences of the alternatives being considered” (Brouwer & Stavros, 2012, 430).

The cost-benefit analysis (CBA) is the most commonly adopted approach used in the decision making for public infrastructure and goods (Pearce, Atkinson & Mourato, 2006). The CBA allows for the assessment of the associated costs and benefits of a particular intervention, where a benefit is defined as an increase in human well-being and a cost a decrease in human well-being (Brouwer & Stavros, 2012). However, there is an argument that says that the CBA, although commonly used, may not always be the most appropriate tool for evaluating technologies, especially when there are impacts that can be considered externalities to the decision. Although the CBA can allow for the inclusion of sustainability aspects (Pearce, Atkinson & Mourato, 2006), there are numerous issues that arise with trying to bring non-financially valued aspects to a monetary value. Unfortunately, when investigating aspects of environmental or human health, the determination of monetary value starts to develop ethical questions as the economic methodologies developed for these measurements, covered in the sections to follow, force monetary value to be assigned to emotional and often intangible assets (Stone, n.d.).

If no attempt is made to quantify these, however, the risk is that impacts on human life and environmental systems will only be noted as concerns and warnings appended to a financial calculation, and it will be the numbers that are remembered and acted upon (Ackerman, 2008). According to Ackerman (2008, 5), “when it comes to valuing nature, there is no way to persuade fish or forests to answer questions; economists have instead asked people how much nature is worth to them”. However, all values are brought to current-day equivalents in order to determine if the net present value (NPV) of the implementation outweighs the cost of the intervention. This again raises questions about the applicability of CBAs in decision making for, often, the impacts on human and environmental health will persist for generations and therefore, the process of future discounting will fail to reflect the true value of the impacts (Pearce, Atkinson & Mourato, 2006).

The basic process of conducting a CBA, as defined by Brouwer and Stavos (2012), is as follows:

*Step 1: Define the objective of the intervention.*

*Step 2: Define the baseline, that is, what would happen if no action is taken.*

*Step 3: Define the alternative options to achieve the objective.*

*Step 4: Quantify the investment costs of each option compared to the baseline.*

*Step 5: Identify and quantify the positive and negative welfare effects of each alternative option compared to the baseline.*

*Step 6: Value the welfare effects in monetary terms, using market prices and economic valuation methods.*

*Step 7: Calculate the present value of costs and benefits occurring at different times, using an appropriate discount rate.*

*Step 8: Calculate the net present value (NPV) or benefit/cost (B/C) ratio of each alternative option.*

Fundamentally, this thesis surrounding poor wastewater management impacts argues that Step 2, the baseline, is currently not fully representative of reality; this is because it does not include the associated externality costs associated with not acting to rectify wastewater treatment inefficiencies. Only once the baseline is properly determined, can the future impacts and strategies for performance improvements be modelled with greater accuracy. This would enable the discussions surrounding water to move from highly technical and often narrow views, to that of a common understanding of the quantitative impacts (McKinsey & Company et al., 2009). Given that this is not the case currently, what results is that a highly constrained and invaluable resource continues to be undervalued and poorly managed.

This could result in costs far higher than those currently experienced in the water sector, as countries are no longer able to meet the requirements for future generations, and are also experiencing disastrous impacts on their economies at present (McKinsey & Company et al., 2009). A fundamental aim of this report is therefore to provide an understanding of how the quantification of externalities can result in a more representative baseline from which CBAs can be conducted in the wastewater performance sector in South Africa.

## 2.6 Existing water policy frameworks in South Africa

It is necessary to understand the existing policy frameworks and the associated responsibilities within which the wastewater sector operates. As water is deemed a public asset there are numerous government departments and agencies tasked with its management. The current flow of responsibility in the water value chain, according to the Department of Water Affairs, places wastewater at the end of the chain and puts its management under that of a 'Regional Water Institution'. However, there is a clear link back to the protection and control of water, directly managed by the Department of Water Affairs (Department of Water Affairs, 2013) (see Figure 13).

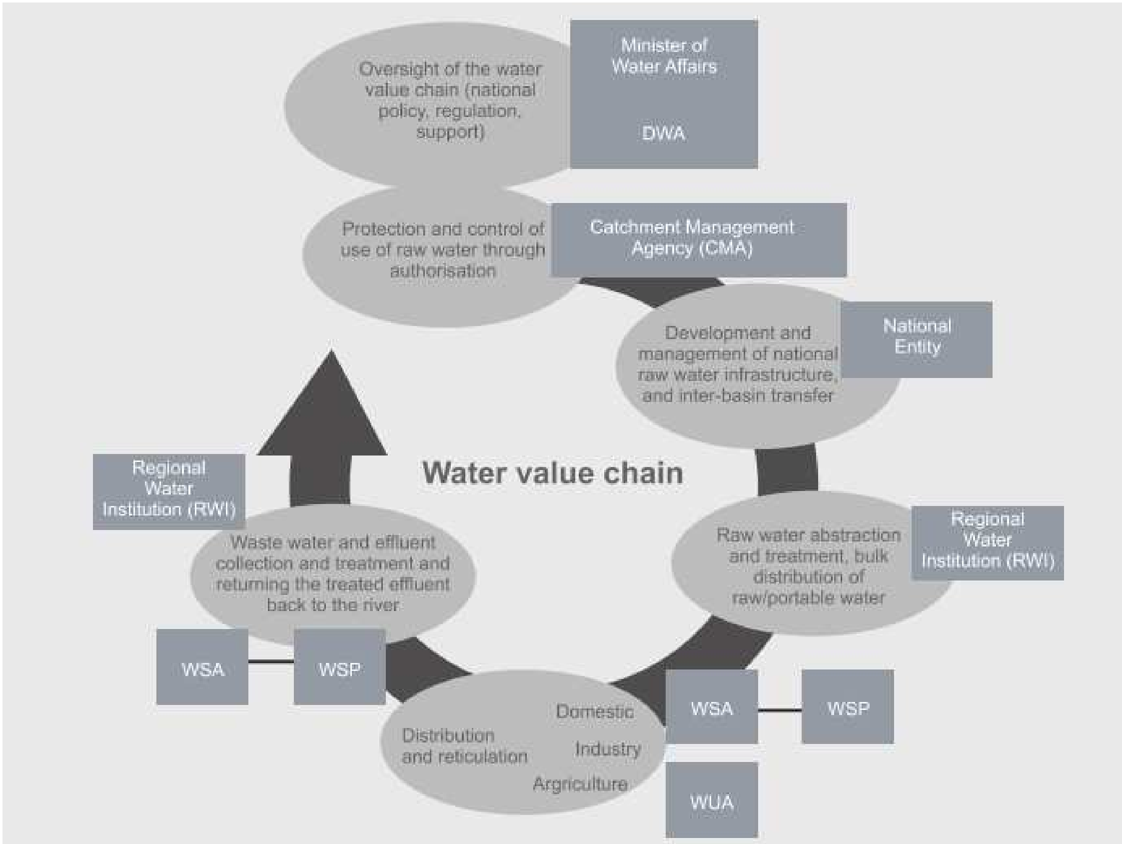


*Figure 13: Flow of responsibility through the water cycle (Department of Water Affairs, 2013, 62)*

In the National Water Resource Strategy (2013), the Department identifies a number of strategic objectives and targets to be achieved by 2017. The main themes that have relevance to wastewater facility performance are:

- Water resource protection
- Institutional establishment and governance
- Compliance monitoring and enforcement
- Development, operation and maintenance of infrastructure.

In terms of compliance monitoring and enforcement, the Green Drop reports are seen as an aligned programme through which to achieve the performance objectives (DWAF, 2013).

| Theme | Strategic objective/ Outcome | KPI/Target | Responsibility | Collaboration and sector support | Alignment with other programmes | Time Frames |
|---|---|---|---|---|---|---|
| Water resource protection | Manage for sustainability using resource directed measures | Management Class, and associated Reserve and resource quality objectives set for 10 significant WR | DWA | DEA, CMA's, DAFF,DMR; chamber of Mines, local government, | NSSD, River Health programmes; | 2017 |
| Institutional establishment and governance | Establish robust and sustainable water sector institutions | 9 CMA's established, Infrastructure agency, 50% WUA established | DWA, National Treasury | DPSA, Unions, CMF's,CSO's, DAFF | Institutional development, capacity building | 2017 |
| Compliance monitoring and enforcement | Enforce compliance to all legal provisions, quality and quantity standards to ensure efficient WRM | 60% green drop compliance, 80% blue drop 100% compliance licence conditions | DWA, CMA's, DEA, DMR,DMR, Water Tribunal | Dept of Justice & Constitutional Development, SAPS, Independent Police Investigative Directorate | Authorisation, Blue Drop, Green Drop, WDCS, WR protection | 2017 |
| Development and operation & maintenance of infrastructure | All water infrastructure is developed in accordance with the requirements of the Reconciliation Strategies and operated and maintained to a high standard and at a capacity required to serve its purpose. | Mobilise capital infrastructure budget allocation for development of new infrastructure as well as for the O&M and rehabilitation of government schemes100% utilisation of allocated budgets for development and O&M | Municipalities, WUAs, Water Boards, TCTA, Infrastructure branch, National Treasury, DCoG, Public Works | Private sector, DBSA, Education, DoH, DAFF, DRALR | RBIG, ACIP, MIG, Green Drop, Transfers, MWIG Investment Framework and funding model | 2017 |

*Table 7: Water KPIs that wastewater influences (Department of Water Affairs, 2013, 68)*

According to the Department of Water Affairs (DWAF, 1997, 6), "ongoing monitoring and assessment is critical to our ability to manage and protect water resources on the basis of sound scientific and technical information and understanding. Adequate information is essential for effective resource management and protection". Despite transparency being a fundamental aspect of the values associated with the Department of Water Affairs, interestingly, as water concerns escalate due to the continued drought, the influence of politics in water and wastewater management gains momentum in the public domain. In 2015, there were numerous accusations that national government was withholding information from the public domain in order to avoid making public the poor performance of the sector prior to local government elections. In 2015, the *Mail and Guardian* published a number of articles which quoted Department of Water affairs employees to have said they had been told by management to 'look the other way' until after the 2016 elections, regarding any municipal plant issues or concerns, or risk their job security. This was despite the same department releasing a high-level summary of the water quality in South African rivers that found that 98% of the bodies assessed had faecal coliform at high risk levels (Kings, 2015a).

## 2.7 The way forward for South African wastewater management

Given the massive pollution and consumption potential of these wastewater systems, combined with the clear lack of management systems and skills to manage them, it seems obvious that South African wastewater systems require attention and perhaps a change of the methodology within which they operate. This would be in addition to the fact that many of these systems are inadequate and require expansion (Otieno & Ochieng, 1998). When factoring in the expense of expanding the existing infrastructure, the logical next step is to look at more efficient use of the existing water resources and infrastructure (Otieno & Ochieng, 1998), thus calling for a paradigm shift in the way that water professionals currently view wastewater, shifting from a mentality of what needs to be removed to what can be recovered, rather (Larsen et al., 2009). Based on this innovative approach, proper management of South African wastewater resources could mitigate our country's water stress and the looming water crisis (Pienaar et al., 2014).

In order to motivate change in the sector, this study investigates three key aspects of the problem: firstly, the real consequences to the South African economy of continuing with the status quo; secondly, determining appropriate methods by which to interrogate these externalities to convert them into real financial impacts on the economy and, lastly, making recommendations as to how these methodologies can then be incorporated into the standard decision-making methodologies utilised by governments and professionals in the sector. It is believed that when an understanding of the real impact of the externalities of wastewater pollution on the South African economy is better understood, there will be more incentive to enforce change within the sector. In order to determine this, a number of research methods will be utilised and these will be discussed further in the following chapter. In concluding, the study hopes to contribute to Hedden's (2016, 10) call in which he declares "South Africa is at a 'tipping point' in terms of wastewater treatment".

# Chapter 3

# Research methods

This chapter will outline the methodology through which the study gathered and analysed data in order to answer the research questions posed. An outline of the report structure will be used to guide the reader through the report and ensure that the intention and direction is clear throughout.

## 3.1 Research strategy

The research adopted a phased approach in order to ultimately make recommendations as to how the methodology through which South African wastewater systems are currently managed and assessed can be altered to reflect a more holistic view of the true cost associated with their operation. As evident by the research questions, a number of research approaches were required in order to address the different questions. Primarily qualitative research methods have been utilised in order to address the different aspects of investigation. Below is an outline of each research question, the method and the data used to answer each question, as well as output.

| | Research question | Secondary data | Primary data | Anticipated output |
|---|---|---|---|---|
| **1** | What are the economic, health and environmental attributes impacted by ineffective wastewater treatment processes and how can these be measured financially? | Narrative review of the economics externalities | Key informant interviews to complement and triangulate evidence from the narrative review | An evaluation table for the economic assessment of wastewater plants |
| **2** | What are the methods currently used to evaluate wastewater system effectiveness and what parameters are considered? Are these parameters inclusive of all the | Assessment of PAT assessment tool to determine parameters included.<br><br>Evaluation table output from question 1 applied | Key informant interviews to complement and triangulate assessment of the case study | Gaps in the PAT tool identified |

| | | | | |
|---|---|---|---|---|
| | associated impacts? | to the case study | | |
| **3** | How can the economic methodologies identified be utilised to develop a framework that will enable municipalities to evaluate the true cost of these systems to the local economy? | Narrative review to identify the economic methodologies best suited to evaluate the gaps identified in the PAT tool from question 2. | Key informant interviews to complement and triangulate assessment of the case study | Recommendations for a framework that will enable municipalities to evaluate the true cost of these systems to the local economy |

*Table 8: Report structure (source: researcher)*

### 3.1.1 Review of the health, environmental and economic attributes impacted by ineffective wastewater treatment processes

A desktop review of local and international literature was used to identify the aspects influenced by the wastewater purification process and system performance. Once the impacts were scoped, a relevant unit of quantification was identified as a way of evaluating the externalities within an evaluation tool.

As there are a number of aspects, such as the health impacts and environmental impacts, that are not traditionally quantified financially, an additional comparative review of the literature surrounding environmental and health economics has been conducted in order to establish the best methodology through which to assign costs to environmental and socio-economic impacts in the South African context.

### 3.1.2 Analysis of the methods and parameters currently used to evaluate wastewater system effectiveness

Given the risks that the health, environmental and economic impacts of ineffective wastewater treatment pose to local economies, the existing methodologies for quantifying and evaluating wastewater systems performance and risks were evaluated using a qualitative method of impact evaluation. A performance investigation was conducted on the broad impacts that the current assessment process has had on wastewater management in South Africa. These impacts were analysed using the data available from the annual Green Drop reports. These reports provide performance data for all the municipal wastewater treatment plants in South Africa. As data is released annually, the impact of the reports as a system of information dissemination towards performance is quantifiable though systematic review of impact variation over time.  The annual change in performance was evaluated by comparing the PAT assessment results from the years 2008 to 2014.

Using the evaluation framework developed from the output from the first research question, the comprehensiveness of the existing tool was assessed. An example PAT assessment was used for the evaluation. This sample data was for the Randfontein Municipality wastewater treatment plants' 2014 Green Drop PAT assessment. All actual data and assessor comments are included for evaluation. From this assessment, gaps in the current assessment methodology in terms of economic externalities were identified.

### 3.1.3 How can the economic methodologies identified be utilised to develop a framework that will enable municipalities to evaluate the true cost of these systems to the local economy?

There are a number of general approaches developed to determine the value of the costs and benefits associated with externalities that have no existing market price. The approaches are based on economic theory and principles but vary with regard to the methodology used for each impact. This study reviewed the literature to identify methodologies that enables the various externalities associated with ineffective wastewater treatment to be quantified. The general approach applied towards determining the valuation and quantification of an externality was conceptualised in accordance with the flow diagram below.

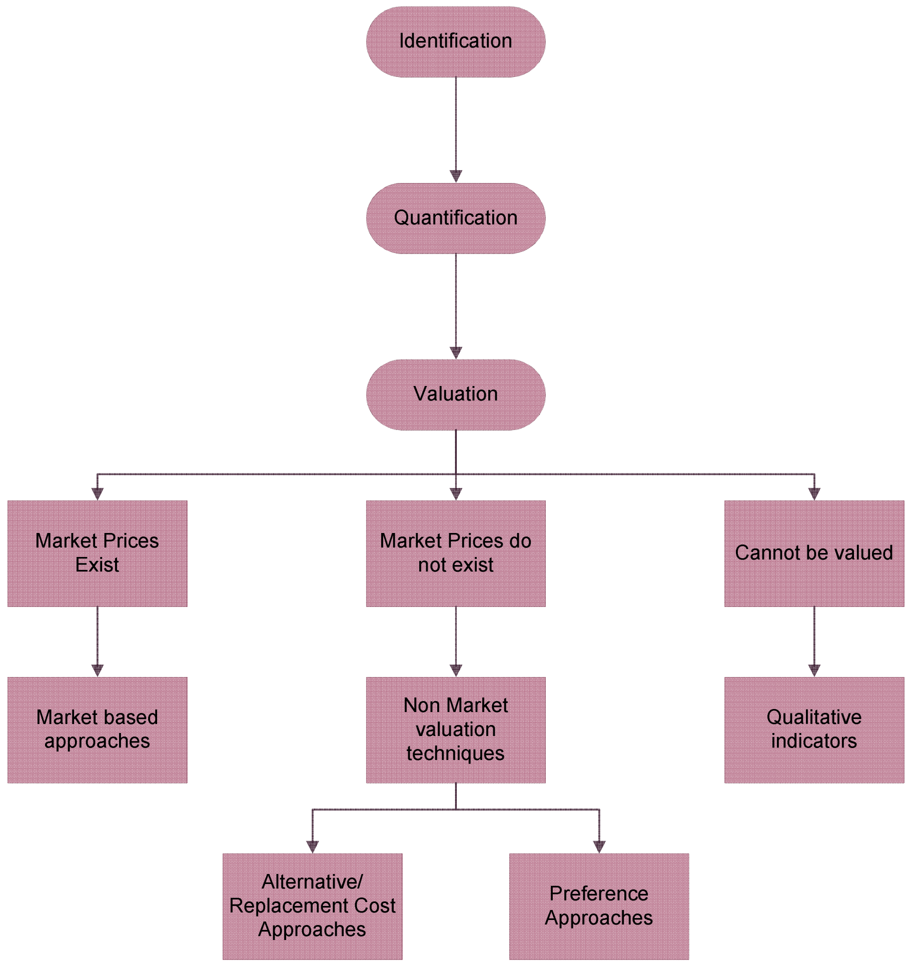


*Figure 14: The externality valuation process (adapted by researcher from Hussain et al. 2010, 8)*

After the impacts have been identified and quantified, the method of valuation of the externality would largely depend on the impact. 'Willingness to pay' underpins all of the options, whether directly (where market prices exist) or indirectly (where market prices do not exist). This is based on an understanding that environmental and human welfare are intangible and can only be quantified based on "the maximum amount of goods or services – or equivalent money income – that an individual is willing to forego (willingness to pay – WTP) in order to obtain some outcome that increases his/her welfare" (Brouwer & Stavros 2012, 430).

### *3.1.3.1 Market prices exist*

Should the impact have existing market prices, conventional market-based approaches would be utilised as these are often the most accepted methodologies. The costs of goods and inputs would be utilised to determine the replacement value or the cost of resources lost due to the externalities of poor wastewater management. Any future or past influences would be converted to current values by using a net present value (NPV) calculation.

*3.1.3.2 Market prices do not exist*

Where market prices did not exist for the externality, this research has utilised preference approaches as a way in which to determine the willingness to pay. The willingness to pay principle is a primary method of determining the value that society is willing to pay for the avoidance of the particular impact or the correction of damages incurred (Hussain, Raschid & Hanjra, 2001). Where possible, observed or revealed preferences have been used, as these are primarily based on actual data. In circumstances where preferences are purely hypothetical, stated preferences based on surveys have been utilised. Any impacts that are not possible to systematically monetise have been evaluated through qualitative methods and included in the discussion.

In order to better understand the externalities associated with wastewater, the impacts needed to be initially identified and then quantified in order to better understand the economics of the current wastewater treatment scenario. Thereafter, through the use of environmental and health economic techniques, the study began to investigate how much the status quo (current practice) is truly costing the South African economy. Given that water is a public good and many of the externalities are not currently monetised, the CBA, typically used to evaluate infrastructure investments, may not be the most relevant methodology to be used in decision making (Hussain et al., 2001).

*3.1.3.3 Operational context*

Key informant interviews were conducted with a select group of wastewater professionals in order to determine their perceptions regarding the major barriers to effective wastewater management. Interviewees were identified through the use of purposeful sampling; these experts and practitioners in the field were then approached for feedback in the format of a semi-structured questionnaire (see Appendix A). The interviews were audio-recorded and transcribed at a later time in order to preserve the flow of conversation during the interview. The professionals spanned a number of sectors, namely academia, policy making and municipal engineering. Key themes emerging from these interviews were identified using thematic analysis and triangulated with secondary evidence.

The interviewees are described as follows:

- Interviewee A is an epidemiologist and a senior lecturer at a local university. She has taken a particular interest in the impact of wastewater outfalls on human and environmental health, and has vast experience in dealing with the inertia of government institutions in this regard.
- Interviewee B is the head of the Wastewater Department at a major international engineering consortium. A chemist by training, he spent many years with the city of Cape Town as Head of Operations for the Wastewater Management Department; having worked both sides, he is able to provide insight as to the divide between the public and the private sector.
- Interviewee C currently runs her own consulting firm providing advice to both public and private sectors with regard to wastewater management. She was an integral part of the conceptualisation of the Green Drop programme. Not only did she develop the assessment tool, but she also wrote all of the Green Drop reports from 2008 to 2013.

3.2 Data collection

Secondary data from literature was sourced from both local and international journal articles and published reports that substantiate the research conducted with regard to local and downstream factor impacts of ineffective centralised wastewater works. Care was taken to acknowledge that there are a number of treatment options available and used, both locally and internationally, and therefore not all the impacts reported were relevant to all South African plants. Similar concerns and approaches were considered when appraising the best strategies in which to price unmonetised externalities. Upon enquiry on how to attain more information on the PAT assessment tool, an example of the tool was received from Water SA. This data was provided with a commitment to utilise the information therein purely for research purposes and the researcher strictly adhered to this commitment.

### 3.3 Ethical concerns

Ethical clearance for the study was obtained from the Department of Architecture and Planning Human Research Ethics Committee. The ethical clearance certificate is contained in Appendix B. With regard to the interviews conducted, care has been taken to ensure that the study adhered to all the ethical requirements as stipulated in the ethics clearance. Each participant received a participant information sheet which outlined the scope and purpose of the study prior to the interview, and a consent form at the point of the interview. Signed copies of the consent forms are available. The interviewees' identities have not been made public, as per the agreement in the consent forms.

# Chapter 4

## Analysis of the health, environmental and economic attributes impacted by ineffective wastewater treatment processes

### 4.1 Introduction

This chapter presents the findings of the narrative review of the externalities associated with ineffective wastewater treatment used to develop a framework to assess the thoroughness of the current wastewater assessment tools in South Africa. Existing data pertaining to the externalities of wastewater have been used, in conjunction with existing health, environmental and market economic theory, in order to fully understand the extent of the economic impact.

### 4.2 Establishing a baseline for CBA analysis

Although there are diverse associated impacts of ineffective wastewater treatment, for the purpose of this research only the aspects related to the direct economic externalities were investigated in order to determine a baseline. Three main themes or categories were identified from the review of the literature: impacts that affect human health; environmental impacts; and impacts on the local economy. Many of these impacts are interlinked and will have feedback mechanisms connecting each other, making it important to ensure that the impact is not double counted when looking at monetising these impacts in chapters to follow.

#### 4.2.1 Health

Fundamentally, the primary difficulty in accurately assessing the economic burden on the health care system due to poor wastewater management is determining the number of patients whose illnesses stem directly from contact with a water source contaminated by wastewater effluent, in other words, the associated incidence rate. Although diarrhoeal diseases place a significant burden on the South African health care system (MacIntyre & de Villiers, 2010), the percentage of these which can be attributed to contact with contaminated water sources, specifically attributable to poor wastewater treatment facilities,  is harder to define. The best methodology through which to achieve this, as indicated by Interviewee A (an epidemiologist), would be to identify the pathogen strain responsible and investigate the potential point of contact.

Rural areas without access to water and sanitation infrastructure are likely to have greater contact with contaminated water sources and therefore, the incident rates of disease are likely to be higher in such regions (Turton, 2016). Numerous diseases are associated with contact with polluted water, especially water sources that have been affected by a poorly managed wastewater treatment plant. This is due to the variety of pathogens and chemicals that can be found in the water body. The most commonly understood are the diarrhoeal and gastrological diseases associated with the E. coli bacteria (Bos, Carr & Keraita, 2006). The numerous diseases associated with wastewater effluent will have varying implications for the health care system, as the severity of illness will depend on the patient and the dilution potential of the receiving water body. Contact that may only cause minor gastrological stress in an adult with a fully functioning immune system may have far greater influences, and in even lead to death, in infants or people with a compromised immune system (Turton, 2016).

This literature was supported by responses from Interviewee A, who has spent a number of years investigating the health care impact of ineffective wastewater treatment plants. She recommended that the health impacts be assessed on a local level, as each catchment area is different and the risks associated will vary geographically. She stated very clearly that inefficiencies at wastewater treatment plants can have severe impacts on the health of local residents who interact with water bodies in the area. The example of the town of Bloemhof was identifed by Interviewee A as a case study that was explored further. It provides evidence from secondary sources as to the health impact possible from contact with wastewater effluent. The details of the implications for the municpality can be seen in the box below.

**Case Study: Bloemhof**

In 2014, the town of Bloemhof in the Lekwa Teemane Local Municipality of the North West Province experienced the impact of the link between poor wastewater management and community health.

Negligence at the wastewater treatment plant led to the E. coli contamination of the Vaal River, from which water was drawn to supply the residents of Bloemhof with potable water. In this particular case, the treatment of this water was not monitored adequately and resulted in contaminated water being distributed to the residents through the potable water network. This led an outbreak of diarrhoeal and related diseases that led to the hospitalisation of over 500 residents and the deaths of three infants (News24, 2014). The water supply to the town was suspended while the entire treatment works was drained and cleaned, and the residents were forced to wait for water from tankers. A criminal case was laid by the residents against the municipal manager. The mayor subsequently resigned, as pressure for the individuals to take responsibility for a disaster that cost the municipality R20 million to rectify was felt (eNCA, 2014).

E. coli is only one of a number of pathogens that can be found in wastewater effluent and, although the most commonly tested for, it is by no means the only bacteria of concern for communities interacting with a polluted water body. Additionally, there are a number of viruses that are also known to be carried in wastewater resulting from urban wastewater effluent (Turton, 2016). Although the health economic aspects potentially influenced by water pollution from wastewater effluent are broad, they can be summarised into three main categories: mortality; opportunity costs due to time off work; and burden on the health care system. Aspects such as mortality, which will require use of the willingness to pay principle in order to value economically, may be harder to quantify accurately given the highly emotive nature of this topic (Majid Sabbagh Kermani, 2010) it is hard to place a value on a human life, as there is so much more to individuals than simply their economic capacity. Figure 16 below provides a graphical representation of the health impacts that are discussed in this research report.

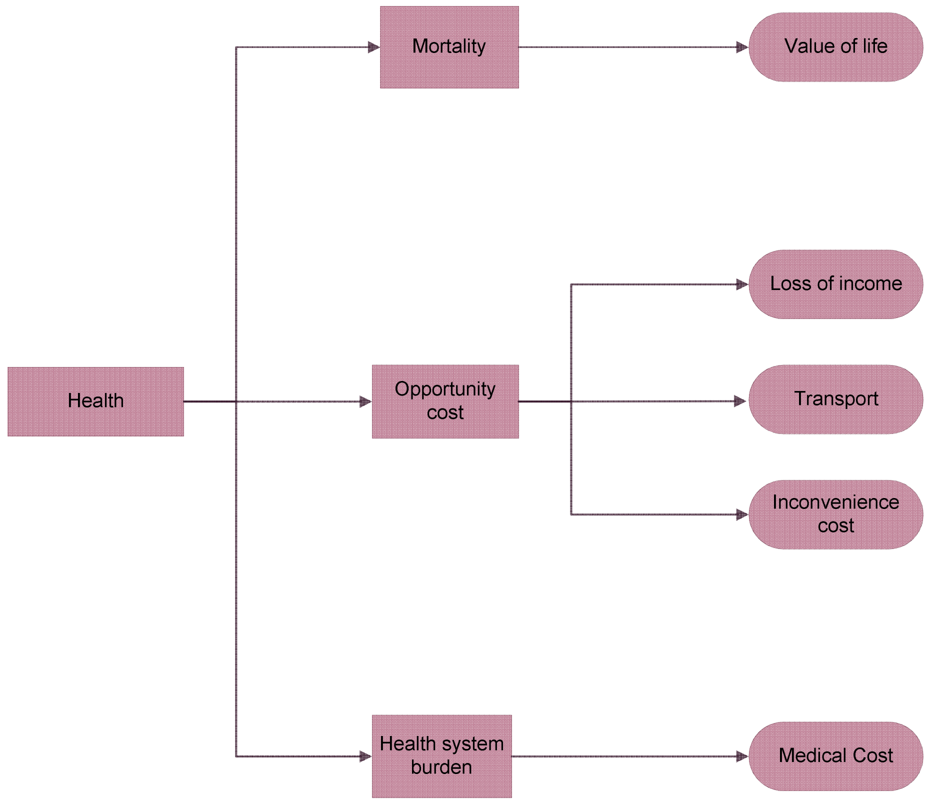


*Figure 15: Schematic of health externalities impacted by ineffective wastewater treatment (source: researcher)*

#### *4.2.1.1 Mortality*

Deaths associated with contact with poorly treated effluent are far higher in infants and children than they are in adults (MacIntyre & de Villiers, 2010). However, the impact of HIV and AIDS, a major factor in South Africa, cannot be ignored as this will place adults at risk due to their compromised immune system (Turton, 2016). Accurately measuring the number of deaths associated with contact with water sources contaminated with wastewater effluent is challenging and in order to be able to make assumptions, in-depth epidemiological studies would be required (Interviewee A, 17 January 2017).

A measurement of the pathogen load at the point of effluent discharge would be a start but the dilution potential of the receiving water body will have a major impact in terms of determining if, and how many, individuals would get sick through contact with the watercourse. If the receiving water body were to be expansive, such as an ocean outfall, only persons interacting with the water close to the wastewater outfall would likely be affected, but if the pathogen and viral load were high and the receiving water body of low volume, the number of individuals impacted is likely to be greatly increased (Interviewee A, 17 January 2017)

In the context of evaluation of wastewater treatment efficiency, determining the pathogen load, in mg/l released, combined with further studies of what exactly each load band would mean for the community's health in terms of number of individuals affected, would be necessary in order to do an economic calculation on the effect of the associated mortality.

**Measurable criteria**: Pathogen load and viral load of the effluent.

#### *4.2.1.2 Opportunity cost*

The opportunity cost relating to wastewater effluent can be defined as the loss of benefit that occurred due to illness (Hussain, Raschid & Hanjra, 2001) associated with contact with contaminated water. This will affect both the families of those who fall ill and those who fall ill themselves. Dependent on the severity of the disease, illness will result in days off work and therefore a loss of income for many individuals. In addition, it may be necesary to account for additional household costs under the opportunity cost. These can generally be measured directly and will include transport costs, additional childcare costs and other incidental and inconvenience costs (MacIntyre & de Villiers, 2010). These costs are often not simply a once-off cost; many of the patients will need to return in a matter of weeks or months (Interviewee A, 17 January 2017). These recurring health concerns can in turn lead to chronic diseases which will have a life-long impact on families. Chronic illness and frequent absence from work can also lead to job loss and, thereafter, a loss of income for households. As the value of the resulting economic burden will again be directly related to the incidence rate of disease, it can be measured through the pathogen and viral load.

**Measurable criteria**: Pathogen load and viral load of the effluent.

#### *4.2.1.3 Health system burden*

The economic burden of the illnesses associated with poor wastewater effluent quality can be measured most simply by evaluating the cost of the associated disease burden on the local hospitals and clinics. The cost to the local municipality will again depend on the number of patients, which is again related to the pathogen and viral load of the effluent. Interviewee A noted that often patients are transported from local clinics to hospitals outside of the local area. This would mean that the economic burden is transferred to another municipality and this will also need to be accounted for.

**Measurable criteria**: Pathogen load and viral load of the effluent.

#### *4.2.1.4 Health impacts summary*

The impacts of poorly treated wastewater effluent on the economic externalities relating to health in terms of measurable criteria for a wastewater treatment assessment can be seen in Table 9 below.

| Aspect | Impact | Variable | Measure |
|---|---|---|---|
| **Health** | Mortality | Number of deaths<br>Incidence rate | Pathogen load<br>Viral load |
| | Opportunity cost | Incidence rate | Pathogen load<br>Viral load |
| | Health system burden | Incidence rate | Pathogen load<br>Viral load |

*Table 9: Health impact summary (source: researcher)*

### 4.2.2 Environmental factors

The negative environmental impact of poor wastewater treatment is well understood and documented, but what that translates to in terms of economic impact is less clear. A majority of the environmental concerns raised relate to the impact of a sudden increase in nutrients on a water body and the organisms that inhabit it, when poor or partially treated wastewater enters a water body. Wastewater is intensely nutrient and resource dense (Winpenny, J., Heinz, I., Koo-Oshima, n.d.), which can be used in a positive manner when looking to harvest energy and resources through alternative wastewater treatment methods, but this can also have many negative environmental externalities. The ones investigated in this research are greenhouse gas emissions and various forms of water pollution. Figure 17 below provides a graphic representation of the environmental impacts that are discussed in this research report.

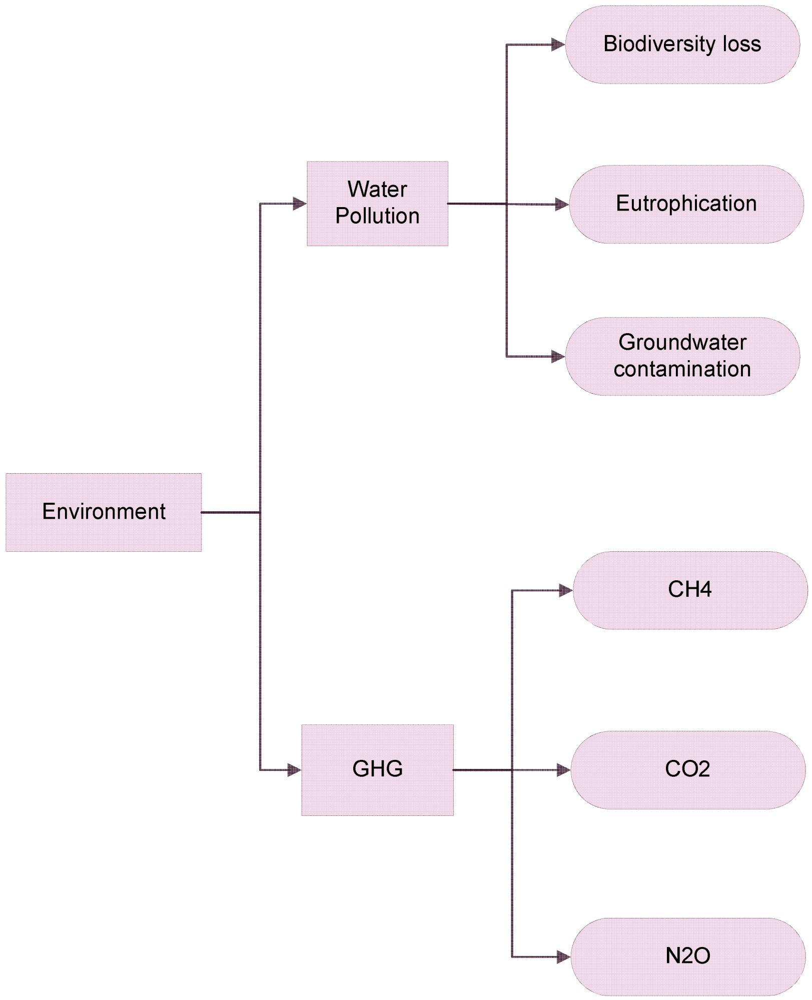


*Figure 16: Summary of the environmental impacts covered in the research (source: researcher)*

### *4.2.2.1 Greenhouse gases (GHGs)*

Greenhouse gases are an externality that has been well researched when referring to energy and global warming impacts. This factor's relationship to wastewater treatment has been investigated but the relevance to the local economy has not been significantly highlighted. The quantity and types of greenhouse gases emitted by a wastewater treatment facility will depend on the treatment system utilised. Those that utilise biodigestors and methane harvesting techniques will have far lower emission potentials than those that use aerobic digestion and settling ponds (Pienaar et al., 2014). In the process of wastewater treatment carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) are released; these are all deemed to be greenhouse gases and can be translated into $CO_2$ equivalent units (Chetty & Pillay, 2015). Studies have been done locally and internationally that provide estimates for a number of common treatment methodologies of the emissions per litre of wastewater treated.

Therefore, in order to estimate the greenhouse gas emissions of a facility, one would need to know the type of treatment methodology in addition to the operation volumes of the treatment plant, that is, the litres processed by the plant within the assessment period. The compliance with the management protocol for the plant's operation will also have an impact on plant efficiency and therefore on the emission potential; however, this is difficult to quantify and further studies would be required to determine the relationship between operational compliance and the change in emission potential of various treatment methodologies

There are also the external $CO_2$ contributors that should also be considered when analysing the GHG emission potential of wastewater treatment. Up to 25% of the treatment costs at South African plants is attributed to energy costs (Chetty & Pillay, 2015); energy is largely generated from coal and therefore has a very high carbon footprint. The impact of the fuels used in transport and the chemicals used in treatment should also be considered but for a high-level estimate, quantifying the emissions through energy consumption and treatment methodology should suffice.

**Measurable criteria**: Operational volumes, treatment methodology and energy consumption.

*4.2.2.2 Water pollution*

*Groundwater contamination*

Contaminated water, if utilised for irrigation, can have two primary impacts on groundwater, namely groundwater recharge, which is deemed a positive impact, and the risk of nitrate contamination, a negative impact (Hussain, Raschid & Hanjra, 2001). Excess nitrates in the groundwater would contribute as a human health risk and therefore should be added to the health risk evaluation, if a sufficient quantity of effluent contaminated water is used for irrigation purposes (Dillon & Schrale, 1993). Wastewater is rich in nitrates in a number of forms, primarily in the forms of ammonia and nitrogen; these are known to be important to human and environmental health and therefore have regulated effluent limits which are typically measured as part of the operation of wastewater treatment plants (Department of Water and Environmental Affairs, 2012). Other chemicals that may pose a risk to groundwater aquifers would not typically result from urban wastewater but would be of concern if an illegal connection from an industrial facility were made to the network.

**Measureable criteria:** Nitrates and chemicals

*Eutrophication*

Due to the high nutrient content of wastewater, the eutrophication potential, if not managed closely, is extremely high. Eutrophication is the enrichment of nutrients in a water body (Matthews & Bernard, 2015) and can result in algal plumes that can cover entire sections of rivers and dams. This can result in lack of sunlight to other organisms (if the plume covers the entire surface) and a decrease in the oxygen content available in the water to sustain life, leading to the loss of aquatic life forms and jeopardising entire ecosystems (Matthews & Bernard, 2015). As eutrophication is already a problem in two-thirds of South African water bodies (Turton, 2016), the close monitoring of the nutrient potential of wastewater is essential. Nitrogen and phosphorous are the two elements most commonly attributed to eutrophication but a measure of the total nutrient load would enable the determination of eutrophication potential; this is deemed to be the total suspended solids (TSS) measure in wastewater. If one knows those nutrient loads and the volume of effluent discharged, the eutrophication potential can be measured.

**Measureable criteria:** Nitrogen, phosphorous, total suspended solids and operational volume.

*Biodiversity loss*

As described, eutrophication can lead to biodiversity loss in aquatic ecosystems but there are a number of other aspects relating to ineffective wastewater treatment that can also contribute to the risk of biodiversity loss. Many aquatic species are very sensitive to the pH levels of water (Momba, Osode & Sibewu, 2006); if the level were to vary too far from neutral, many species would die out. According to Interviewee C, chlorine is often used as a last ditch resort by South African wastewater facilities that are unable to treat wastewater by traditional methods. Chlorine has a very high pH value and therefore has the potential to influence the habitat of aquatic plants and animals by altering the natural pH of the water body. Additionally, many species are sensitive to changes in temperature. As biological and chemical processes are temperature dependent in nature (Rhode Island Rivers Council, n.d.), varying temperature can impair photosynthesis in plants and the metabolic rate of organisms, potentially resulting in species loss if wastewater effluent is released at a temperature vastly different from that of the receiving body.

As discussed previously, the nutrient load in wastewater effluent is high; this means that there is potential for effluent to contain high levels of dissolved solids, commonly salts. Aquatic organisms are sensitive to the dissolved salts in the water body, as this impacts the rate at which water moves in and out of the organism's cells (Rhode Island Rivers Council, n.d.). If there is a sudden change in the dissolved mineral content of a water body, it can limit growth or result in the death of numerous aquatic organisms. A measure of the dissolved solids used in wastewater treatment is the total dissolved solids (TDS) test and this can be used to ensure that limits within the receiving water body are not exceeded.

The last aspect of wastewater effluent that can be used to measure the potential threat to the local ecosystem is that of the dissolved oxygen requirement in the effluent. As mentioned when discussing eutrophication, sufficient oxygen levels in a water body are essential for aquatic life and, as water can only carry a certain amount of oxygen, these levels are very sensitive to fluctuations. As the effluent can contain organics that will be decomposed by micro-organisms that require oxygen in order to survive, this measure of oxygen requirement is termed the biological oxygen demand (BOD) (Rhode Island Rivers Council, n.d.). If more oxygen is consumed than produced in an ecosystem, biodiversity loss will result. Chemical pollutants can also have an impact on the oxygen content of water resources; if these pollutants have oxidation potential, there will be an oxygen demand similar to that of the oxygen demand of the organic organisms. The chemical oxygen demand test in wastewater treatment is a measure of both the organic and inorganic oxygen demand potentials of effluent.

**Measureable criteria**: pH, temperature, total dissolved solids, biological oxygen demand, chemical oxygen demand.

*Environmental impact summary*

Table 10 below shows the numerous environmental externalities associated with ineffective wastewater treatment in terms of measurable criteria for a wastewater treatment evaluation.

| Aspect | Impact | Variable | Measure |
|---|---|---|---|
| **Environment** | Water pollution | Groundwater contamination | Nitrates and chemicals |
| | | Eutrophication | TSS<br>Nitrogen<br>Phosphorous<br>Operational volume |
| | | Biodiversity loss | pH<br>Temperature<br>TDS<br>BOD<br>COD |
| | Greenhouse gas emissions | $CO_2$ equivalents | Operational volumes<br>Treatment methodology<br>Energy consumption |

*Table 10: Summary of environmental impact influences (source: researcher)*

## 4.2.3 Economic factors

The impact of ineffective wastewater treatment on the receiving water body will often have numerous further downstream impacts that cannot be ignored, as they have a significant impact on the local economies. As the environmental value of a water body decreases, the human economic activities that sought to harness this value will be affected. This means that industries such as tourism and property will likely see a reduction in value as the affected location becomes less desirable. Local agriculture and nearby industry will also be affected, as they will no longer be able to utilise the water body for inputs and this will likely lead to an increase in costs. Figure 18 below provides a graphic representation of the economic impacts that are discussed in this research report.

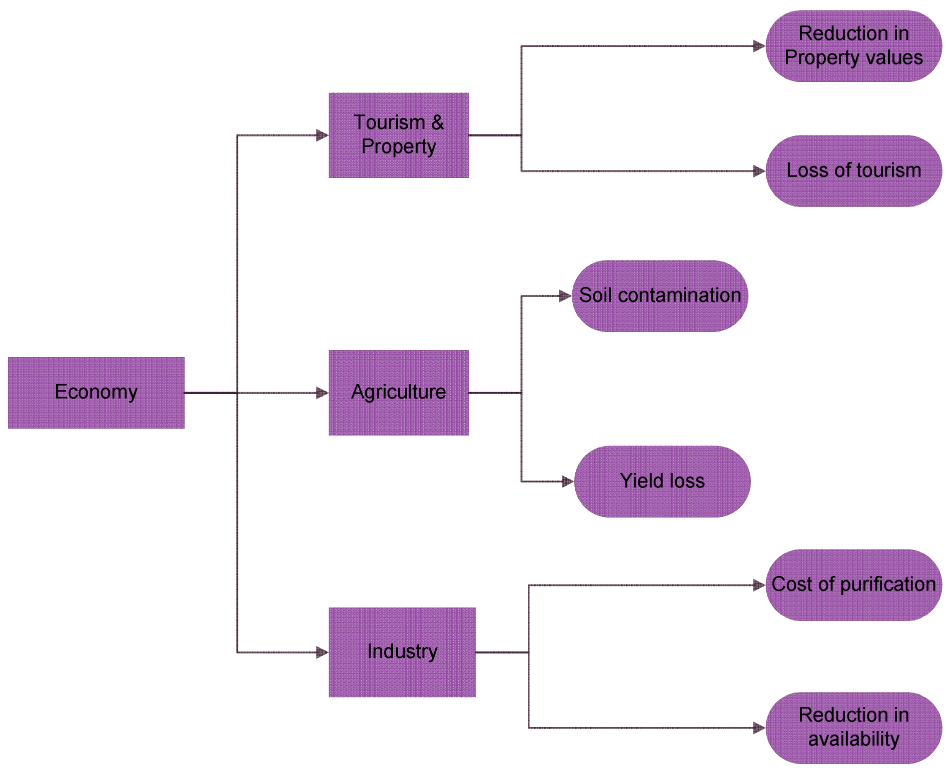


*Figure 17: Summary of externalities associated with poor waste water treatment (source: researcher)*

### *4.2.3.1 Tourism and property*

Water pollution and its associated odours and unsightliness will affect the amenity value of the receiving water body (Schwermer, 2002). Much of South Africa's local and international tourism value is considered to be in environmental tourism and, if the aquatic ecosystems that individuals wish to visit become deteriorated, the revenue and associated tourism economy will suffer (Matthews & Bernard, 2015). Likewise, property values can become affected by poor water quality, as previously prestigious waterside properties become undesirable due to their location adjacent to a polluted and potentially hazardous water body (Matthews & Bernard, 2015). The reduction in waterside property values or tourism returns can be evaluated with market-related factors, as these have direct financial implications. The difficulty would be to determine the pollution load required to trigger a decrease in the value of the water body amenity. This will differ from water body to water body, based on a number of factors such as dilution and distance from the wastewater outfall (Brouwer & Stavros, 2012).

**Measureable criteria:** Location specific but directly linked to the extent of water pollution.

#### *4.2.3.2 Agriculture*

The two main ways in which wastewater effluent can impact the agricultural sector is through soil contamination or when the level of water pollution makes the water source unusable for irrigation (Dillon & Schrale, 1993). Soil contamination can result if water from the polluted water body is used without an awareness of the danger posed. This is particularly of concern for treatment plants that have fluctuating water quality results, as a temporary breakdown at the treatment plant could result in contaminated agricultural land, a challenge that can only be overcome with time and resources. The impact of soil contamination can be analysed by measuring the change in productivity of the field; should the impacts be minor, or should the land become unviable for crop production, the value lost per annum due to crop failure van be used to value this externality (Hussain, Raschid & Hanjra, 2001). This means that direct market prices can be used to value the impact.

**Measurable criteria**: Location specific but directly linked to the extent of water pollution.

#### *4.2.3.4 Industry*

Impacts of ineffective wastewater treatment on industry will, like agriculture, be linked to the impact of wastewater effluent on the water quality of a water body. Industries that have gained permission to use water directly from the water body will be affected by a decrease in water quality, as this water may become unusable for industrial processes or require additional treatment. This will increase operational costs and can have adverse effects on business viability, which can in turn lead to job losses and other negative impacts on the local economy (Hernández-Sanch et al., 2015). The impact of the externality can again be valued through standard market drivers, as the impact of effluent contamination will have direct measurable impacts on the costs of industry, such as additional input costs or additional water treatment. Again, the primary measure to evaluate the impact on local industry would be the extent of water pollution of the water body used as the wastewater treatment outfall.

**Measurable criteria**: Location specific but directly linked to the extent of water pollution.

#### *4.2.3.5 Industrial impact summary*

The externalities associated with economic impact on industries linked to ineffective wastewater treatment in terms of measurable criteria for evaluation can be seen in Table 11 below.

| Aspect | Impact | Variable | Measure |
|---|---|---|---|
| **Economy** | Tourism and property | Directly linked extent of water pollution | No test possible |
| | Agriculture | Directly linked extent of water pollution | No test possible |
| | Industry | Directly linked extent of water pollution | No test possible |

*Table 11: Summary of economic impact influences (source: researcher)*

Although there is no direct laboratory test to measure the variable effect on the economic aspects, there is a direct link to water quality and therefore the water quality test results can be used to speculate the impact on the economic externalities.

### 4.4 Conclusion: Evaluation matrix

This chapter has explored the various economic externalities related to ineffective wastewater treatment in the literature and for each of the impacts identified a measure that should be included in a wastewater treatment plant evaluation process. These values will enable any cost-benefit analysis of wastewater treatment systems to be conducted with a more inclusive baseline and therefore should be part of a comprehensive evaluation system. The resulting evaluation framework can be seen in the table below; this table will be used to evaluate the existing wastewater treatment plant assessment methodology in the following chapter.

| Aspect | Impact | Variable | Measure |
|---|---|---|---|
| **Environment** | Water pollution | Groundwater contamination | Nitrates |
| | | | Chemical content |
| | | Eutrophication | TSS |
| | | | Nitrogen |
| | | | Phosphorous |
| | | Biodiversity loss | pH |
| | | | Temperature |
| | | | TDS |
| | | | BOD |
| | | | COD |
| | Green House Gas emissions | $CO_2$ equivalents | $CH_4$ released |
| | | | $CO_2$ released |
| | | | NO2 released |
| **Health** | Mortality | No of deaths | Pathogen load |
| | Opportunity cost | No of patients admitted | Pathogen load |
| | Health system burden | No of patients admitted | Pathogen load |
| **Economy** | Tourism and property | Directly linked to extent of water pollution | No test possible |
| | Agriculture | Directly linked to extent of water pollution | No test possible |
| | Industry | Directly linked to extent of water pollution | No test possible |

*Table 12: Evaluation table for existing wastewater management tools (source: researcher)*

# Chapter 5

# The methods and parameters currently used to evaluate waste water system effectiveness

## 5.1 Introduction

This chapter identifies the gaps in the existing assessment and management tools utilised on South African wastewater treatment plants. This was achieved by applying the externality framework developed in Chapter 4 onto the existing PAT assessment tool. An example PAT assessment was sourced as a form of secondary data from Water Group SA in order to achieve this understanding and evaluation, the details of which can be found in Appendix C. Before this analysis is presented, a brief overview of how this tool works and its current performance within the sector is provided.

## 5.2 Existing evaluation methodology at the time of the study

At the time of this study, the Green Drop assessment reports were the primary method through which the performance of wastewater treatment systems was monitored and disseminated nationally. The reports were compiled every alternate year by the Department of Water Affairs and were based on the results of the Progress Assessment Tool (PAT), which was issued to each treatment plant annually. Although the Green Drop report was only assembled every second year, the PAT assessment was conducted and reported annually in order to monitor performance and therefore, the PAT assessment constitutes the primary focus of this study.

An example PAT assessment tool was sourced from Water Group SA to be used as secondary data on which to conduct the evaluation. The PAT assessment involves an intelligent Excel spreadsheet that requires basic input from the operations staff in order to determine a final compliance percentage, namely the percentage compliance as quoted in the Green Drop report. Any result below 90% is indicative of a breakdown in at least one aspect of a site's operations. The three main risk areas covered by the PAT assessment tool are that of operational capacity, effluent quality and available technical skills. These would have differing requirements based on the treatment methodology adopted and this was therefore the first requirement of the PAT assessment tool. The cumulative risk rating (CRR) was the value used to indicate the level of concern for each plant and this was quantified based on the scores of each of the three main functional areas, which are: capacity (A & B), technical skills (C) and quality (D). The relationship between these is expressed in the following equation:

**Cumulative risk rating [CRR] = (A x B) + C + D**

The method through which the three main areas were assessed in the PAT assessment is discussed in the sections to follow.

### 5.2.1 Functional areas of the PAT assessment

#### *5.2.1.1 Capacity*

The size of the plant (A) has an impact its pollution potential of the plant and, in the PAT assessment, this was measured and scored according to the methodology below.

| Design capacity (Ml/d) | | Weighting Factor |
|---|---|---|
| **CRR design capacity rating [A]** | >400 | 7 |
| | >200 to 400 | 6 |
| | >100 to 200 | 5 |
| | >50 to 100 | 4 |
| | >20 to 50 | 3 |
| | >5 to 20 | 2 |
| | < or = 5 | 1 |

*Table 13: Extract from the Randfontein PAT assessment (design capacity assessment) (see Appendix C)*

Linked to the size of the plant was the average operational capacity. The design capacity was the maximum flow that the plant could withstand before the effectiveness of the process was diminished. If the operational capacity exceeded the design capacity (B), this was indicative of the increased risk that the effluent quality would be negatively impacted. The PAT assessment tool quantified this as a percentage, with 100% representing a maximum flow and therefore a very high risk of failure. The scoring of capacity exceedance listed capacity factors between 100 and 150% as only second highest rating factor (see Table 14).

| Capacity Exceedance (%) | | Weighting Factor |
|---|---|---|
| CRR capacity exceedance rating [B] | >150% | 5 |
| | >100 - 150% | 4 |
| | >50 - 100% | 3 |
| | >10 - 50% | 2 |
| | 0 - 10% | 1 |

*Table 14: Extract from the Randfontein PAT assessment (capacity exceedance assessment) (see Appendix C)*

### *5.2.1.2 Technical skills*

The next aspect investigated by the tool was a qualitative review of the skills available for operational management present at the plant. Regulation 17 of the South African Water Services Act (108) of 1997 was published in order to ensure that there were sufficient competent individuals at each water treatment facility. This required there to be a minimum of one Supervisor, four Process Control Officers and four Maintenance Team members. Facilities were given scores based on the percentage of staff they had in compliance with Regulation 17, in order to get a total percentage score out of 300%. These scores are then agglomerated in order to determine a score for (C).

| | Verification of Item 4 by the Assessor and Moderator | | | | |
|---|---|---|---|---|---|
| | Actual no. | Required no. as per Reg. 17 | Actual no. compliant | Compliance status | % Compliance |
| **Supervisor** | 1 | 1 x CV | 0 | No | 0% |
| **Process Control Officer** | 10 | 4 x Class IV | 0 | No | 0% |
| **Maintenance Team** | 3 | 4 | 3 | Partial | 75% |

| Technical Skills Compliance (Reg 17) | No | 75% |
|---|---|---|

*Table 15: Extract from the Randfontein PAT assessment (technical skills assessment) (see Appendix C)*

| CRR weighting factor (WF) for the technical skills rating | | WF |
|---|---|---|
| Technical skills rating [C] | Superintendent + Process Controllers + Maintenance Team | 1 |
| | Superintendent + Maintenance Team but no Process Controllers | 2 |
| | Process Controllers + Maintenance Team but no Superintendent | |
| | Process Controllers + Superintendent but no Maintenance Team | |
| | Superintendent but no Maintenance Team + no Process Controllers | 3 |
| | Process Controllers but no Maintenance Team + no Superintendent | |
| | Maintenance Team but no Superintendent + no Process Controllers | |
| | No Superintendent + no Process Controllers + no Maintenance Team | 4 |

*Table 16: Extract from the Randfontein PAT assessment (technical skills assessment) (see Appendix C)*

### *5.2.1.3 Quality*

The final area evaluated was the effluent quality. This was measured against the three main pollution potential requirements, namely microbiological, physical and chemical.

| | |
|---|---|
| **Microbiological** | E. coli/faecal coliform |
| **Physical** | pH |
| | Electrical conductivity |
| | Suspended solids |
| **Chemical** | Ammonia as nitrogen |
| | COD |
| | Nitrate/nitrite as nitrogen |
| | Ortho-phosphate as phosphorus |

*Table 17: Extract from the Randfontein PAT assessment (quality assessment) (see Appendix C)*

A year of sample results were measured for compliance and the samples that were deemed compliant to standards were measured as a percentage. Should the number of compliant samples be fewer than 90%, the aspect was considered to be a high risk area and scored accordingly, with a value of 1 for a maximum score of 1.

| No. of non-compliant parameter failures | Weighting Factor |
|---|---|
| **CRR effluent failure rating [D]** | 8 |
| | 7 |
| | 6 |
| | 5 |
| | 4 |
| | 3 |
| | 2 |
| | 1 |
| | 0 |

*Table 18: Extract from the Randfontein PAT assessment (quality assessment) (see Appendix C)*

There was no weighting on effluent quality results, making it difficult for plant operators to understand which performance results should be of primary concern. Each of the effluent quality results is weighted equally on each of the chemical, physical and microbiological aspects, making it impossible for operators to understand at a glance the main areas of concern. In addition, the score was simply the percentage of tests passed; therefore, the results were not indicative of the actual plant performance or its compliance with the requirement for weekly testing. Interviewees A and C also indicated that there was opportunity to edit the results in the current format of the PAT and, although moderated, there was always the chance that the plant managers may edit the results in order to achieve a higher rating.

### *5.2.1.4 PAT results*

Once obtained, the individual scores for A, B, C and D were inserted into the formula to get the total CRR rating for the plant. The maximum score possible for any plant was 22 points and the percentage risk was allocated as the score percentage value of 22 (% CRR/CRRmax).

These scores were thereafter documented in the Green Drop report and formed part of a national dataset of wastewater plant performance monitored annually by the Department of Water Affairs and Sanitation. The scores were also issued back to each treatment plant on a score sheet that was intended to be an indicator of progress and to highlight areas where improvement was required. Should the performance of a particular plant be particularly poor, a Waste Water Risk Abatement Plan (W2RAP) was required to be compiled and issued to DWS for approval.

### 5.2.2 Performance evaluation

In order to evaluate the performance of the Green Drop assessment, a review of the progress made with the implementation of the incentive-based system since its inception in 2008 was undertaken in this study. As the 2015 results had not been made available at the time of the study, the 2014 results were utilised for analysis. The 2014 progress report illustrated an average decrease in performance of plants nationally, across almost all the evaluation criteria, since the inception of the programme. This would possibly explain the reluctance by the Department to release the results into the public domain.

The Green Drop risk categories were defined by the CRR/CRR max results of each Green Drop PAT assessment. The number of plants that annually fall into the risk categories of low, medium, high and critical risk are released with each Green Drop report. The number of plants that fell into each category for the years 2008, 2011, 2012, 2013 and 2014 were then extracted from the Green Drop reports and plotted by the researcher in order to visually interpret the performance trend resulting from the Green Drop assessment programme. When the risk profile of all the plants evaluated annually from 2008 to 2014 was plotted on a graph, the rapid decrease in performance became clearer. The total number of plants assessed over the years has remained relatively constant at around 820 per annum, with the greatest number of plants (848) assessed in the inception year, 2008.

| Year | 2008 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| **No. plants** | 848 | 821 | 831 | 824 | 824 |

*Table 19: Number of plants assessed over the period*

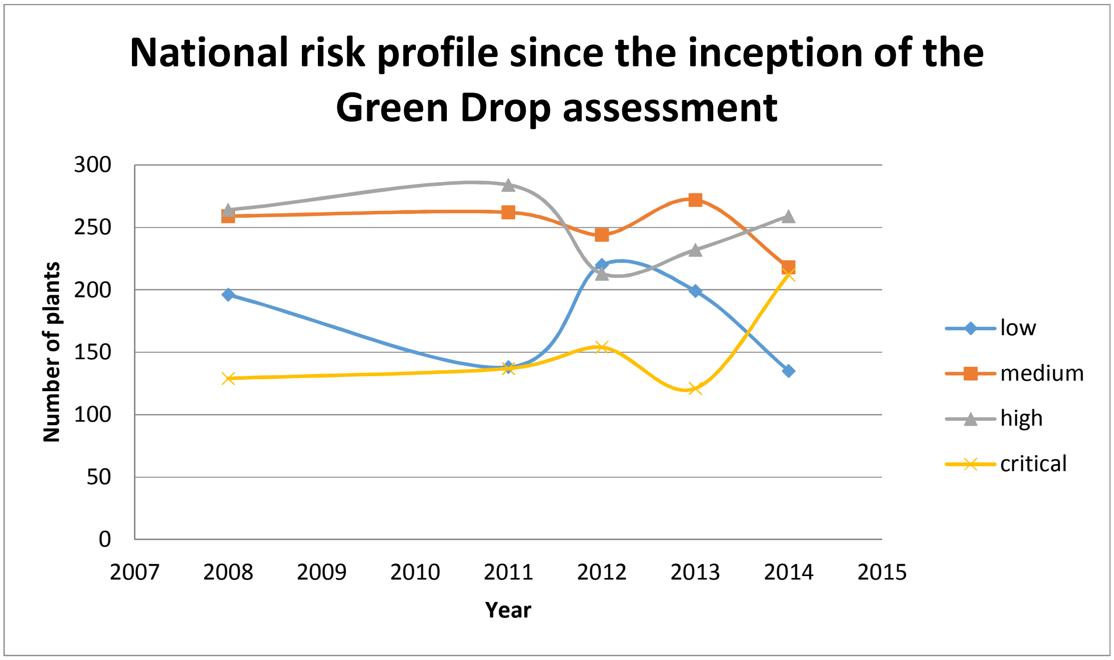


*Figure 18: Graphical illustration of the declining performance of plants nationally (source: researcher)*

From 2013 to 2014, the number of plants that have been evaluated as critical increased from 121 in 2013 to 212 in 2013, which indicates a 75% increase in one year. The high risk plants follow a similar trajectory with, despite a noticeable decrease from 284 in 2008 to 213 in 2012, an average of a 10% increase in number of plants in this category being seen annually.

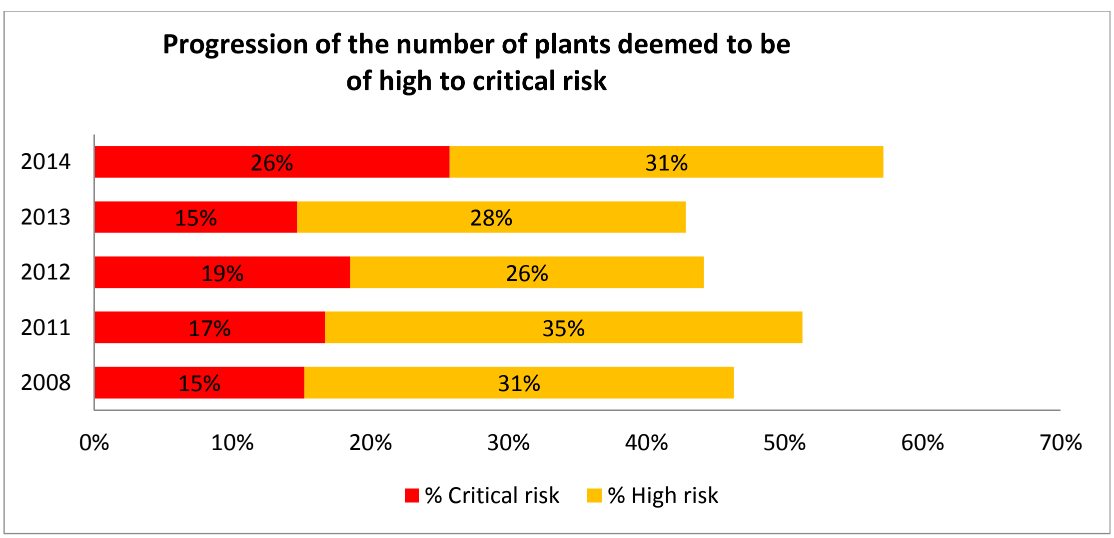


*Figure 19: Annual percentages of plants deemed to be of immediate concern (high to critical risk) (source: researcher)*

Although the performance of the plants does not appear to be improving over the years, it should be noted that according to Interviewee C, this can be attributed to the increasing requirements of each iteration of the Green Drop report. She revealed that the first Green Drop reports required very little from the municipalities and focused on seemingly basic questions such as:

- Do you know that you have a wastewater treatment works?
- Do you know where it is?
- Do you know what the technology in it is?
- Do you monitor it?

As the base from which the assessment was starting was so low, it involved very broad scoring in terms of A, B, C, and D that left lots of room for interpretation within the scoring categories. It is, however, difficult to then measure the effectiveness of the tool as a method of incentivizing improvements to effluent quality, as this was a constantly moving target.

As the official 2015 Green Drop assessment did not take place, Afriforum (an NGO focused on minority rights) conducted E. coli testing on the effluent of 58 wastewater treatment plants. They were refused access to many of the plants but the results from those where they were granted access showed E. coli present at volumes higher than the limit of 1000 units per 100ml at 26 out of the 58 systems they measured (Afriforum, 2015). At two plants in the Free State, the results were 1000 times the allowed amount, indicating a near total breakdown of the plant's effectiveness.

Although this sample is far smaller than the 824 measured under the national Green Drop report, it is an indicator that the results for the 2015 report would not have shown massive improvement over the 2014 results, if it had been conducted. If 45% of the plants that allowed access showed poor performance, it can be assumed that the plants which refused access were more likely to have emerged with far poorer results. As the performance of the wastewater plants nationally is a reflection on the effectiveness of local and national governance, there is pressure for the reports to show results that do not portray the Department in a negative light. Therefore, there are concerns that reports may be held back or the results doctored in order to mitigate embarrassment for these government departments.

## 5.3 Economic externality evaluation of the PAT assessment tool

From the results of the performance evaluation for the Green Drop progress report, it is evident that the methodology of evaluating the performance of wastewater treatment plants, despite being technically comprehensive, is not achieving the objective of improving the effluent quality and performance of South African wastewater plants. In order to use economic externalities as a motivation for improved performance, one needs to ensure all the measurable criteria are assessed in the evaluation methodology used with South African wastewater plants. In order to determine this, the evaluation framework developed in Chapter 4 will be used on the PAT assessment in order to identify any areas of potential improvement. The table below illustrates the areas included and highlights the measureable criteria outstanding.

| Aspect | Impact | Variable | Measure | Included in PAT |
|---|---|---|---|---|
| Environment | Water pollution | Groundwater contamination | Nitrates | Yes |
| | | | Chemical content | Partially |
| | | Eutrophication | TSS | Yes |
| | | | Nitrogen | Yes |
| | | | Phosphorous | Yes |
| | | Biodiversity loss | pH | Yes |
| | | | Temperature | No |
| | | | TDS | Yes |
| | | | BOD | Yes |
| | | | COD | Yes |
| | Greenhouse gas emissions | $CO_2$ equivalents | Operational volumes | Yes |
| | | | Treatment methodology | Yes |

| | | | | |
|---|---|---|---|---|
| | | | Energy consumption | No |
| **Health** | Mortality | No of deaths | Pathogen load | Partially |
| | Opportunity cost | No of patients admitted | Pathogen load | Partially |
| | Health system burden | No of patients admitted | Pathogen load | Partially |
| **Economy** | Tourism and property | Directly linked to extent of water pollution | No test possible | No |
| | Agriculture | Directly linked to extent of water pollution | No test possible | No |
| | Industry | Directly linked to extent of water pollution | No test possible | No |

*Table 20: PAT evaluation according to externality criteria (source: researcher)*

### 5.3.1 Gaps identified in existing wastewater evaluation methodologies

The primary section in the PAT relevant to externality evaluation is that pertaining to effluent water quality and capacity. The eight tests conducted under the quality section of the PAT are listed below

1) E. coli/faecal coliform
2) pH
3) Electrical conductivity
4) Suspended solids
5) Ammonia as nitrogen
6) COD
7) Nitrate/nitrite as nitrogen
8) Ortho-phosphate as phosphorus

Although these tests cover many of those needed for an economic externality evaluation, the PAT assessment only indicates the percentage of the tests that pass the required standard rather than the actual results. This means that, even for those aspects included, edits to the existing format will be required in order to utilise the data for an economic analysis.

*5.3.1.1 Health*

The E. coli test is the only pathogen test conducted on wastewater under the PAT assessment. As mentioned in previous chapters, although this is commonly understood to be the major concern, there are a number of other pathogens and viruses that should be tested for in order to understand the risk to human health. The pathogen and viral load will, combined with further research as to how the local community interacts with the water body, enable estimates to be made of the burden on the health care system and individuals. Therefore, additional tests should be added to that of the E. coli content if one wishes to be able to adequately estimate the pathogen load of a receiving water body.

*5.3.1.2 Environmental impacts*

Although nitrates are tested for in terms of tests 5 (ammonia as nitrogen) and 7 (nitrate/nitrite as nitrogen), unless the actual nitrate volumes are known, the calculation of their impact on groundwater evaluation will be unknown. Likewise, although the COD test is indicative of chemical content, it does not drill down into the exact chemical composition of the effluent and will therefore not be able to identify the high risk chemical attributes such as mercury content or other heavy metals that pose a risk to groundwater aquifers.

Eutrophication calculation requires the TSS, nitrogen, and phosphorous test results to be included in order to attain a good indication of the eutrophication potential of the wastewater effluent. The costs of this will still need to be calculated through environmental economic methodologies. Likewise, a majority of the tests relating to biodiversity loss are included in the PAT assessment but their actual results data is missing in terms of being able to estimate the externality of cost of the resulting biodiversity loss. The temperature of the effluent is also not included and would need to be measured to determine if there was a temperature variance between the receiving water body and that of the effluent released from the wastewater treatment plant.

#### *5.3.1.3 Industry*

As indicated, the impact of ineffective wastewater treatment on local industry is difficult to estimate from a performance assessment tool. If one were to explore this in greater detail, area-specific studies would need to be done in order to identify the number of potentially impacted businesses, farms, properties and recreational facilities. Then, based on the extent of water pollution evaluated previously in the tool, estimates of the economic impact of this can be conducted.

## 5.4 Conclusion

It is clear from the performance and economic evaluation conducted on the PAT assessment that there was substantial room for improvement in the Green Drop and PAT assessment methodology at the time of this study. As this report is primarily an assessment of how economic externalities can be utilised to drive change, the aspects included in the PAT pertaining to skills and technical expertise have not been explored in detail. However, it is still necessary to understand the context in which the tool worked in order for relevant recommendations to be made. The following chapter will attempt to provide insight into the operational context of wastewater evaluation tools in South Africa, as well as providing the economic methodologies that can be used in the identified gaps in the existing assessment tool.

# Chapter 6

# Economic methodologies that can be utilised to develop a framework that will enable municipalities to evaluate the true cost of ineffective wastewater systems

## 6.1 Introduction

This chapter will attempt to provide economic methodologies to evaluate the gaps in the PAT assessment identified in Chapter 5. In addition, the operational context in which wastewater evaluation techniques are utilised is explored, as an understanding of the status quo will enable useful recommendations to be made. Wastewater treatment plants are by and large publicly managed infrastructure and therefore, the political and municipal environment will play a vital role in the effectiveness of any evaluation tool.

## 6.2 Gaps identified in PAT assessment

Measurable data that can be utilised to value the economic impact of wastewater externalities were identified in Chapter 5. This information can be used in economic methodologies to monetise the impact of ineffective wastewater treatment with respect to health, environmental and economic influences.

### 6.2.1 Health

#### *6.2.1.1 Mortality*

There are a number of economic methods that estimate the economic value of mortality caused by contact with effluent. As no market values exist for the value of life, non-market valuation techniques must be used to evaluate this. One method would be to estimate the productivity lost due to the loss of an economically active individual over the remaining average lifespan (Hussain, Raschid & Hanjra, 2001). However, this is a contentious method as it excludes many of the additional aspects of value an individual's life can contribute. An alternative could therefore be to use the willingness to pay premise, in which a combination of the individual's willingness to pay in order to save their own life and the willingness to pay for others can be assessed. The formula utilised in order to estimate the value of life through economic contribution as detailed by Hussain et al. (2010) is stated as follows:

$$PV_{ml} = \sum \{[AN_i - C_i)/(1+d)^i]*[MR_{ij} * P_{ij}] + \ldots + [AN_n - C_n)/(1+d)^n] * [MR_{nz} * P_{nz}]\}$$

*Where:*

*AN is average per capita income per year*

*C is the average per capita consumption per year*

*MR is the mortality rate*

*P is the total population in a given community or project area*

*n is the average number of years of remaining life period with i = 1 to n*

*z is the number of population cohorts with j = 1 to z*

#### *6.2.1.2 Opportunity cost*

Opportunity cost due to illness can be economically assessed using the 'damage function' approach by associating levels of contamination with health impacts (Brouwer & Stavros 2012). The cost of these impacts on the health care system can be directly measured but the economic burden due to lost productivity and output would not be reflected under that approach and does not account for other social and economic costs attributed to the illness of an individual.

The loss of productivity using the opportunity cost principle can be estimated by using the number of restricted days (sick days, time off work, etc.), the earning potential of the individual and the disease prevelance (Hussain et al., 2010). For those who are not economically active, this can be harder to determine but can be considered by adjusting the wage aspect of the calculation. The formula with which to estimate the productivity loss due to illness is as follows:

$$PV_{pl} = \sum \{(SD_i * WR_i * ID_{ww} * TP_i)/(1+d)^i\} + \ldots + \{(SD_n * WR_n * ID_{ww} * TP_n)/(1+d)^n\}$$

*Where:*

*SD is the number of sick days attributed to wastewater use per person per year*

*WR is the average wage rate*

*n is the total period of employment in years with i = 1 to n*

*IDww is the incidence of diseases or percent of population affected*

*TP is the total population in a given community or project area* *d is the discount rate* (Hussain, Raschid & Hanjra, 2001)

#### *6.2.1.3 Medical system costs*

Given that market prices exist for this component of the framework, conventional market-based modelling can be done to assess the health system burden due to effluent-related disease. The direct medical costs incurred would include the facility cost (hospitalisation, clinic, etc.), the medication, the professional service cost and the diagnostic test costs. The medical costs can be estimated through health economic methodologies as detailed in the calculation below:

$$PVMC = \sum \{ (CC + MC + PC + OC)i\ (IDww * TPi\ )/(1+d)i\ \} + \ldots\ldots + (CC + MC + PC + OC)n\ (IDww * TPn\ )/(1+d)n$$

*Where:*

*CC is the cost of medical consultation*

*MC is the cost of medicine*

*PC is preventive cost*

*OC are the other costs*

*n is the total period of employment in years with i = 1 to n*

*IDww is the incidence of diseases or percent of population affected*

*TP is the total population in a community or project area*

*d is the discount rate* (Hussain, Raschid & Hanjra, 2001)

The case study below provides an example of the costs that can be expected per incident stemming from contact with a water body contaminated by wastewater effluent.

**Case Study**

MacIntyre & de Villiers (2010) conducted a survey of 77 South African individuals impacted by diarrhoeal disease in 2005, in order to determine the economic burden at a tertiary level hospital in Gauteng.

Although the study was based on a small urban sample, the results investigated the medical costs and opportunity costs due to the disease most closely linked to wastewater effluent contamination.

*Opportunity costs*

*The financial losses were difficult to calculate, because only 13 caregivers (17%) were formally employed. Of these, four reported that they would lose wages as a result of the child's illness. The remainder stated that wages would not be deducted provided they had proof of their hospital visit. The children's illness affected all but one carer financially. The majority (70%) met the expenses by cutting spending in other areas, while 20% borrowed money. The mean total out-of-pocket cost to the caregivers for the diarrhoeal episode was R100.00, with a maximum of R650.00. Previous treatment contributed most to this cost (71%), followed by transportation costs (20%). Other expenses incurred during the illness were minimal.*

*Medical costs*

*The average hospital stay for patients positive for Rotavirus was six days, with total facility and professional costs totalling R6 565.00. Diagnostic costs varied but averaged at R381.00, with medication and treatment averaging R152.83.*

*They estimated the mean cost to the hospital per inpatient admission to be approximately R7 079.00 for the combined 2004 and 2005 samples.*

### 6.2.1 Environmental impact

#### *6.2.1.1 Water pollution*

Water pollution is an aspect that particularly cannot be valued by direct market drivers because, even though some aspects will have market-related impacts, the number of associated externalities makes it difficult to evaluate impact purely with market-related values. Eutrophication is a primary concern related to wastewater effluent and, although studies have not been done locally to determine the economic cost of the related loss of biodiversity and deterioration of water sources for the South African economy, studies in the USA reported that the cost of eutrophication exceeded $2.2 billion in 2009 and $160 million in Great Britain in 2003 (Matthews & Bernard, 2015).

when looking at industries such as agriculture and fisheries, the ‘change in productivity’ methodology can be utilised in order to determine the economic losses attributed to water pollution (Hussain, Raschid & Hanjra, 2001), whilst direct market values can be used to evaluate the loss of water resources available for potable supply. However, the ‘loss of species and amenity’ value is better assessed through the willingness to pay principle. As the extent and number of impacts associated with water pollution will vary from location to location, it is recommended that plant-specific wastewater treatment studies be conducted in order to accurately reflect the externalities’ economic impact.

*6.2.1.2 Greenhouse gas emissions*

In the process of wastewater treatment carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) are released into the atmosphere. These have global warming potential and can be converted to $CO_2$ equivalents from which a carbon tax value can be attributed. The $CO_2$ equivalent of $N_2O$ is 298 times that of $CO_2$ and $CH_4$ is 25 times that of $CO_2$ (Chetty & Pillay, 2015), meaning that even small quantities of these emissions can have serious effects on the environment, and on climate change in particular.

Chetty and Pillay (2015) have developed a calculator that calculates the $CO_2$ equivalent pollution potential of different wastewater treatment methodologies and that only requires basic input values that are easily accessible by operations staff. This will enable the easy determination of the kg$CO_2$ equivalents produced by the plant, which can thereafter be multiplied by the carbon tax in order to get a market-related value for greenhouse gas emissions. The impact of greenhouse gas emissions, although an indirect cost, can in fact be measured according to market methods, as this has already been extensively researched and analysed with regard to energy and its impact on climate change.

The two most common methods of imposing the externality costs of GHGs is through the implementation of a carbon tax or a carbon offset policy. The carbon tax imposes the cost per ton of $CO_2$ emitted directly onto the business in order to incentivise the shift to more carbon-friendly processes and technologies, whilst the carbon offset approach allows polluting industry to support environmentally positive industries by buying what is called carbon credits. South Africa has chosen to implement the carbon tax rather than a carbon offset programme in order to ensure that the market drivers are there to direct industry towards making more sustainable choices. The white paper on carbon tax has been developed and is widely understood to come into effect in 2017.

The value assigned to carbon in South Africa is largely anticipated to be R120/ton (South Africa National Treasury et al., 2013). Although this is the value that would be applied in market analysis, it is a value less than the true externality cost which has been researched and released in the 2016 draft Integrated Energy Plan at R0.27/kg (2012 exchange rate) or R270/ton (IEP 2016). This is due to the fact that the carbon tax is based not on the actual externality cost but rather on the market drivers deemed to be adequately addressed in order for South Africa to meet the carbon reduction goals commitment, especially under international treaties on climate change. The case study below provides an example of the costs that could be incurred by wastewater plants should the carbon tax be implemented.

**Case Study**

In July 2013, Chetty and Pillay (2015) conducted a study on the $CO_2$ emission potential of the KwaMashu wastewater treatment facility. They investigated the actual $CO_2$ equivalent emissions and thereafter analysed savings possible through the implementation of a biogas to electricity component to the plant.

By using the standard processes, the KwaMashu plant was contributing 2 389 806kg $CO_2$ equivalents/month. This would translate to R287 857.00 per month in carbon tax should the R120/ton be implemented. The study went on to further establish that, through the implementation of a biogas digester, the $CO_2$ emission potential of the plant could be reduced by 48% to 1 235 653kg $CO_2$ equivalents/month.

**TABLE 9**
**Total and scope-based emissions: KwaMashu WWTW**

| Emission category | Current emissions in $CO_2$ eq. (kg/month) | Option 1 emissions in $CO_2$ eq. (kg/month) | Reduction in emissions (%) |
|---|---|---|---|
| Total emissions | 2 398 806 | 1 235 653 | 48 |
| Scope 1 emissions | 1 534 246 | 716 049 | 53 |
| Scope 2 emissions | 842 360 | 509 720 | 39 |
| Scope 3 emissions | 22 199 | 16 887 | 24 |

### 6.2.3 Industry

A reduction in the water available for use in industrial processes or the need for additional purification will have rand value implications for the input costs of businesses and can therefore be used to value the externality directly.

#### *6.2.3.1 Property*

One method that can be utilised to estimate the decrease in property values is the following:

*PVs = ∑ {Pi A-Pwi A/(1+d)i } +…..+{Pn A-Pwn A / (1+d)n }*

*Where:*

*PVs is the present value of differential in sale value*

*P is the market price of unit of land unaffected by wastewater*

*Pw is the market price of unit of land affected by wastewater*

*A is the area of land in a given community/project area*

*d is the discount rate*

*n is the total number of years of measurement beginning from i = 0 - n.* (Hussain, Raschid & Hanjra, 2001)

#### *6.2.3.2 Agriculture*

The impact of water pollution can also be measured directly through market pricing as two options are available for farmers should a water body become too polluted for agricultural use. One would be to conduct additional purification of the water in order for it to be utilised; the additional cost can be priced by valuing the cost of the purification process. The alternative would be to purchase the water from an alternative source, in which case the associated replacement value could be utilised to price the externality.

## 6.3 Current operational context

A number of key themes came up during the key informant interviews, most of which pertain to the environment in which South African wastewater systems operate. The sections below detail the concerns raised by professionals within the sector. This is an aspect that cannot be undervalued, as it relates to the operational environment of any tool and provides insights that cannot be achieved through literature or secondary data.

### 6.3.1 Governance

All of the key informant interviewees reiterated the highly politicised environment surrounding water and wastewater services. They all believe that the influence of national leadership on municipal spheres of service delivery is a major obstacle to the future of effective and high quality wastewater management. In addition, there seems to be a breakdown in accountability between the various levels of governance. Although national government is responsible for the issuing of guidelines and performance requirements, local governance at municipal level is responsible for the day-to-day operations of the plants. One retired official indicated that the Department of Water Affairs had no authoritative means by which to make changes at plants in which problems were identified and could merely use guideline documents and Green Drop reports as methods by which to highlight areas in which improvement is encouraged (Kings, 2015a).

This is then compounded by issues of corruption with regard to the awarding of operations and maintenance tenders, which leads to degradation of the plant's operations and maintenance (SAHRC, 2014). An example of this attitude was reported in another *Mail and Guardian* interview in which a treatment plant employee was quoted as saying, "Nobody cares what we release from our works, and nobody checks. We get a paycheque regardless of quality" (Kings, 2015a).

Interviewee B also expressed frustration at the policy requirements of the Municipal Finance Management Act (56) of 2003, which he believed to be hindering the ability of local governments to adequately and timeously maintain their treatment works. Although they had managed to get the response time for the notification of required maintenance or a breakage at the plants, the Municipal Finance Management Act (56) of 2003 would mean that for parts that were valued at over R20 000.00 (which would include most of the parts on a wastewater treatment facility), a full tender process would have to be undertaken. This would result in delays of months as the procedures were followed for what was often simply an off-the-shelf item. The resulting delays mean that often systems would be forced to bypass this aspect of treatment and then commonly, it would just remain as this way indefinitely.

The primary method through which the public would become aware of the inadequacies of plant performance and the associated risks would be through the Green Drop reports. The 2014 report was one such report in which allegations of withholding of information were reported. A municipal official in Polokwane was interviewed by the *Mail and Guardian* newspaper in 2015 with regard to the speculation surrounding the delay in the release of the Green Drop report and was quoted as responding: "What you are essentially doing is giving people an in-depth list of your failings and basically asking them to link these to deaths; you would be crazy as government to hand over something so damning" (Kings, 2015b).

The fear of potential legal action against the DWS by a current opposition party, the Democratic Alliance (DA), was what resulted in a summarised version of the report being released. This was the last Green Drop report to be published in the public domain, to date. It should be noted that key informant Interviewee C confirmed that there was a complete halt on the Green Drop reporting programme after the last progress report of 2014. No assessments or quality control work have been done on any plants since then but a decision was taken at the end of January 2017 to resume the programme in the new financial year. As the Green Drop reports are the primary method of monitoring and information dissemination regarding wastewater in South Africa, this study attempted to substantiate the effectiveness of the methodology with the goal of driving performance improvements in the sector.

### 6.3.2 Skills levels within municipalities

All of the interviewees expressed concern around the level of competence at both the municipal management level and at plant operator level. Interviewee C said that despite efforts made and programmes in place to upskill operators, the results of such training was deemed a failure. She believes that future programmes should be directed at managers and supervisors to instil a top-down learning environment. Interviewee B also expressed frustration but attributed the lack of interest and understanding by plant employees to their educational background and recommended that employees have a university degree if they are to manage municipal infrastructure. Realistically, given the shortage of engineers and technically trained individuals in South Africa, the feasibility of this suggestion is questionable. One way to achieve this could be to make employment in the government sector more attractive to university graduates, most of whom find employment in the private sector. If training programmes were to be made available for supervisors, it is essential that the method through which the information is transferred is adapted. Wastewater treatment is a complicated field of study, and although the concepts can easily be relayed in an understandable real world context, there is a tendency to focus on the highly technical and mathematical, which may drive individuals away.

### 6.3.3 Feedback timeframes

Another area of concern raised by all the interviewees is that of the frequency of the Green Drop reports and the delays resulting from the Municipal Finance Management Act (56) of 2003 on plant maintenance. The Green Drop report assessment has not been conducted reliably since its inception in 2008 and has recently been suspended indefinitely. This lack of consistency makes it difficult for plant operators and managers to validate the effort expended in attaining a Green Drop certification, especially if there is uncertainty as to whether or not the process will be implemented for that year.

No Green Drop or PAT assessments have been conducted since 2014 and although Interviewee C indicated that the Green Drop report will be reactivated in 2017, the three-year hiatus will certainly have an impact on any gains made previously. Three years is a substantial amount of time without monitoring and there would certainly have been staff turnover in that time. The results of the 2017 report will, however, assist in showing if the annual audits are in fact the optimal way to encourage performance. Interviewee C anticipates that there will be a significant decrease in the national performance due to the three-year period in which no compliance was required. She believes that many plants will have done little to maintain their risk-abatement strategies and that much of the knowledge and upskilling achieved up to 2014 will now be lost. However, as the audits are now to continue, the concept of continual improvement to the system is of even greater relevance.

Interviewee B also indicated frustration at what he deemed to be the 'red tape' within municipal governance structures that impose delays on maintenance and often result in shortcuts being taken by operational staff at the wastewater plants. The Municipal Finance Management Act (56) of 2003 is apparently very restrictive in terms of the budget allowed for maintenance items, while the complex and time-consuming tender process required for higher value items results in maintenance delays of months to years. As a municipal wastewater treatment works is a very large and complex infrastructure system, individual off-the-shelf items often exceed the allowed value for the municipal finance non-tender process and thus simple part replacement may require an extensive tender process that further delays maintenance at wastewater plants.

### 6.3.4 Costs that are currently considered by municipalities

In order for this research to make sense, it is important to understand what municipalities currently understand their costs to be. This enables engagement with the argument that the 'true' costs are substantially underestimated. Interviewee C directed the researcher towards a study conducted in 2011 by Scheepers and Merwe-Botha in which the operational costs for treatment plants across South Africa were aggregated across what are deemed high- and low-end technology plants. Although a majority of the plants in South Africa are currently deemed 'low end', this report indicates that there is a move by municipalities to move to 'high-end' plants in order to meet the effluent standards required, this despite the possible lack of financing and skills available to do so efficiently (Scheepers & Merwe-botha, 2013).

In 2011, it cost municipalities on average R0.708/kl for low-end plants and R1.801/kl for high-end plants to operate the treatment works (Scheepers & Merwe-botha, 2013). Given the incredibly low assumed 'cost' of running the existing systems, one can see why municipalities would be reluctant to make any changes to the status quo. However, if they were to understand what the externalities of poorly treated wastewater effluent were costing them in other areas, the argument may look very different.

## 6.4 Conclusion

Interestingly, the gaps identified as problematic in the economic externality evaluation are very different from those identified as the key themes from the interviews. Although greater understanding of the impact of the externalities of ineffective wastewater treatment is needed to better understand at a policy level what the poor functioning of the wastewater infrastructure is costing the South African economy, one cannot ignore the environment in which any tool or technology will operate. What is also clear is that the assumed price of wastewater treatment is nowhere near the actual cost to the South African economy, if poor operation is left unchecked. Although economic methodologies exist to quantify the value of the identified externalities, the scope of research required to achieve this cannot be achieved in this research report. However, given the national significance of the externalities associated with ineffective wastewater treatment, this research should be encouraged in institutions and in government.

# Chapter 7

# Recommendations and Conclusions

This research has highlighted the need to identify the economic externalities of wastewater treatment as they have been proven to have a significant impact on the local communities which interact with the environment surrounding a wastewater treatment plant. These externalities can have significant economic impacts on the local and national economy, and, although often contextual, there are methods that can be integrated into a wastewater evaluation framework that will enable the impact of these externalities to be monitored and calculated. There is, however, a substantial amount of further localised research required in order for these externality values to be truly reflective of the impacts. It is anticipated that research will need to be done in specific catchment areas in order to estimate the incidence of disease that can be attributed to the wastewater treatment works, the extent of the water pollution and the types and numbers of industries using that particular water body as a resource.

Although much further work is required to achieve the actual monetary value of what ineffective wastewater treatment means for South African communities, it is also clear that the status quo cannot continue and that change is needed within the wastewater sector. The poor performance of these systems cannot be allowed to continue, and the political agenda that is inhibiting progress needs to be addressed. A number of recommendations as to how these concerns may be addressed are discussed in the recommendations section below.

## 7.1 Recommendations

There are a number of issues that need to be addressed systematically in order to see a positive shift in the wastewater sector. From this study, gaps and opportunities have been identified but it is important to note the context of operations and decision making. As the context for new plants is different to that of existing plants, differing recommendations are made. Additionally, it is evident from the findings that policy and governance play a major role in this sector and therefore recommendations are made as to how the current approach can be improved.

### 7.1.1 Existing plants and upgrades

A new methodology of analysing the costs and benefits of continuing to run ageing plants with insufficient skills available to correctly manage them should be adopted. Instead of the engineering-based cost-benefit analysis, a revised analysis that allows for the inclusion of externalities should be used to correctly establish if it is better to move to smaller, decentralised and privately managed plants. Privately managed plants typically have a much better performance record; 80% of the plants analysed in the 2014 Green Drop report achieved 'excellent' status (Department of Water and Sanitation, 2014). The same analysis methodology would apply when contemplating reopening many of the plants that had anaerobic digesters that had been 'mothballed' due to the low cost of electricity that South Africa has been afforded for many years.

The PAT assessment tool should continue to be utilised as a performance management system but should be moved to an online platform that will enable a closer and more responsive feedback system with the local and national governance structures. By moving this tool from an Excel spreadsheet onto a virtual platform, the monthly quality results can be entered as soon as the tests are done; this would allow for central management to undertake the continual monitoring, and therefore the identification, of issues at the plant as soon as they start to occur. In addition, by moving the platform online, certain areas of concern can be identified and should any of the testing results reach a critical level, this could activate an automated, standardised risk-abatement plan for the concern, with measurable targets, while also allowing the municipality to warn downstream communities and industries of any concerns that they may impact on them. In addition, this tool should be linked to existing tools such as the carbon impact calculator and carbon costing platforms so that the operators of the plant are aware of the implications and, should this be required, appropriate fines or consequences can be put in place.

Further research is required into the development of a tool that will enable the actual pricing of the externalities of particular plant. Unfortunately, the timeframes of this report did not allow for its full development and rather became an investigation into how such a tool can ultimately be achieved. The recommended method for this research would be to identify one catchment area that is affected by the effluent of a wastewater plant. Water quality samples above and below the outfall would be required in order to get an idea of the impact on the watercourse itself. From this, an idea of the impact of eutrophication and biodiversity can be measured. Then, the communities using and directly interacting with the watercourse upstream of the plant can be identified and their health statistics over a period of time measured; these can then be compared to those of the communities downstream of the outfall in order to determine if the plant does indeed have an impact of community health. From the estimated number of individuals directly impacted, the calculations of the actual health care costs can be made. In addition, care should be taken to ensure that referral cases to larger or specialised hospitals are tracked. The measurement of the economic factors will be more difficult to pin down but one methodology for conducting this would be to determine if farms and industries downstream of the outfall are spending more on water purification for inputs than those upstream.

### 7.1.2 New plants

The approach taken to the development of new plants is where the majority of scope to shift the trajectory of wastewater management is possible. Many of the plants currently in use are ageing and often operating over capacity, meaning that as more South Africans get access to safe drinking water, the greater will be the need to develop new plants. A revised approach to the conceptualisation of water treatment should be encouraged, looking at not only the impacts that the poor management of centralised plants have on the South African economy, but also the potential that wastewater has to be not only energy positive but also an economic producer. It is possible that one day, businesses could be paying residents of South Africa for their waste, rather than them paying for its removal. Again, the framework could be used in this case, not only to price the negatives but to price the positives of effective management.

### 7.1.3 Policy and governance

Although evident through the research and interest in the field of wastewater efficiency, the timeframes currently used to evaluate performance and influence change are not conducive to proactive management. A common theme that emerged through all the key informant interviews was the commentary on the influence of politics on the effectiveness of municipalities to adequately run their wastewater services. Interviewee A added a comment on the efficiency of the policy structure currently surrounding water in South Africa. She claimed that the Water Use Guidelines were part of the inability of the country to properly manage its water resources. As these documents are only guidelines, and are additionally constantly under review, there is no 'stick' to motivate water users and potential polluters to abide by the regulations; this allows them to be complacent about the quality of the effluent released into the natural water system. It is therefore recommended that pressure is placed to formalise the Water Use Guidelines and put in place fines for non-compliance.

The issue is then compounded by the limitation placed by many local governments on the waste water systems that they will allow to be developed with local municipalities. All the interview respondents agreed that although public-private partnerships (PPPs) have been proven to be the most effective method of ensuring effluent quality, many municipalities will not allow the privatisation of wastewater plants as the municipalities are still responsible for the bulk infrastructure delivery and maintenance. This means that there needs to be a re-evaluation of the ways in which PPPs are approached by the public sector.

The plant designs that municipalities will allow often place limitations on the engineering designs possible, limiting ingenuity from an engineering perspective, despite South Africa clearly having a skills shortage in terms of staff capable of running the traditional plants. Although the treatment of waste water (regardless of the quality of treatment) is a revenue stream for local municipalities, there is so much potential for wastewater to become an asset rather than a liability, and private sector management of smaller, decentralised plants could be a way in which to achieve this. There is potential for this to be an attractive business model for the private sector and a structure not dissimilar to the independent power producer (IPP) agreements could be one method of achieving this. An added benefit of privatising the service would be the potential for this to depoliticise one aspect of water in South Africa and ensure that service delivery and efficient management occur, regardless of the political environment at the time.

## 7.2 Limitations of the study

As there are a wide variety of waste treatment options available, the framework of the study was limited to the ones covered within the Green Drop PAT assessment tool. As each specific plant will have its associated set and levels of impacts, this is acknowledged as an aspect that will require further research and investigation. The literature has provided common impacts and the fact that these impacts are not seen in all South African treatment plants is acknowledged as a key limitation of the study.

The derivation of the methodology of economic evaluation of the impacts with non-monetised impacts relies on the personal judgement of the researcher and could therefore be argued as subjective. However, this was mitigated through consistent and systematic application of principles and guidelines available in published studies. The Green Drop assessment results are only available for the years 2008 to 2014, as no further reporting has been published to date. In addition, there are two years missing in between reports, namely 2009 and 2010.

The time frame within which this study was undertaken is also identified as a limitation. The scope of data available and the level of detail required in order to price each externality, although originally aimed for by this study, turned out to be beyond the available time and resources of the study. It is therefore recommended that the study be taken further in order for the results to be of greater relevance at national and policy level.

## 7.2 Conclusions

From this study, it is clear that the current wastewater management system in South Africa is flawed, not only in terms of the effectiveness of the plants themselves and their associated impacts, but additionally with regard to the potential to rectify these concerns. South Africa finds itself in a difficult situation as water security continues to worsen, demands for service delivery increase and the infrastructure on which this all relies degrades. The trajectory of the performance as monitored by the Green Drop reports indicates that this is not a temporary or localised concern. The context of a national and systemic breakdown of wastewater service delivery and the apparent political agenda to keep these failings out of the public domain present a red flag for the future of South African water security. It should, however, be noted that a revised Sanitation Policy was approved by Cabinet in December 2016. This policy, for the first time, makes provision for not only a diversity in the approaches taken towards sanitation in South Africa, but additionally encourages private-public partnerships (PPPs) as a methodology for addressing the existing inadequacies in the roll-out of sanitation systems nationally. I believe this indicates that there is a shift in thinking happening at a national level but there is still the risk that this is yet another excellent policy and guideline document, but with no strategic methodology on how to actually deliver.

This study has demonstrated that the price South Africans pay for the purification of their wastewater is in no way reflective of the 'true' cost; in addition, local municipal failings at wastewater plants are impacting on the local economies of the communities surrounding the plants that are not performing. These externality costs, although not easily quantified, can be estimated through the use of both environmental economics and standard market economics; further research as to what these numbers really are is needed in order for the argument to have weight. It is believed that if we can estimate the costs of what the current failings are, the arguments to maintain the status quo will be difficult to make and that this may force change in the way these systems are viewed, both by the public and the private sectors.

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# Appendices

## Appendix A - Interview questions

For water professionals:

1) When designing or contemplating designing a waste water system, what are the most important aspects that are considered?

   Probe to determine whether it is aspects concerning the operations of the system or the design of the system that are deemed important and why. Ask them to rank the considerations from most to least important.

2) How much consideration is given to the operational context of the system during the design selection?

   Probe to determine whether the availability of skilled operations staff in rural contexts is considered, operational costs etc.

3) Do you believe that the current method of waste water treatment delivery in South Africa is the most appropriate method given the context of most cities? Why or why not?

   Probe to determine whether they are aware or think about the costs, especially the non-pecuniary costs associated with ineffective operation of the plants.

4) If a framework existed that allowed you to include the often uncounted for costs that the system may create, would you use the tool to motivate for alternative designs?

   Why or why not?

For policy makers

1) In wastewater policy development, what would you say the primary concerns are in the decision making process on whether a revision is required to a policy?

   Ask them to rank these concerns from most to least important.

2) Wastewater policy in South Africa can be interpreted as quite restrictive in terms of design and operation requirements, limiting the privatisation of this service. What, do you believe, would be the most important aspects to be managed should wastewater treatment be allowed by the private sector?

   Ask them to rank these from most to least important.

3) There has been a big push to rectify the issues at wastewater treatment facilities in South Africa since the inception of the annual Green Drop reports by the Department of water affairs. What would you say was the primary driver behind the attempt to clean up the sector?

   Probe to determine if it was environmental concern, social pressure, etc.

4) In terms of your experience, how would you define an ineffective wastewater system?

5) Have you or your colleagues ever considered the impacts of ineffective wastewater treatment facilities on the local economies?

   If so what impacts did you consider and what did you feel the most pressing concern to be?

6) Is the economic impact of policy considered in the determination and review of policy documents?

   Probe to determine what aspects are considered. Is it purely capex related, lifecycle costing, are any non-financial aspects considered?

7) If a framework existed that allowed you to include the often uncounted or unaccounted for costs that the system may create, would you use the tool to motivate for alternative designs to be accommodated within policy?

   Why or why not?

Appendix B – Ethics Clearance

# SCHOOL OF ARCHITECTURE AND PLANNING
# HUMAN RESEARCH ETHICS COMMITTEE

## CLEARANCE CERTIFICATE
## PROTOCOL NUMBER: SOAP117/10/08/2016

| | |
|---|---|
| **PROJECT TITLE:** | A framework to determine the true cost of centralized wastewater systems on the economies of South African cities |
| **INVESTIGATOR/S:** | Cleo Forster (Student No. 1234017) |
| **SCHOOL:** | Architecture and Planning |
| **DEGREE PROGRAMME:** | MArch in Sustainable and Energy Efficient Cities (March SEEC) |
| **DATE CONSIDERED:** | 21 November 2016 |
| **DECISION OF THE COMMITTEE:** | APPROVED |
| **EXPIRY DATE:** | 21 November 2017 |

**CHAIRPERSON** ______________________

(Professor Daniel Irurah)

**DATE:** 21·11·2016

cc: Supervisor/s: Brian Boshoff

**DECLARATION OF INVESTIGATORS**

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to endure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

**Signature** 10/12/2016 **Date**

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Appendix C – Example PAT

# Randfontein

| Wastewater Treatment Works: Risk Assessment Areas | | | Randfontein | | | |
|---|---|---|---|---|---|---|
| 1 | Confirmed Plant Classification | Class of Works | A | | | |
| | | Type/s of technology applied (Liquid) | Activated sludge and BNR | Activated sludge and BNR | Select process by clicking on drop-down arrow | |
| | | Type/s of technology applied (Sludge) | Anaerobic digestion | Solar/ Thermal drying beds | Gravity thickening | |
| | | Effluent Discharge (Water Use) | River / Stream Discharge | River / Stream Discharge | Select process by clicking on drop-down arrow | |
| | | Sludge Use/ Disposal | Sludge Lagoon/ pond | Sludge Lagoon/ pond | Select process by clicking on drop-down arrow | |
| 2 | ADWF Design Capacity (Ml/d) | As captured on Green Drop scorecard 2013 | 19.5 | OK | | |
| | | Confirmed capacity | 19.5 | | | |
| 3 | Operational Capacity (Ml/d) | Frequency of inflow measurement | Daily | | | |
| | | Average daily inflow (Ml/d) for period July 2012 to June 2013 | 19.4 | | | |
| | | Operational Capacity (%) | 99% | | | |
| 4 | Process Control Skills [Compliance with Reg 17] | Supervisor + Process Controllers + Maintenance (1) | 4 | | | |
| | | Supervisor + Maintenance & No Process Control (2) | | | | |
| | | Process Control + Maintenance & No Supervisor (2) | | | | |
| | | Process Control + Supervisor & No Maintenance (2) | | | | |
| | | Supervisor & No Maintenance & No PC's (3) | | | | |
| | | Process Controllers & No Maintenance & No Sup (3) | | | | |
| | | Maintenance & No PC's & No Supervisor (3) | | | | |
| | | No Supervisor & No Maintenance & No PCs (4) | | | | |

| | | |
|---|---|---|
| A | 2 | 2 |
| B | 3 | 5 |
| C | 4 | 4 |
| D | 8 | 8 |

Note: If the Design Capacity is unknown or NI, insert number 0. If cell E8 "Not Ok", then give reason in Cell Q7-8 and provide new evidence

Note: If the Daily Inflow is unknown or NI (no data or evidence), insert number 0

**Verification of Item 4 by the Assessor and Moderator**

| | Actual No. | Required No. as per Reg 17 | Actual No. Compliant | Compliance Status | % Compliance |
|---|---|---|---|---|---|
| Supervisor | 1 | 1x CV | 0 | No | 0% |
| PCs | 10 | 4x Class IV | 0 | No | 0% |
| Maintenance Team | 3 | 4 | 3 | Partial | 75% |
| Technical Skills Compliance (Reg 17) | | | | No | 75% |

**5 Wastewater Quality Compliance for 3 CRR Categories:**
**(1) Microbiological**
**(2)-(4) Physical**
**(5)-(8) Chemical**

**Note 1:**
In Column D, insert Value (Number) or Waived or NMR (No monitoring required) or NI (no monitoring done)

| | | |
|---|---|---|
| Number of determinands that do not comply 90% of the time with Authorization Limits | 8 | |
| Authorisation in place | Exemption | Expired |
| Authorisation number (If no authorisation, insert None) | 1962B | |

**Note 2 for Cells F24 to F31 and G24 to G31:**
(1) If NMR or Waived insert 0 in Column F and leave Column G blank.
(2) If "NI" insert total results/ samples required to be taken in Column F and insert "0" in the total no. compliant results/ samples in Column G

| Annual Compliance record (%): July 2012 to June 2013 | | | Insert total results/ samples required to be taken | Insert total no. compliant results/ samples | Total results/ samples per category | Total no. compliant results/ samples per category | Compliance per category |
|---|---|---|---|---|---|---|---|
| (1) E. coli / Faecal coliform | | 1 | 88 | 26 | 88 | 26 | 29.5% |
| (2) pH | | 1 | 88 | 88 | 264 | 137 | 51.9% |
| (3) Electrical Conductivity | | 1 | 88 | 42 | | | |
| (4) Suspended Solids | | 1 | 88 | 7 | | | |
| (5) Ammonia as Nitrogen | | 1 | 88 | 0 | 352 | 152 | 43.2% |
| (6) COD | | 1 | 88 | 17 | | | |
| (7) Nitrate/Nitrite as Nitrogen | | 1 | 88 | 88 | | | |
| (8) Ortho-Phosphate as Phosphorus | | 1 | 88 | 47 | | | |
| Average Annual Compliance (%) | | | | | | | 44.7% |

| | | | |
|---|---|---|---|
| 6 | $W_2RAP$ | 2013 Green Drop Report $W_2RAP$ Status | Draft document (unapproved by Council) |
| | | Current $W_2RAP$ Status | Draft document (unapproved by Council) |
| 7 | Capital Projects | Capital & refurbishment projects - expenditure (Rand in million over 2012/13 financial year) | 3.5 |
| | | Brief description of the projects undertaken over the 2012/13 financial year | As and when maitenance tender advertised to appoint service providers |
| 8 | Green Drop Implementation Plan [GDIP] and/or Corrective Action Plan [CAP] | Is there a GDIP in place for the Green Drop Audit 2014/15 | Yes |
| | | Is there a CAP in place where Green Drop Score is less than or equal to 30% | NA (>30% Municipal and/or System GD score) |
| | | Brief description of GDIP | Build balancing dam for stormwater |
| | | Brief description of the action targets for GDIP achieved to-date | N/A |
| | | Brief description of CAP | N/A |
| | | Brief description of the action targets for CAP achieved to-date | N/A |

**Summary of the Key Evidence to be presented and submitted at the 2014 CONFIRMATION SESSION for Assessor to verify and validate the System data and CRR scoring:**

**Item 1** - DWA Works Classification Certificate or proof of registration; and Works Flow Diagram or WWTW layout drawing
**Item 2** - Documented evidence of design capacity or WWTP layout drawing indicating the capacity of each of the process units or Professional Engineer calculations
**Item 3** - Daily inflow records and the summated monthly inflow records or a verifiable method used to calculate the daily inflow over low, normal and peak periods with tangible calculation process demonstrated
**Item 4** - DWA PC and Supervisor certificates or registration forms and proof of registration; Maintenance team trade certificates and key educational qualifications and PSP contracts (external Contractors); and Staff Organograms for both
**Item 5** - Copy of the Permit/ Exemption/ WUL or GA letter or registration forms and proof of registration; Complete and submit the excel EFFLUENT DATA tables and submit the External Laboratory Analysis Reports for the period 1 July 2012 to 30 June 2013 for verification by the Assessor - **see Note (3)** below
**Item 6** - Non-returnable hard copy of the $W_2RAP$ document for the Assessor to review or **see Note (3)** below
**Item 7** - Non-returnable hard copy of the 2012-13 financial year budget and expenditure (direct, indirect and support services) and latest progress report for the Assessor to review or **see Note (3)** below
**Item 8** - Non-returnable hard copy of the GDIP or CAP document for the Assessor to review or **see Note (3)** below

**Notes:**
**(1)** Failure to provide the required key evidence mentioned above at the Confirmation Session will not enable the System Data to be verified and may invalidate the System Data provided. Where no information submitted, it will taken as 'NI = No Information' and the maximum CRR score or worst case scenario will be applied to the System
**(2)** All the key evidence required above must be placed in a "Portfolio of Evidence" linked to each System. Evidence not presented in this manner will not be reviewed at the Confirmation Session
**(3)** It is recommended that all the key evidence mentioned above be placed on a CD and submitted to the Assessor at the Confirmation Session

| | |
|---|---|
| **2013-2014 Cumulative Risk Rating (CRR)** | 18 |
| **2013-14 Maximum CRR** | 22 |
| **2013-2014 WW Risk Rating (% CRR/$CRR_{max}$)** | 81.8% |

| Verification of Item 5 by the Assessor and Moderator | | | |
|---|---|---|---|
| Microbiological Compliance (%) | 29.5% | 88 | 26 |
| Physical Compliance (%) | 51.9% | 264 | 137 |
| Chemical Compliance (%) | 43.2% | 352 | 152 |
| Average Annual Compliance (%) | 44.7% | | |

**Assessor's Note for cells E45 to E47:**
(1) If monitoring undertaken, insert TOTAL no. r esults/ samples over the monitoring period July 2012 to June 2013 in Cells E45 to E47;
(2) If monitoring not undertaken but a requirement, insert the REQUIRED TOTAL no. results/ samples over the monitoring period July 2012 to June 2013 in Cells E45 to E47 that should have been monitored per licence/ permit [minimum = CRR requirement]; and
(3) If no monitoring required [NMR], insert zero '0' in Cells E45 and/or E46 and/or E47 as where applicable
**Assessor's Note for cells F45 to F47:**
(1) If monitoring undertaken, insert no. COMPLIANT results/ samples over the monitoring period July 2012 to June 2013 in Cells F45 to F47;
(2) If monitoring not undertaken over the monitoring period July 2012 to June 2013 but a requirement, insert zero '0';
(3) If no monitoring required [NMR], leave BLANK

**Additional Clarifying Comments and Notes**

Classification Confirmed from BDS, but system calculates class as C. Recommend that the Municipality submit the classification for review.

Unit processes updated from PFD.

Design capacity confirmed from O&M manual.

Average flow calculated from provided flow data.

Staff Registered on the GDS (Active)
Superintendent: 1xI
Supervisor - 1x 0
PC's: 10x I
Maintenance: Qualified (Red Seal) Electricians; Please confirm if fitter/millwright is appointed. Previously outsourced; No evidence of civil (plumbers) or instrumentation. Assume instrumentation can be outsourced, but qualified plumbers should be available in-house.

Expired WUL (Exemption 1962B - valid 5 yrs. from 2002)
Please provide evidence of application for new WUL.
Limits as specified in the expired exemption should be applied in the interim. Please provide copy of exemption for verification.
Monitoring: 100%
Micro: 27.59%
Physical: 53.03
Chemical: 42.33
Since no analysis data provided the data from the GDS was used to inform the compliance calculation. Compliance data was calculated from a substantial dataset.

W2RAP prepared by EON consulting. Final Draft.

No evidenc e of capital expenditure provided.

An action plan drawn up from the gaps from the previous GD assessment with action, responsible person and intervention was presented at the 2013 Green Drop assessment. No updated GDIP was presented to PAT moderators.

Since no analysis data provided the data from the GDS was used to inform the compliance calculation. Since monitoring exceeded the license requirements, the number of analyses were used for the compliance calculation.