ASSESSING THE SUSTAINABILITY OF DIRECT POTABLE WATER REUSE: THE BEAUFORT WEST RECLAMATION PLANT

A Research Report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

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Declaration

I declare that this Research Report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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(Signature of candidate)

_____day of _____20_____in_____

Abstract

A growing population, rapid urbanisation, and climate change are increasing the pressure on water supplies. The chances of finding new freshwater sources for urban areas are becoming nearly impossible, implying that existing water supplies must go further to satisfy the basic need of potable water.

Water reclamation involves the treatment of wastewater to meet defined water quality standards so that it may be reused. Direct potable reuse refers to the introduction of wastewater, which has been treated to meet specified standards, directly into the potable water supply distribution system. Water reuse has become an attractive alternative since wastewater is constantly being produced by populations, which can be treated for reuse.

This study examines the sustainability of water reclamation for potable purposes, through an assessment of the Beaufort West Water Reclamation Plant, which includes interviews with the plant manager and process controllers, as well as a review of the relevant documentation. The study employs the use of economic, environmental and societal indicators as a tool in determining the sustainability of water reclamation.

The results of the research show that direct potable reuse may be a sustainable solution to reducing the stress on water resources, although certain aspects of the reclamation process require further development in order to progress toward sustainability. In order to provide a long term solution, water reclamation will have to be implemented in conjunction with other water conservation strategies.

“Water should be judged not by its history, but by its quality.”

Van Vuuren, a pioneer of water reclamation in

South Africa during the 1970s.

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I would also like to thank the following people:

Anne, who is simply brilliant

Feroze, my guiding light

My parents, who have given me everything

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1. Introduction

Globally, approximately 2.4 billion people live in water stressed regions, with another 500 million people approaching this situation. Sub-Saharan Africa currently has the highest proportion of people without water (UN, 2007). Human populations and water resources are not distributed evenly across the world, and densely populated regions do not coincide with those areas with sufficient water supply, which poses a problem in terms of ensuring an adequate water supply. This uneven distribution, combined with an increase in population and therefore demand, places a large percentage of the world's population in a condition of water scarcity (Kummu *et al*., 2010).

Unclean water is the destiny of poor people across the world. A fifth of the people living in the developing world lack access to sufficient clean water, a suggested minimum of 20 litres per day. This can be compared with the average water consumption in developed countries, such as the United States and Europe, which is between 200 and 600 litres per day. Most of the suffering due to water stress occurs in the developing world, with poor people living in informal settlements often paying five to ten times more than wealthy people living in the same city (UN, 2007).

The study of sustainability has become an important part of ensuring water supply for present and future generations. Sustainable development has been defined in the Brundtland report, 'Our Common Future' as: ''development that meets the needs of the present without compromising the ability of future generations to meet their own needs'' (United Nations World Commission on Environment and Development, 1987: 41). Water reuse has become an attractive solution to reducing water scarcity issues in many countries. In an age where there is great concern regarding environmental degradation, and the need to reduce global sanitation problems, disease, and poverty, water treatment processes should be designed in order to achieve sustainability.

The aim of the introductory chapter is to provide a contextual background to the study, through a discussion of water scarcity, as well as climate change and its predicted impacts on water scarcity. Each concept is discussed on a global level, and then particular attention is drawn to the situation in Southern Africa. The town of Beaufort West and its water history is presented, to provide a basis for discussion of the Beaufort West Water Reclamation Plant in the following chapters. The chapter concludes with a discussion of the objectives of the report, and a brief outline of each chapter.

1.1 Water Scarcity

Water scarcity refers to a shortage of water in a supply system, due to the demand exceeding the available resources. Scarcity originates from both human actions, such as inefficient use, poor management, population growth, inequitable access, and natural occurrences, such as drought and climate change (Kharraz *et al*., 2012; Vairavamoorthy *et al*., 2008). Climate and freshwater share a complex relationship, and a change in climate will induce a change in freshwater supplies. Nations which are already confronting the issue of sustainable water use, will be over stressed by the anticipated effects of climate change. Where natural water resources are completely depleted, or nearly so, nations may have to look at the sustainability of a potable water reclamation system as an alternative (Aloj *et al*., 2012). The United Nations (2007) has defined a water consumption of less than 1700*l* of water per person per capita as 'water scarce'.

The most widely used measure of water stress is the Falkenmark indicator. This indicator is a measure of the fraction of the total amount of runoff that is available for human utilisation. In order to quantify water scarcity, Falkenmark (1989) conducted surveys in many countries, and used this information to calculate the water usage per capita per day. Based on this water usage, the severity of water stress in an area can be differentiated. As shown in Table 1.1 the water conditions in a specific area can be categorized as; no stress, stress, scarcity, and absolute scarcity.

Table 1.1: Water Barrier Differentiation (Falkenmark, 1989)

Index (m^3/capita)	Category
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

1.2 Freshwater Availability

Less than 1 percent of all freshwater on earth can be accessed by humans, since much of the freshwater is either locked in the ice cover of the Arctic or Antarctic, or in aquifers too deep for extraction. This means that approximately 35 million cubic kilometres of water cannot be accessed, the result of which is a physically accessible global fresh water potential of 90 000 cubic kilometres annually (Department of Water Affairs, 2012).

1.3 Water Consumption

In most countries, the largest consumer of water is the agricultural sector. In 2007, the United Nations estimated that 14% of freshwater is used for agriculture, and it is assumed that by the year 2030 this use will increase to 55%, as a result of the increased food production. This vast increase in a single sector suggests that all other sectors may need to use significantly less water, or a large amount of additional water will need to be provided to support agriculture. Although the agricultural sector consumes large amounts of water, it is beneficial in that it has played a major role in the development of rural economies, supporting economic growth and poverty reduction. Most countries in East and North Africa, Mexico, Pakistan, South Africa, India and parts of China are experiencing acute water scarcity. The bulk demand of water in these countries is irrigated agriculture, which contributes to a substantial portion of the economy. In order to sustain their demand for water, these countries need to focus on the efficient use of all water and integrated management strategies (UN, 2007).

1.4 Climate Change and Water Resources

The Intergovernmental Panel on Climate Change (2007) has stated that the increased level of atmospheric greenhouse gases will result in climate change, which will cause the sea level to rise, and increase the frequency of extreme climatic and heavy rainfall events, including droughts and floods. This will have a significant effect on human populations, resulting in the loss of life, social disruption and economic hardships (IPCC, 2007). Climate change may occur both naturally, and anthropogenically. Human activities such as the combustion of fossil fuels which release greenhouse gases into the atmosphere, as well as land use changes, are some of the causes of anthropogenic climate change (Kiem, 2014).

1.4.1 Impacts of Climate Change on Water Resources

In terms of water resources, it is predicted that the costs of climate change will outweigh the benefits, on a global scale. The reason for this is that the variability of rainfall is likely to increase, as well as the occurrence of extreme events, such as floods and droughts (Bates *et al*., 2008).

There is an increased consensus amongst the scientific community that climate change will affect water supply systems (Bates *et al*., 2008; Kiem, 2014). The potential impacts of climate change on water availability and quality could be (Bates *et al*., 2008):

- An alteration in the reliability of raw water sources and supply infrastructure such as dams and reservoirs due to a change in the magnitude of flows
- The demand for water, and ability to meet demands, particularly at peak times may be altered

- Raw water quality may be altered due to an increase in temperatures which affects the ability to treat raw water to potable standards
- There may be increased precipitation intensity, resulting in increased runoff, which would increase nutrient and pathogen loadings to surface water sources

Domestic water availability will be affected by the changes in precipitation, floods and droughts. Floods may cause damage to water supply infrastructure which may take long periods of time, even years, to repair. Flooding of sanitation facilities may cause the contamination of water sources, such as groundwater, resulting in the spread of disease. This degradation of raw water supplies may require a change in the type and nature of treatment processes for the production of water for potable use. This change in treatment may not be feasible, technically and economically, in some countries. In addition to the effects of floods on water sources, droughts will also deplete the groundwater sources, and people will have to travel further for water (Babel *et al*., 2014).

1.4.2 Impacts of Climate Change on Freshwater Demand

In addition to climate change having an effect on the availability and quality of water resources, the predicted effects will also affect the demand for freshwater. For example, the predicted increased temperatures and variability of rainfall, would lead to increased irrigation water demand, even if the overall quantity of rainfall in the growing season remains constant (Bates *et al*., 2008). In terms of secondary effects, more energy would be required for the cooling of buildings due to increased temperatures, which would require increased water requirements at the power plants.

1.4.3 Impacts of Climate Change on Water Stress

It must be noted that climate change would appear to reduce water stress globally, if the water availability per capita is considered. Increased runoff is predicted for the most populous parts of the world, such as south and East Asia. It must be noted that this runoff will occur during the high rainfall seasons, and would need to be stored for the dry seasons. These countries have to make sufficient provision for the storage of this water, and ensure that the infrastructure network is able to cater for the increased runoff, so that it does not result in floods. An increase in runoff has only been predicted for specific parts of the world, and would not assist in reducing water scarcity in other parts of the world. Even in countries with a predicted increase in runoff, the increased probability of extreme events, as well as population growth, may negate the effects of increased available freshwater resources (Bates *et al*., 2008).

There is much debate among researchers regarding the predicted impacts of climate change. For example, Gosling and Arnell (2013) predict that in central Europe runoff will decrease with climate change, but does not agree that runoff will increase in south and East Asia.

1.4.4 Planning for Climate Change and Water Resources

Climate change challenges conventional assumptions regarding water resources, and provides a new dimension to water management. In addition to the increased pressure the effects of climate change may place on already stressed water resources, it can no longer be assumed that past climatic and hydrological conditions will continue into the future (Aloj *et al*., 2012). In the planning of future water management projects, the key drivers of climate change must be understood, as well as their future impacts. The wide range of impacts of climate change on water resources create an undeniable need to strengthen water management systems and institutions in southern Africa, and incorporate the concept of integrated water resources management on a large scale. Although the effects of floods and droughts could be reduced by appropriate infrastructure investments and changes in water and land-use management, these measures will entail costs, and detailed planning (Bates et al., 2008).

In the planning of future water resources management systems, and evaluating the impacts of climate change on water resources, it is important to draw on all knowledge, technological advancements in the field of geographical information systems, remote sensing, information management, and computer science (Kusangaya, 2014). It is recommended that considerations regarding climate change should be included even at the regional level, using structures such as the South African Development Community (SADC) protocol when approaching shared water courses, since the region has 12 shared river basins (Kusangaya, 2014).

Many researchers consider water reclamation as a key element to integrated water resources management, and for coping with the effects of climate change on water resources (Asano *et al*., 2007; Aloj *et a*l., 2012; Bates *et al*., 2008).

1.5 Water Situation in South Africa

It is important to note that different groups in South Africa experience varying levels of water scarcity, despite the country's commitment to equity in terms of access to a water supply. The greatest victims of water scarcity, currently and historically, are the rural poor and marginalised urban communities, who may be affected on a daily basis due to the lack of access to a potable water supply. Unfortunately, a false sense of water security has been created within the privileged communities of

South African society, who have a secured adequate water supply, which, according to the Department of Water Affairs (2012), results in water over consumption.

The current state of water resources in South Africa is discussed below to provide the context in which the sustainability of direct potable reuse will be assessed.

1.5.1 National Water Resource Strategy (NWRS)

In order to understand the management of water resources in South Africa, the main objectives of the NWRS must be discussed. The NWRS is a document which is binding on all authorities and institutions, as required by the National Water Act of South Africa (Act 36 of 1998). The first edition of the National Water Strategy, NWRS-1, was released in 2004 and set out the strategy for the management of water resources in the country. The second revision of the water resources strategy, NWRS-2, provides a strategic direction for the management of water resources for the next 20 years, with a particular focus on the years 2013 – 2017. This document provides a framework for the protection, use, development, conservation, management and control of water resources (Department of Water Affairs, 2012).

The NWRS-2 places emphasis on equity in access to water resources for all South Africans, in a country where water resources are under pressure due to increased abstraction, habitat destruction, pollution as well as climate change. The NWRS-2 lays out strategies for achieving effective water resource management with a particular focus on the Department of Water Affairs as the leader of the water sector. This strategy outlines water reuse, among other options, as a viable strategy for South Africa, which requires intensive further investigation (Department of Water Affairs, 2012).

1.5.2 Water Scarcity

South Africa has been classified as the 30th driest country in the world, and is facing an increase in demand for water, an already stressed resource. This demand is driven by population growth, the connection of households previously unreached by municipal water services, growth in the industrial and economic sectors, rural-urban migration, and a range of other factors (Adewumi *et al*., 2010). In addition, the country faces a number of other challenges in the water sector, the most concerning of which is a lack of appreciation for water and inadequate management and governance (Mattheus, 2013).

1.5.3 Water Quantity

The South African water supply is characterized by low rainfall levels, erratic runoff, high levels of evaporation due to high temperatures and shallow dam basins, as well as inter-basin water transfers on a large scale. Many parts of the country are reaching a point where all of their financially viable resources are exhausted. South Africa is therefore investigating a number of strategies aimed at meeting the current and predicted water demand, such as improved water use efficiency, development of new infrastructure, reuse and recycling of wastewater, sea water desalination, and the removal of water consuming alien plants (Department of Water Affairs, 2012).

1.5.4 Water Infrastructure

Although South Africa is classified as a water scarce country, there is well-developed water infrastructure. There are 4 395 registered dams in South Africa, 2 528 of which are supply related. Despite this well-developed infrastructure, water supply is affected by natural phenomena such as floods and droughts, common occurrences in South Africa, which require effective water management. Also, regardless of the well-developed infrastructure, there are problems of equity in terms of access to water resources, as mentioned previously. The poor and marginalised communities are subject to intense water scarcity, especially in rural areas and the former homelands (Department of Water Affairs, 2012).

1.5.5 Surface Water

A large portion of the available yield from surface water, throughout most of the country, has been developed and fully utilised. The uThukela, Mzimvubu and Pongola basins, where additional water is available, are located in remote areas which are far from where the water is needed. To transport water over these long distances requires a large investment. It is important that there remains a balance between the water remaining in rivers and the water being extracted. About 25% of the mean annual rainfall each year needs to remain in the rivers to maintain ecological functioning and the river systems. This process requires effective management on behalf of the Department of Water Affairs (Department of Water Affairs, 2012).

1.5.6 Groundwater

Despite the low local yields, groundwater is also a significant source of freshwater supply. Although current groundwater extraction is estimated at about 2 000 million m^3 per annum, the estimated sustainable potential yield is 7 500 million m^3 per annum. Despite the availability of additional groundwater, this resource is difficult to access since it is sparsely distributed, not readily available in

accordance with water demand, and there is not a high level of knowledge regarding groundwater resources (Department of Water Affairs, 2012).

1.5.7 Water Resource Quality

South Africa experiences major water quality problems. The main contributors to these problems are mining, which increases the acidity and metals content of water; urban development, which increases the salinity and microbiological content of the water; industries, which add chemicals and toxins to the water; and agriculture which adds sediments and chemicals to the water. Many rural communities rely on groundwater as their main water source, and are placed at risk since the mineral content of the water exceeds the recommended levels. Water quality is also being affected by untreated or poorly treated wastewater (Department of Water Affairs, 2012).

South African ecosystems are also in a state of risk. About 65% of the 792 wetland ecosystems have been identified as threatened and 48% critically endangered. This is a grave concern since ecosystems are involved in the provision of many services, such as water purification and flood mitigation. The degrading of these natural systems has a negative impact on human health, especially on rural communities who depend directly on natural systems for their livelihood (Department of Water Affairs, 2012).

The issues of water quality and water quantity are directly linked and need to be addressed in an integrated manner.

1.5.8 Sectoral Water Use

An adequate water supply is crucial to ensure economic growth and development. The volume of water used per sector, in South Africa, is shown in Figure 1.1. The greatest consumer of water is irrigated agriculture followed by municipal/domestic consumption.

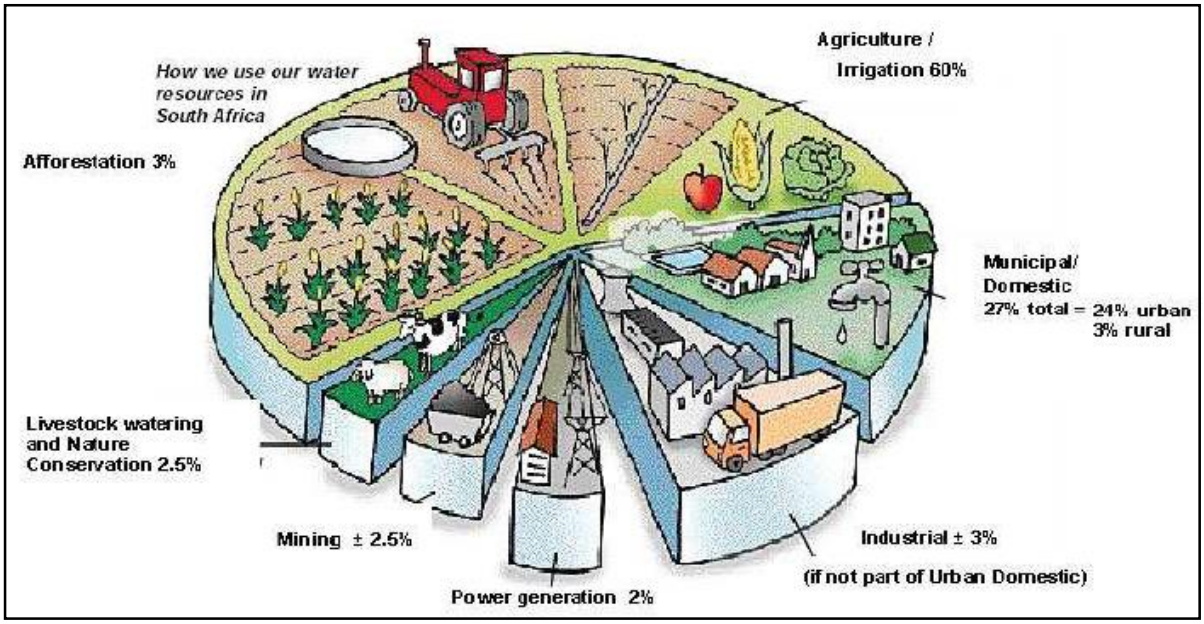


Figure 1.1: Estimated Water Usage per Economic Sector (Department of Water Affairs, 2012)

1.5.9 Impacts of Climate Change on Southern Africa

Southern Africa, highlighted in Figure 1.2, has been recognized as having a changing climate due to the increased frequency in the occurrence of extreme events such as droughts, floods, and cyclone activity. It has been predicted that the effects of climate change on southern Africa will be significant in that they will affect almost every aspect of human systems. These systems include agricultural productivity, energy use, flood control, wildlife management, and municipal water supply. This is exacerbated by the fact that the southern Africa region is subject to rainfall which has great spatial and temporal variations, scarce water resources, low adaptive capacity, widespread poverty, and a historically low level of technology uptake (Kusangaya *et al*., 2013). The Intergovernmental Panel on Climate Change (2007), has therefore declared southern Africa as one of the most vulnerable regions in Africa, to climate change.

Figure 1.2: Map Showing Southern Africa (Author)

In Africa, the main source of drinking water is groundwater, especially in rural areas which rely on wells and boreholes. The recharge of this groundwater is expected to decrease, with the variability in rainfall patterns and increased runoff, which will result in water stress in those areas which rely on groundwater sources. The main effects of climate change on water resources in Africa have been summarised by Bates *et al*. (2008):

- An increase of 60 – 90 million hectares of arid and semi-arid land is predicted by the 2080s
- Declining agricultural yields due to predicted droughts
- Increased runoff in East Africa and decreased runoff in other areas such as southern Africa

1.5.10 Future Water Resources

It is essential that planners in the country seek out additional water resources to supplement the water supply. The South African water authorities have predicted that unless the water consumption

patterns are altered significantly, or alternative sources are introduced, the country will be unable to meet the growing water demands, and the water shortage problem will become extremely severe in 20-25 years (Adewumi et al., 2010). The manager of planning and information at the Department of Water Affairs has warned that South Africa is at a great risk if water is not taken seriously by all citizens and interventions are not applied timeously (Mattheus, 2013).

The results of the water shortage is that the government may then be forced to place water use restrictions on the country, leading to a disruption of essential activities, for example agriculture and industry, and a discontent amongst the general public. The freshwater constraints on South Africa, necessitate that the government implement sustainable water reuse strategies, including wastewater reclamation, both for potable and non-potable purposes. With the advances in technology wastewater reuse has become an attractive alternative for furthering existing water supplies (Adewumi *et al*., 2014).

1.6 Wastewater Reuse

Wastewater reuse has become an attractive alternative for both potable and non-potable purposes as a result of the decreasing freshwater availability and increasing water demands (Adewumi *et al*., 2010). The factors which discourage the reuse of wastewater are the potential risks to public health, and the potential for reduced sewer or stream flows which can lead to blockages in the system. If wastewater reuse is implemented without the appropriate technologies in an unregulated environment, the results may be the production of water which is harmful to humans (Adewumi *et al*., 2010).

1.6.1 Wastewater Reuse Globally

Wastewater reuse, mostly for non-potable purposes has already become popular as a water demand management strategy in countries such as Jordan, Kuwait, Israel, Spain, Australia, Namibia, Germany, United Kingdom and America. The successful implementation of wastewater reuse in these countries, as well as the wide range of treatment technologies available, indicate that it is essential to investigate the potential of wastewater reuse as a viable alternative to address the current and future water shortages in South Africa (Adewumi *et al*., 2010).

1.6.2 Wastewater Reuse in South Africa

Water reuse was discussed extensively by the Department of Water Affairs in National Water Resource Strategy 2012, also known as the NWRS-2, as discussed above. The strategy focussed on the

best possible use of the country's limited water resources, to ensure sustainability and the benefit of society and the environment. At the Water Institute of South Africa International Conference on Water Reuse for Drinking Purposes 2012, it was established that water reuse and recycling forms one of the key pillars of using water resources responsibly and efficiently (Mattheus, 2013).

The chief engineer at the National Water Resource Planning for the Department of Water Affairs, performed an investigation into water reuse aimed at highlighting key strategic actions that need to be undertaken in the local context, before and while implementing water reuse. He recognised that water reclamation and reuse is an important source of water in terms of the water resource planning process, and there is great potential for water reuse in the agricultural sector, as well as the in the municipal sector, for both potable and non-potable purposes. Direct reuse is considered a challenge in the water sector, with the main concerns including the presence of micro-pollutants, the cost of treatment, risks associated with operation of a water reclamation facility, and public perception and acceptance (Mattheus, 2013).

In order to support a national water reuse strategy, a number of key strategic actions need to be undertaken by the relevant role players, including sound transparent decision making, clear policy and legislation, sufficient research and information to support water reuse and the capacity to implement projects, and ultimately the financing of projects. In order for the implementation of reuse projects to be viable they need to be cost effective and sustainable in comparison to other water supply alternatives. Prior to the implementation of water reuse, it is imperative that current wastewater treatment works function efficiently and meet the current discharge standards (Mattheus, 2013).

The final consensus at the conference is that the solution in South Africa is no longer to build more dams and infrastructure, instead direct potable reuse is imminent and will probably be a reality in the next decade in most areas. It was also stated that direct potable reuse is just one of the many solutions, and in order to achieve this political commitment and sensitising the public must be encouraged (Mattheus, 2013).

1.6.3 Water Reuse Division

The Water Reuse Division (WRD) of the Water Institute of South Africa was founded in 2013. This division was formed as a result of the increased attention that water reuse had been receiving in Southern Africa, predominantly in Windhoek, Beaufort West, eThekwini, Cape Town, Hermanus, Mossel Bay and George. This attention created a need for local and regional platforms which enable

planners, researches and professionals to share information and provide sustainable solutions regarding water reuse. Thus, the main objective of the WRD is to provide a communication platform for engineers, scientists and practitioners to share information regarding water reclamation, recycling and reuse to facilitate the implementation of safe water reuse practices in Southern Africa. An additional objective of the WRD is to inform national, regional and local authorities of the benefits of reuse, health aspects, public acceptance, governance and regulatory matters (Brown, 2014).

1.7 Beaufort West

The information presented provides evidence that wastewater reuse for potable purposes may soon be a reality on a large scale, in South Africa. This creates a need for the sustainability of direct potable reuse for South Africa to be assessed, which can be done using the existing water reclamation plant in Beaufort West as an example.

Beaufort West lies in the heart of the Great Karoo, in the Western Cape of South Africa (Fig 1.3), in a semi desert area, which was once an ancient swamp (BWM, 2015). It is home to the first direct water reclamation plant in South Africa.

Beaufort West is the centre of an agricultural district based primarily on sheep farming and meat production. The town is positioned strategically so that the N1 freeway, which serves as the main route between Cape Town and Johannesburg, runs through it, thereby bisecting it in two, and generating a large portion of the town's income. Tourists passing through the town on the N1 are the mainstay of the town's economy (BWM, 2015). The governing authority is the Beaufort West Municipality (BWM), with the towns of Beaufort West, Merweville and Nelspoort, falling under its jurisdiction. There are 41 000 inhabitants within the Beaufort West Municipality (BWM, 2010).

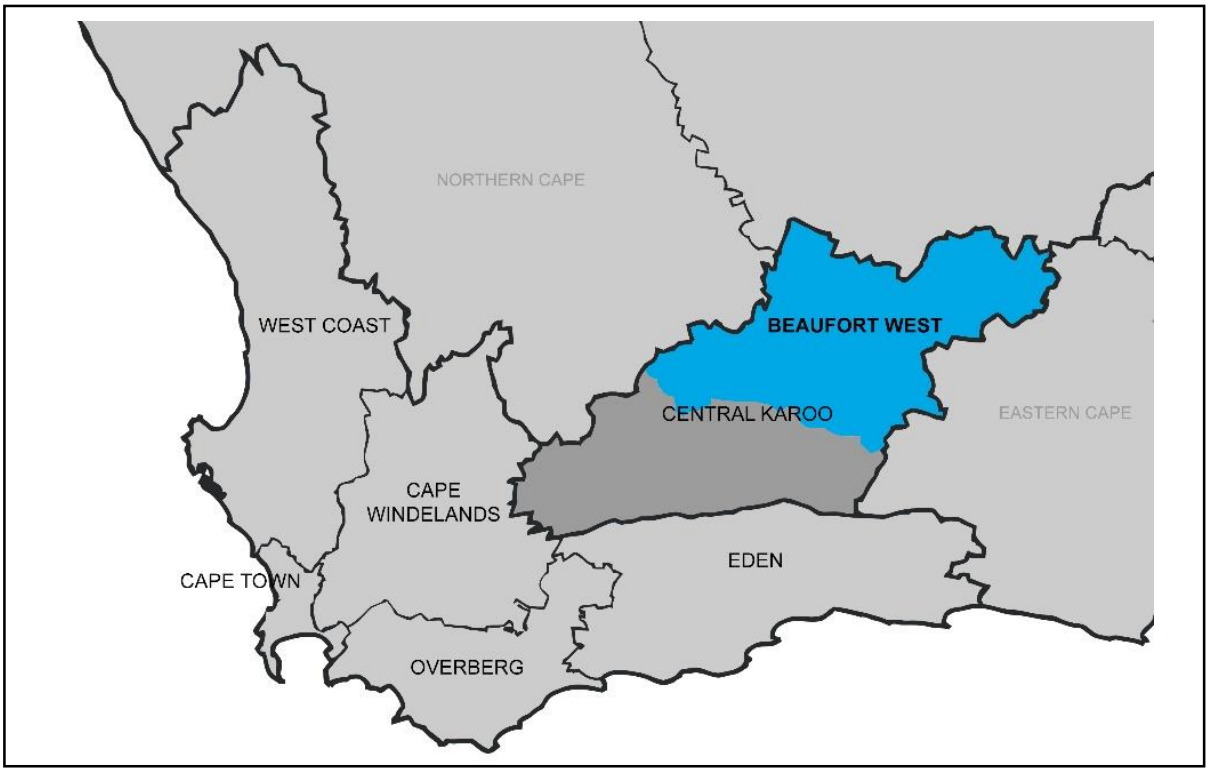


Figure 1.3: Location of Beaufort West (Author)

1.7.1 Water History: Prior to WRP

In order to gain insight into the reasons necessitating the construction of the Beaufort West Water Reclamation Plant, the history of Beaufort West, in terms of water supply must be understood. This history is outlined briefly, as well as the shortcomings of the municipality in delivering basic water services to the community.

Water Supply system

Beaufort West is well known for its shortage of potable water (BWM, 2010). The Beaufort West water supply is extremely stressed since there are no perennial rivers in the surrounding areas. The water supply is heavily reliant on rainfall, thus increasing the susceptibility to drought. Prior to the construction of the plant, the municipality had two sources of raw water, surface runoff that is captured in the Gamka Dam, and the groundwater derived from 17 boreholes around the town. The treated water from the dam was mixed with the water from the boreholes via three reservoirs and then distributed to the community (Wright, pers. comm, 2015).

Essential Shortcomings of the Municipality

Every municipality is required, in terms of the Water Services Act, Act No 108 of 1997, to prepare and maintain a Water Services Development Plan (WSDP). According to the WSDP 2010/2011 produced by the Beaufort West Municipality, one of the main shortcomings identified is the inequitable access to water services. All the formal households in the urban areas of the municipality are provided with water connections in the house, while informal settlements have been provided with shared services as an intermediate measure. These shared services are in the form of communal standpipes and toilets shared between households. The maintenance cost of these shared services is not sustainable, and the goal of the municipality is that all houses, both formal and informal are provided with services which meet national basic water supply standards, as a minimum. Once this is accomplished, the municipality has made a commitment to provide all households with a water connection inside the yard or house (BWM, 2010).

Drought Conditions

The presence of drought conditions is evident from the reduced rainfall between 2008 and 2010, shown in Table 1.2. These values are very low in 2010 when compared with the global average rainfall of 870mm (Department of Environmental Affairs, 2011). An additional problem is that the rainfall pattern is erratic and tends to fall in small quantities at a time, producing a minimal amount of runoff (Wright, pers. comm, 2015).

Table 1.2: Rainfall in Beaufort West from 2001 to 2010 (Adapted from Holloway et al., 2012)

Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total Rainfall (mm)	323.5	358.8	240.3	359.9	229.5	314.0	336.6	**218.95**	**249.0**	**192.25**

In Beaufort West, the municipal engineer who has monitored rainfall changes since the 1980s reported that rain is falling predominantly over the town itself, and not over the Gamka Dam mountain catchment, as it previously did. The implications of this are reduced surface water supply, and lower rates of aquifer recharge. This resulted in the groundwater supplies in Beaufort West reaching critical levels during the 2008 - 2010 drought. This can be illustrated by the diminishing levels in the Noorde Einde Aquifer, which from November 2008 to December 2010, progressively dropped from 13m to 36m below ground level (Holloway et al., 2012). This resulted in the boreholes, which are supplied by aquifers, having a diminished water supply. Since the water supplied to the town by the boreholes was reduced by approximately 50%, more water had to be drawn from the Gamka Dam, which was

originally only used for backup purposes in the dry summer months. The extreme drought conditions, and continual extraction from the Gamka Dam, led to its running dry in September 2010, which necessitated the introduction of water restrictions to the community (Wright, pers. comm, 2015). As shown in Table 1.3, the drought occurred in three phases, beginning in January 2008, and progressively intensifying until December 2010. Although in 2003 and 2005 there was low rainfall, it was only in 2008 that the aquifer levels depleted to such an extent that there was insufficient water to supply the town. The drought conditions stabilised in January 2011, which has been labelled drought phase IV in the table.

Table 1.3: Phases of the 2008 – 2011 Drought in Beaufort West (Holloway et al., 2012)

Phase	Dates	Classification	Description
I	Jan-Dec 2008	Risk accumulation	Declining annual rainfall, combined with increasing water demand
II	Jan-Oct 2009	Risk escalation	Poor rainfall, declining dam levels. Demand measures implemented
III	Nov 2009 - Dec 2010	Risk intensification	Poor rainfall: Domestic water restrictions introduced (Jan 2010) Local disaster declaration for Beaufort West (May 2010) Gamka Dam empty (Sep 2010) Domestic water restriction intensified (Nov 2010)
IV	Jan-May 2011	Risk stabilisation	Domestic and industrial water use restrictions lifted (April 2011)
V	June - Dec 2011	Risk de-escalation	Rainfall in many areas. Gamka Dam begins refilling (June 2011). Water demand management

Introduction of Water Saving Strategies

Based on the water history, the municipality identified water supply as a key strategic resource, and was forced to introduce a short-, medium- and long-term strategy to secure the water supply for the town (Marais & Durckheim, 2012).

The focus of the short term strategy was water demand management. This included creating awareness among the community regarding efficient water use, detecting and managing water losses, developing additional boreholes, installing pre-paid water meters, implementing water restrictions, and water shedding, which will be discussed below (Marais & Durckheim, 2012).

The awareness program, intended to educate the community regarding the drought and water saving measures, included the use of local radio stations, newspapers and pamphlets. It was found that the community were most receptive to the pamphlet which is shown in Figure 1.4 (Wright, pers. comm, 2015). The translation of the text in the pamphlet is: 'Water will only be available from the dam until approximately 30 September - thereafter only from boreholes. Steps are currently underway to exploit extra water sources. If this proves to be unsuccessful, in the absence of rain, then stricter water restrictions will have to be implemented. Your co-operation in saving water is appreciated'. Awareness was also increased through the publication of the names of high water users in local newspapers (Holloway *et al*., 2012).

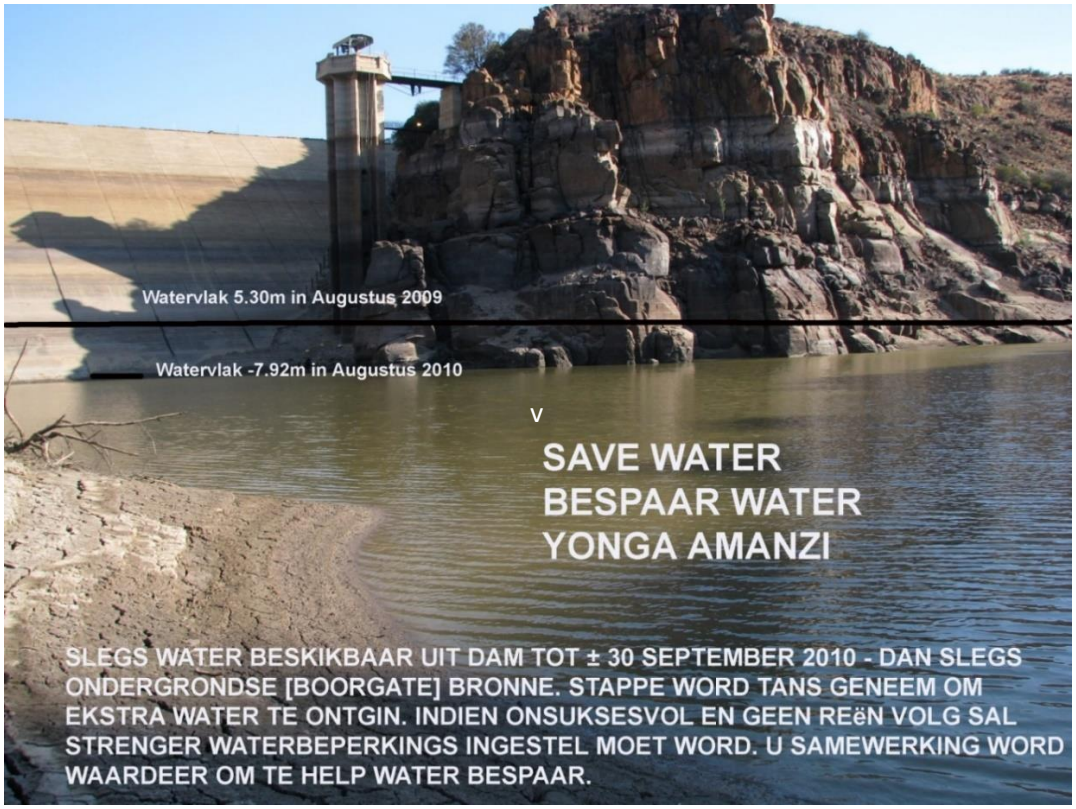


Figure 1.4: Pamphlet Supplied to Community (Wright, 2015)

Water restrictions limited each household to the use of 12kl of water per month. If this amount was exceeded a fine of R1000 was imposed, and if water use exceeded 15kl users were charged an extra 200% on their account. Restrictions also prohibited users from irrigation of gardens and car washing (Wright, pers. comm, 2015). Signage used to warn the community of water restrictions is shown in Figure 1.5. This signage was mounted on poles around the town, as well as displayed on government vehicles.

Figure 1.5: Examples of Signage (Holloway et al., 2012)

Water 'load shedding' was introduced to the town in November 2010. The water shedding aimed to distribute the disadvantages of no water to all residents equally. The town was divided into 12 areas, and each area had no water for 36 hours at a time (Saving Water SA, 2010). Water tanks were set up in at least five places to ensure that people had access to drinking water, with a ration of 5 litres per day (Mayer, 2011). The Beaufort West central business district was excluded from the water shedding programme for economic reasons, in order to minimise financial loss due to the drought. There were many technical problems with water shedding, as well as objections from the community. Residents were unhappy due to the lack of water supply, and felt that their basic rights were being infringed. Technical problems included issues such as pipe bursts due to the build-up of pressure during water shedding periods when they were shut off. In order to ensure that people had sufficient water during load shedding periods, bottled water was supplied to households, which created logistic problems with storage and delivery of the water bottles. A total amount of 120 000 bottles was received from the Western Cape Disaster Management Centre (Wright, pers. comm, 2015).

The medium-term strategy focussed on increasing the water supply. This included further groundwater exploration, water reclamation, and desalination of existing boreholes. The long term-strategy is to develop a field of boreholes 30 kilometres out of town, which will operate in conjunction with the water reclamation plant (Marais & Durckheim, 2012). A summary of the water saving measures discussed is shown in Table 1.4, which includes the date the measure was implemented, as well as a short description.

Table 1.4: Summary of Emergency Water Management Measures: Beaufort West 2009 – 2011 (Adapted from Holloway et al., 2012)

Date	Measure	Description
Apr 2009	Water restrictions	First introduced
Nov 2009	Water restrictions increased	Consumers fined R150 for monthly water consumption > 12 kl
Jul 2010	Drought tariff coupled with Gamka Dam level	Consumers fined R1000 for monthly water consumption > 12 kl. If consumers exceeded 15 kl/month consumption, a 200% surcharge was applied to their water accounts
Nov 2010	Water demand shedding introduced	Necessary as reservoirs had run dry. Water supplies to 700 households cut for 48 hours initially, then extended to 2000 households for 36 hour stretches. The CBD, hospitals and industrial areas were not required to comply with water load shedding
	Bottled water distribution	120 000 x 5 l bottles of water were distributed (20 l/household every 48 hours). This constituted a major logistics exercise. Ninety temporary staff members were locally employed for this operation
	10 additional boreholes drilled	To acquire additional groundwater

Effects of Water Saving Strategies

The effects of water demand measures on consumption are shown in Figure 1.6. The measures presented in Table 1.4 resulted in an overall reduction of water consumption of approximately 50% (Wright, pers. comm, 2015). Although, it is evident from the graph that the demand measures did have a significant effect on consumption levels, this was not sufficient to solve the water scarcity problem in the long term.

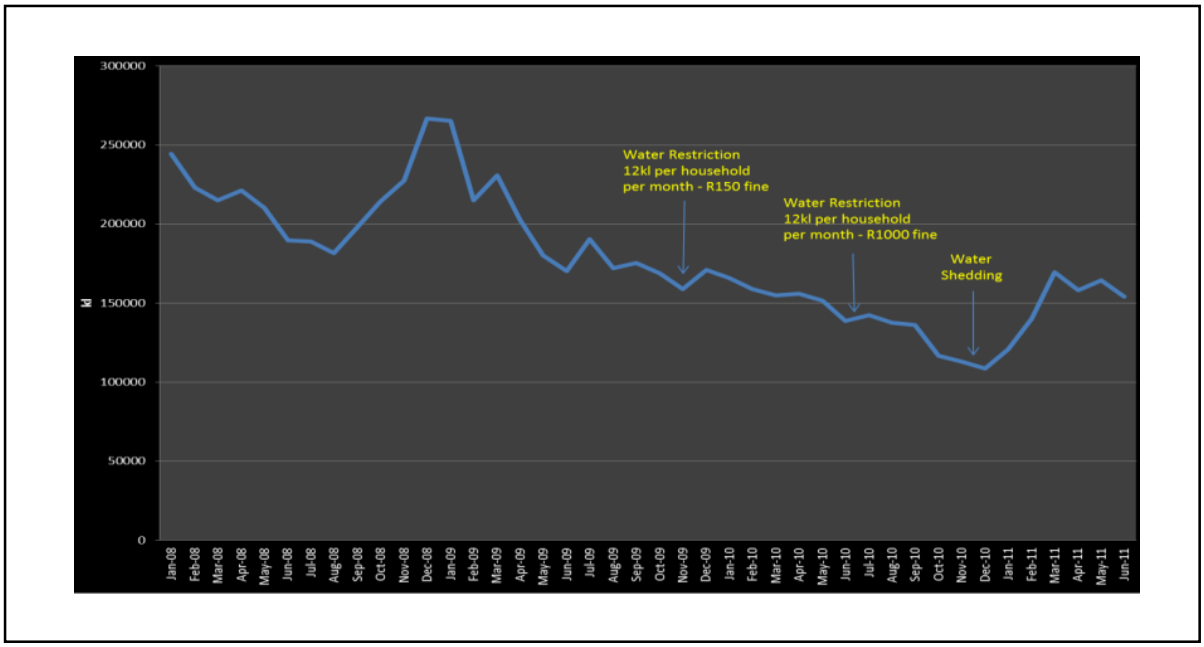


Figure 1.6: Water Consumption from Jan 2008 to June 2011 (Holloway et al., 2012)

1.7.2 Implementation of Beaufort West Water Reclamation Plant

After the completion of the short term strategy and the groundwater exploration, the next sustainable solution as part of the medium term strategy was the implementation of the Beaufort West Water Reclamation Plant. The demand measures implemented thus far were relatively inexpensive and easy to implement, contrary to the reclamation plant which would require government funding. This funding, enabling the construction of the plant, was received from the National Treasury in 2010.

The project included the construction of a new rising main to the existing reservoirs, for blending of the reclaimed water with water from different sources. The project was conducted in three phases, the EIA/planning phase, construction phase and the operational phase. Since the water scarcity situation in Beaufort West had been declared as a disaster, the project was fast tracked, and completed in 6 months. The first reclaimed water was delivered to the community of Beaufort West in January 2011.

1.8 Research Outline

1.8.1 Research Objective

The objective of the study is to explore the concept of the sustainability of water reclamation for potable purposes, through an assessment of the Beaufort West Water Reclamation Plant, as well as an examination of the relevant literary material. The study incorporates the use of economic, environmental and societal indicators to aid in determining the sustainability of water reclamation.

Furthermore, through the assessment of the plant, and review of the relevant theoretical literature, the study aims to determine whether potable water reuse can be employed as a viable solution to the problem of water scarcity.

1.8.2 Rationale for the Study

As a result of the widespread water scarcity in South Africa, there is high interest in the project within the water sector, as water reclamation plants are considered for a number of other South African towns and cities (DWAF et al., 1999).

Due to the prediction of an increased stress on water sources in the future, resulting from climate change, population growth, urbanisation and economic growth, it is imperative that we research alternatives such as water reclamation and evaluate their long term sustainability. The impacts of wastewater treatment have an impact on both local and global sustainability. There is growing concern globally on the impact of current practices on the environment, resulting in the necessity to develop wastewater treatment technologies which consider environmental, economic and societal sustainability (Muga & Mihelcic, 2007).

A major challenge to the implementation of water reclamation for potable purposes is public perception. People have a negative perception towards water which was previously sewage, and refuse to consume it (Asano et al., 2007) The research will investigate the extent of public participation and stakeholder engagement during the project definition phase, as well as any records of public dissatisfaction post-implementation. This will allow an understanding of whether the public is aware that they are drinking reclaimed water, the education they have received regarding the reclamation process, and the extent to which they were involved in the decision making process.

1.8.3 Research Delineations (Scope)

The intended research will assess one water reclamation plant, the Beaufort West Water Reclamation Plant, and then draw on this information to assess the sustainability of direct potable reuse.

The public of Beaufort West were not interviewed for the determination of the social sustainability of the plant, since this does not fall within the scope of the research, and would be more suited to a social science study. In order to determine public perception, the information provided to the citizens regarding the plant is reviewed, and conclusions regarding sustainability aspects drawn. Any negative feedback received from the public is discussed.

The method of assessing each indicator, as defined in section 3.4, dictates whether the evaluation of a specific indicator will be qualitative or quantitative. Although certain indicators are assessed quantitatively, it can be noted that the assessment performed is predominantly qualitative.

The research aims to assess the sustainability of the chosen indicators, without considering which indicators carry more weighting than the others. The prioritisation of indicators is not considered since this requires a substantial amount of research, which could be considered for future research.

1.8.4 Expected Outcomes

Considering Beaufort West as a pilot plant, based on the assessment performed, an indication is provided as to whether water reclamation for direct potable reuse is a sustainable solution to the problem of water scarcity. This is done by comparing the indicators for Beaufort West Water Reclamation Plant to South African and International Standards.

This type of system will become important to those countries currently and potentially suffering water scarcity, especially if it proves to be sustainable in the long term. Thus, research in this field is crucial for further development and ensuring that people have access to the basic resource of water.

1.8.5 Report Outline

Chapter 1: Introduction

This chapter provides a background to the study, through a discussion of water scarcity on a local and global scale, climate change and its predicted impacts on water resources, and the need for water reuse. The water history of Beaufort West is presented, in order to contextualise the sustainability assessment of the Beaufort West Water Reclamation Plant. Furthermore, the chapter introduces the research objective, rationale for study, scope, and outcome of the study.

Chapter 2: Literature Review – Water Reuse

The literature review explores the concept of water reclamation and reuse. This includes a discussion of the evolution of wastewater reclamation, its future potential, benefits and shortfalls, and the current technology available. The chapter also reviews public perception regarding water reuse projects. The New Goreangab Reclamation Plant, in Namibia, is presented as an example of a successful reclamation facility.

Chapter 3: Research Method

The research method for the study is described in this chapter. A description of the site visit, and the methods that have been applied to draw a conclusion regarding the sustainability of each indicator are provided. Thereafter, the chosen indicators are discussed, as well as the reasons for their choice. This includes an exploration of the applicable literature, previous studies, and South African Regulations.

Chapter 4: Beaufort West Reclamation Plant Sustainability Assessment

In chapter 4, the selected sustainability indicators are applied to the Beaufort West Reclamation Plant, in order to assess the sustainability of water reclamation for direct potable reuse. Information regarding each indicator is drawn from the visit to the plant, data sourced about the plant, and relevant literature on water reclamation.

Chapter 5: Conclusions and Future Research

This chapter has two main objectives. Firstly, it aims to provide a summary of the findings of the literature study, as well as the main findings regarding the chosen indicators, with special regard to the Beaufort West Water Reclamation Plant. Secondly, the chapter outlines future research needs, which will aid in assisting decision makers regarding the implementation of potable reuse projects.

2. Literature Review: Water Reclamation and Reuse

Water reclamation involves the treatment of wastewater to meet defined water quality standards so that it may be reused. Reuse has become an attractive alternative since the supply of water cannot meet the demands of growing communities. Water reuse offers a dependable alternative water source because it is always available in urban areas, even during drought periods. There are many elements involved in in incorporating a water reclamation system into a sustainable water resources plan, such as costs, public acceptance and treatment technology choices. Advances in technology have made water reclamation safer, more reliable and economical, which helps to address public health concerns. New technological advances, such as membrane treatment, may encourage the greater use of reclaimed water (Asano *et al*., 2007).

Water reclamation and reuse requires a considerable amount of infrastructure development and planning as well as specific attention to public health, since the source of the water is normally of the lowest quality. The main aim of water reclamation is to close the hydrologic cycle on a much smaller scale, through the conversion of the wastewater effluent to a valuable resource, which is readily available to the community (Asano *et al*., 2007).

This chapter begins with a general discussion of water reclamation and reuse, and provides examples of where it is currently practiced in South Africa. Alternatives to water reuse for obtaining additional water sources are discussed, before proceeding to an evaluation of potable water reuse. The review then considers direct potable reuse, which is the main focus of this study. Finally, the case of the Goreangab Reclamation Plant is reviewed, as an example of a successful direct potable reclamation plant. The aim of the chapter is to gather information about water reuse, which can then be applied to the sustainability assessment of the Beaufort West Plant.

2.1 The Evolution of Water Reclamation and Reuse

Wastewater reuse can be traced back approximately 3 000 years, when water was reused for agricultural irrigation (Asano *et al*., 2007). The beginning of modern water reclamation systems can be traced to the mid nineteenth century, when wastewater systems were employed for the transportation of household waste from urban settlements into the nearest water courses. This polluted water caused nauseating conditions in cities such as London, but also resulted in outbreaks of cholera amongst those using water from public water supplies such as the River Thames. Due to the water supply – disease link, engineering technologies advanced to include alternative water sources such as reservoirs and aqueduct systems, and the introduction of water filtration during the

1850s and 1860s. A large step toward the advancement of wastewater treatment and the development of biological wastewater systems occurred in the early 1900 with the advent of the activated sludge process. It was around this time that references involving public health and water quality requirements were first made. Advances in technology as well as the biological and chemical processing of water and wastewater led to the contemporary era of water reclamation and reuse, which began in 1960. In 1968 in Namibia, direct potable reuse was successfully introduced as a solution to the extreme drought conditions. This was the first direct potable reuse scheme in the world (Asano *et al*., 2007). Table 2.1 below provides a summary of the issues and constraints regarding both direct and indirect potable reuse.

Table 2.1: Potable Water Reuse Applications, Experiences and Challenges (WRC, 2015)

Type of reuse		**Application**	**Issues and Constraints**	**Experiences**
Indirect potable reuse (IPR)	Replenishment of aquifers	Groundwater replenishment by means of infiltration	Groundwater contamination Toxicological effects of organic chemicals	Successfully practiced since 1970s Multiple barrier treatment ensures safe potable water
	Replenishment of dams	Surface dam augmentation	Health concerns Public acceptance	Successfully practiced since 1970s
Direct potable reuse (DPR)		Pipe to pipe blending of purified water and potable water	Health concerns and issues of unknown chemicals Public acceptance Economically attractive in large-scale reuse	Multiple barrier treatment ensures safe potable water production No health problems related to recycled water in Namibia since 1968

Potable reuse is the reuse of wastewater for drinking purposes after it has undergone sufficient treatment to produce water that is safe for human consumption. Direct reuse involves the use of wastewater which has been treated to meet the required standards, without the use of an environmental buffer, such as an aquifer, between the site where the water is produced and the end

user. Indirect reuse involves the release of treated wastewater to a natural buffer, such as an aquifer, surface water or groundwater body, prior to being extracted for further use (WRC, 2015).

2.2 Current Wastewater Reuse Practices in South Africa

A few communities in South Africa are currently practicing wastewater reuse. The categories of reuse in practice are household, district, urban/agricultural and industrial reuse. Urban/agricultural reuse involves the collection of wastewater at a central point, from domestic and non-domestic sources within the area. This wastewater is then treated and the effluent used for non-potable purposes. This category of reuse in practiced in KwaZulu-Natal under the authority of the eThekwini municipality, and in the Western Cape, under the authority of the City of Cape Town (Adewumi *et al*., 2010).

2.2.1 Household Wastewater Reuse

Household wastewater reuse involves the collection and treatment of wastewater for non-potable purposes, within the same building it was generated. This category of reuse is practiced in the towns of Carnarvon and Kimberley in the Northern Cape (Adewumi *et al*., 2010).

Prior to 2005, the village of Carnarvon was facing a heavy financial and environmental burden over the management of domestic wastewater, which included bath, shower, and kitchen water. Since infrastructure to remove wastewater from households was not present at the time, residents stored their wastewater in containers, which was collected twice a week by municipal workers and deposited at the existing wastewater treatment works (Adewumi *et al*., 2010).

To address the wastewater issue, several wastewater recycling systems were investigated and pilot projects undertaken. The outcome of this investigation was the choice of a system which requires residents to direct their wastewater into a 50l drum via a filter trap and sump. When the sump fills up, a submersible pump is activated which pumps the water through a hose and sprinkler onto the garden for irrigation. Operation and maintenance workshops were performed with households to ensure awareness and efficient functioning of the system. This type of system may be harmful to animals and children that use the irrigated lawns, and may have a negative environmental impact in the long term due to the accumulation of unwanted chemicals in the irrigated soil (Adewumi *et al*., 2010).

In Hull Street, Kimberly, houses are fitted with a dual pipe system which supplies drinking water and non-potable treated wastewater to their appropriate uses. Wastewater produced by washing

machines is reused to irrigate lawns while wastewater from the kitchen sink is filtered through rock-filled trenches before entering the groundwater system (Adewumi *et al*., 2010).

2.2.2 District Wastewater Reuse

In this category of reuse wastewater is collected at a central location from several buildings, and then treated and used for non-potable purposes in the same or other buildings. This form of recycling is used in the Lynedoch Eco-village, Western Cape Province (Adewumi *et al*., 2010).

The Eco-village is a pilot sustainability project that was implemented in 1999 as a response to the water scarcity crisis in the Western Cape. Due to the water scarcity crisis there was a predicted increase in water tariffs due to the need to supplement water supplies with new dams, ground water aquifers or desalination, and the need to achieve economic efficiency through the reuse of wastewater (Adewumi *et al*., 2010). The project included the construction of two wastewater treatment works. The first treatment facility removes the solids, and leaves the nitrogen and phosphorus in the water, making it suitable for irrigation. The second treatment facility removes the nitrogen and phosphorus producing an effluent which is low in nutrients, suitable for toilet flushing. This project did not turn out to be economically viable, since the overall costs of producing the effluent were above the drinking water tariff, by about 400% for the first treatment facility, and 300% for the second. However, the system was successful in meeting the goal of saving drinking water since there was a 54% saving in drinking water over the tenth month period it was tested (Adewumi *et al*., 2010).

2.2.3 Urban/Agricultural and Industrial Reuse

The eThekwini Unicity Council has entered into a public-private partnership agreement with private investors regarding the production of treated wastewater for industrial applications. The wastewater treatment works, which treats both domestic and industrial wastewater, supplies 74% of its effluent to Mondi Paper. Benefits of this project include a reduced cost of water services to Durban's citizens, a reduction of Mondi's water bill by almost half, and the creation of revenue from the production of recycled water (Adewumi *et al*., 2010).

The City of Cape Town is one of the few South African authorities which has had a wastewater reuse system for several decades. This system has become an essential part of the city's integrated water management plan. This system involves supplying treated wastewater to non-domestic consumers for irrigation and industrial use. The water is only provided to non-domestic consumers to ensure public safety by avoiding human contact. The use of treated wastewater is highly attractive to large non-

domestic consumers, since the tariffs are approximately 50% less than for drinking water (Adewumi *et al*., 2010).

2.3 Future for Water Reuse

Progress in the design of the technology used in water reclamation systems has been made steadily since the 1970s. Even with the advancement of technology, there are many factors which have stalled the use of these systems such as; economic and institutional challenges, regulations, and social aspects, especially public acceptance. Water reclamation and reuse may be economically viable in the long run, however the extended treatment of water for reuse can be costly and energy intensive, in comparison to using alternative freshwater supplies such as groundwater and inter-basin transfers (Asano *et al*., 2007).

Although the experts have embraced water reuse and reclamation as a new water source for multiple reasons – water conservation, economic advantages, environmental benefits, long term sustainability - the public perception of reclaimed water as well as official decision making has hindered its progress. As technology advances and the reliability and safety of water reuse is demonstrated, public policy and perception will hopefully grow to embrace these advances, as well as understand the important role of water reclamation in the future. Water reclamation has been identified by many experts in the field as a vital element in sustainable, integrated water resources management (Asano *et al*., 2007).

2.4 Alternatives to Water Reuse

In a study performed by Golder Associates (2012), to evaluate the potential for the introduction of a direct potable reuse plant in Durban, South Africa, a comparison was done between water reuse and other reuse options. This comparison was initiated by a number of stakeholders opposing the proposed reclamation project. The following alternatives were suggested to achieve water security:

- Reuse of treated water for grey purposes only, i.e., commercial and domestic applications such as landscaping, laundry and toilet water;
- Construction of additional dams;
- Desalinisation of seawater from the Indian Ocean, possibly powered by alternative energy;
- Implementation of strict conservation measures such as tariffs, cuts, restrictions, demand reduction incentives, and repairs to leaks in the distribution infrastructure.

Upon investigation it was found that the reuse of treated water for grey purposes only, and the implementation of strict conservation measures are cost prohibitive due to the extensive nature of

the infrastructure overhaul that would be necessary for their implementation, and would result in steeper increases in water prices than reuse. Efforts to reduce demand through consumer incentives and education are being explored, but enforcement of violations is costly and difficult to implement. The remaining two measures, the construction of additional dams and desalination of seawater, are being investigated by the eThekwini Municipality in parallel with the water reuse alternative, but are costly, and cannot be implemented soon enough to meet current demand (Golder Associates, 2012).

2.5 Worldwide Potable Reuse

Most of the development in water reuse has taken place in the USA, Australia, Middle East, Southern Europe, China, Singapore and Southern Africa. The regions in which potable reuse has developed are either arid or semi-arid areas, characterised by water scarcity as a result of low rainfall and prolonged periods of droughts.

A list of all plants producing potable water around the world is provided in Appendix B. It must be noted that the only direct potable reuse plants are in Namibia and South Africa, while the remainder are indirect potable reuse plants (WRC, 2015).

Urban growth in developing countries has led to a pressing water situation. In many parts of Asia, Africa and Latin America engineered wastewater collection systems and treatment works are quite rare. Even where wastewater collection systems have been introduced, they often discharge the untreated effluent into the nearest watercourse. In many developing countries wastewater is too precious to discharge into natural watercourses as it contains valuable water, as well as nutrients which produce higher crop yields than when using fresh water for irrigation. In developing countries, farmers may use wastewater out of dire necessity, and not as a result of a planned reuse and reclamation system. The unplanned use of this wastewater results in public health risks as well as environmental risks, especially during the era of rapid urbanisation in developing countries, and gives water reuse a negative perception among the public (Asano *et al*., 2007).

2.6 Direct Potable Reuse

Direct potable reuse refers to the introduction of wastewater which has been treated to meet specified standards, directly into the potable water supply distribution system (Asano, 2007). Globally, direct potable reuse has become an attractive alternative to finding new water sources, since is provides a dependable water source, with relatively consistent quality and quantity, in close proximity to the demand (Leverenz *et al.*, 2011; Tchobanoglous, 2011). The rationale for the increased interest

in this alternative is that technology is available to produce treated water which satisfies all drinking water standards, and to obtain dependable water sources in areas with limited sources (Schroeder *et al*., 2012). Areas considering direct potable reuse are generally characterised by a combination of dry climate, population growth, increased agricultural requirements, urbanisation, and industrialisation (Ishiia *et al*., 2015).

In South Africa there is a lot of interest in direct potable reuse for several reasons. Since it is an arid region, southern Africa experiences difficulties with the availability of conventional water sources. The effects of prolonged droughts have resulted in the formation of short term contingency plans, and a need to re-evaluate water supply systems in the medium and long term. This has led to large scale interest in the application of water reclamation to sustain development and economic growth in the region. Water plants already constructed as a result of water shortage include; direct potable reuse plant in Beaufort West, the indirect potable reuse plant in George, and a plant in Mossel Bay which reuses water for industrial purposes. Furthermore, direct potable reuse plants have been proposed for Durban, Port Elizabeth, Cape Town and Hermanus (WRC, 2015).

Unlike in indirect potable use, in direct potable use there is no environmental buffer between the production of reclaimed water, and its delivery to the end consumer. In extreme cases, with severe drought conditions, direct potable water reuse consists of pipe-to-pipe blending of reclaimed and potable water. Direct potable reuse schemes are uncommon in the world, with the only two direct potable reuse schemes in southern Africa (WRC, 2015).

2.7 Potential Benefits

Direct potable reuse allows for the conservation of fresh water supplies, which are rapidly being depleted. There are also environmental benefits, such as the management of nutrients which may lead to environmental degradation, as well as the protection of aquatic environments by reducing the amount of effluent discharged. The need for supplemental water sources and associated infrastructure introduces economic advantages to water reclamation. In urban areas where water resources are most needed and highly priced, water reclamation is particularly advantageous since it can be performed in the vicinity of the urban environment. Reclaimed water is a highly dependable source of water, even in drought years, since the production of wastewater remains fairly constant (Asano *et al*., 2007).

Direct potable reuse can provides benefit in that it provides a new stable water supply source for cities. It also provides benefits to agriculture and environmental and energy conservation, which may be more important. In the National Water Research Institute White paper, Schroeder et al (2012) consider direct potable reuse as a better solution to the others proposed. The reasons for this will be discussed below.

2.7.1 Benefits for Public Water Supplies

With inter-basin transfers, only a limited amount of water for food production is available, and source area ecosystems are vulnerable and may be destroyed. Transmission systems such as pipelines which are used to transport the water from the source to supply area, are exposed to damage from natural disasters such as earthquakes and floods, which could ultimately result in the breakage of transmission of the water (Schroeder *et al.*, 2012).

Direct potable reuse seems preferable to desalination, since the energy required for desalination is much larger, and the brine disposal is a serious environmental issue. Direct potable reuse, comparatively, requires a modest amount of energy, and provides a stable water supply which is in close proximity to the need. Direct potable reuse cannot be used the sole water supply, since the water requirements of a city are greater than the wastewater produced. Water reclamation must be employed in conjunction with other sustainable solutions to provide an adequate water supply (Schroeder *et al.*, 2012).

2.7.2 Benefits for Agriculture

Water used for other purposes decreases its availability for agriculture. Water requirements for food production have increased due to the increase in population, as well the increased amount of animal and dairy products people consume. While satisfying these additional water requirements, aquatic systems must be protected. The following statistics illustrate the impact of diet on water requirements (Pimentel & Pimentel, 2003):

- Beef requires 100 m^3 of water per kg produced
- Soybeans require 2.0 m^3 of water per kg produced
- Wheat requires 0.90 m^3 of water per kg produced

These statistics illustrate that as people move away from a traditional diet including large amounts of carbohydrates, toward a diet consisting of meat such as beef, water consumption increases enormously. If direct potable reuse is applied to agriculture, the reuse of wastewater produced by a

population of 1 million people, could result in the production of a sufficient amount of water for the annual production of 1 050 tons of beef, or alternatively 115 000 tons of wheat (Schroeder *et al*., 2012).

2.7.3 Environmental Protection

Inter-basin transfers require the construction of infrastructure such as pipelines, reservoirs and canals. Direct potable reuse, and resultant minimisation of water importation to cities, will reduce the environmental impacts incurred from the construction of infrastructure (Schroeder *et al*., 2012). This is particularly significant for Southern Africa, which practices large scale inter-basin transfers, as discussed.

In a direct potable reuse system, there is a limited discharge of effluent into natural water systems. If the treated water is returned to the environment, there is less risk of contamination than wastewater water that has been treated to non-potable standards and therefore contains greater levels of pollutants (Golder Associates, 2012). This is especially important as direct potable reuse will protect ecosystems which are currently being degraded. Although this is considered a benefit according to some researchers (Asana *et al*., 2007; Ishiia *et al*., 2015), other researchers believe that water reuse will result in the build-up of contaminants, which will be discussed later in this chapter.

2.7.4 Reduced Energy for Pumping Water

The transport of water across watershed boundaries increases the embodied energy of the water and requires a well-developed extensive infrastructure network, which may result in adverse changes in an ecosystem's hydrology (Muga & Mihelcic, 2007). Direct potable reuse by comparison, requires less energy input and a more localised infrastructure network. This energy requirement can be contextualised by looking at the Colorado River Aqueduct project in the US. To transport 1 500 hm^3 of water per year from the Colorado River to Southern California, requiring the water to be lifted 493m, consumes 2 400 gigawatt hours of energy per year. This calculation does not include the resources required to construct and maintain the 387 km aqueduct, consisting of 101 km of canals, 147 km of tunnels, and 134 km of pipes (Wilkinson, 2007).

The consideration of energy requirements for various water scarcity solutions is debated among authors. As will be discussed, the energy requirements for direct potable reuse could be seen as extensive.

2.8 Factors Hindering Direct Potable Reuse

In the case of direct potable water reuse several complications may be encountered such as cost factors, technological capabilities, public perceptions and health risks. Municipal wastewater is received from multiple sources, such as, commercial facilities, hospital, houses and schools. The quantity and quality of the effluent reaching the wastewater plant depends on the source, industrial establishments in the area, condition of the wastewater collection system and several other variables. As a result of this, wastewater contains many pollutants and contaminants, some of which may be hazardous to human health and natural environments (Asano *et al*., 2007).

2.8.1 Public Acceptance

Communities experience psychological difficulties when faced with the idea of drinking water which once contained human wastes, such as excreta. There exists the most resistance towards the direct potable reuse category regardless of the level of treatment and water quality produced. The lack of a natural buffer results in a feeling among communities that there is no loss of identity by natural purification, regardless of the treatment undergone, and the water is still viewed as wastewater (Asano *et al*., 2007; Dishman *et al*., 1989). Based on recent studies it has been found that through proper education and understanding of water reclamation for potable purposes, support can be gained from communities (Asano *et al*., 2007). Since public acceptance is a determining factor in the success of reuse projects it is discussed in detail in section 2.13.

2.8.2 Health Concerns

As with traditional water supplies, reclaimed water must be safe for human consumption, in terms of pathogenic organisms, inorganic pollutants, and organic micropollutants (Dishman *et al*., 1989). Despite the advances in analytical techniques used for measuring inorganic and organic constituents in wastewater, it can be concluded that consumers still perceive the same amount of unknown risk regarding the consumption of traditional water supplies and direct potable use. It Is not possible to be certain that direct potable reuse will be 100% safe, but Asano et al. (2007) maintain that there is sufficient information regarding the health impacts of many trace constituents, that it would be prudent to wait for further information before proceeding with direct potable reuse.

Waterborne diseases are spread by microorganisms such as protozoa, bacteria and viruses. These diseases are spread to humans by consumption of contaminated water, person-to-person contact, and contaminated surfaces or food. It is possible that any potable water supply receiving human or animal wastes can be contaminated by microorganisms. There have been no documented cases where

the use of reclaimed water meeting the specified quality standards has caused disease, although the most common concern in water reclamation and reuse is the spreading of diseases. However, in developing countries the use of municipal wastewater which has been inadequately treated remains a public concern (Asano *et al*., 2007).

With sufficient water quality monitoring to guarantee that the final reclaimed water adheres with the South African National Drinking Water Guidelines, the risks posed to public health are minimal. A system must be designed to ensure water quality, as well as sufficient safety measures, and methods to ensure that if there is a failure the water reaching consumers is not contaminated.

2.8.3 Technological Capabilities

There is emphasis on the machinery and processes used to treat the influent wastewater since it will not undergo any natural processes to act as an environmental barrier and further improve the water quality. The technology used to produce safe reclaimed water should be such that it poses no additional health risk over traditional drinking water sources (Asano *et al*., 2007).

The high degree of reliability required for the production of safe drinking water has been overcome by the use of multiple barrier systems, which use sequential and redundant processes to remove constituents of concern. A redundant system ensures that if one process fails to remove a certain type of contaminant there are other processes capable of removing the same type of contaminant. Technology has progressed to allow for real-time process monitoring and control, as well as enhanced membrane systems and oxidation processes which are capable of fully removing trace constituents resulting in the production of high quality potable water which exceeds current drinking water standards (Asano *et al*., 2007). The availability and cost of this technology may pose a problem for communities.

The main engineering issues in a water reclamation and reuse project are:

- water quality
- public health and protection
- wastewater treatment alternatives
- pumping, storage and distribution system design
- matching of supply and demand for reclaimed water
- supplemental and backup water supplies

2.8.4 Lack of an Environmental Barrier

Consumers consider a natural buffer, such as a dam, river, reservoir, aquifer or wetland, as an important indicator as to whether they are drinking water of an acceptable quality. For a direct potable reuse scheme, there are no natural buffers between the wastewater treatment plant and the consumer (Golder Associates, 2012).

Research undertaken by the United States National Research Council (2012) on the assessment of water reuse as an approach to meeting future water supply needs, has found that buffers do not provide any cleansing properties that are not available through the use of engineered processes, and are not essential in offering quality assurance. This research shows that direct potable reuse, by comparison, does not place public health at greater risk than indirect potable reuse, which releases water into dams and aquifers.

2.8.5 Cost Considerations

There are several factors which influence the cost of a water reuse programme, including the location of the municipal wastewater treatment works which supplies the reclaimed water source, the size and location of the reclaimed water facility, treatment infrastructure, influent water quality, and energy requirements (NRC, 2012). Therefore, capital costs are site specific and can vary significantly from one community to another.

In general, reclaimed water treatment facilities would be placed in close proximity to a water treatment facility, which supplies them with treated effluent, to be treated further. Wastewater treatment facilities are usually constructed at lower elevations, and close to discharge points such as a river, lake or ocean. The result of this is that there are pumping costs to transfer the water from the treatment works to the reclamation facility, as well as to the end users (NRC, 2012).

In terms of size, multiple smaller decentralised plants may ultimately be preferable, contrary to the historical preference of centralised treatment facilities. The advantage of these decentralised plants include the location of water treatment closer to consumers, allowing a reduction in the cost of pumping and distribution infrastructure (NRC, 2012). A noteworthy disadvantage of decentralised plants is that many highly trained plant operators will be required, instead of the few plant operators needed for centralised treatment facilities.

The quality of the incoming water, i.e. the effluent from a wastewater treatment plant, is a significant factor in the production costs of reclaimed water. The poorer the quality of water, the more treatment it requires, increasing the cost. An example of a factor which affects water quality negatively, is water conservation. As water conservation measures become more effective, the volume of wastewater discharged diminishes, but the pollutant mass may remain unchanged. This causes the concentration of contaminants in the wastewater to increase, requiring additional treatment, and increased costs at the treatment facility on a volume basis (NRC, 2012). An example of a measure that increases the water quality is the implementation of an industrial pre-treatment program, which limits the discharge of harmful contaminants, and improves the quality of the effluent, thereby requiring less treatment (NRC, 2012).

Another concern, is the energy requirement, especially in the South African context where energy supply is already a problem. In addition to the energy requirement of the wastewater treatment plant, energy is needed in several phases of the reclamation process, including transmission to the reclamation plant, advanced treatment, and distribution to the consumer. The energy costs would be specific to a particular reuse project as it is affected by variables such as the distance from the wastewater treatment works to the reclamation plant, treatment technologies used, the size of the plant, the water quality requirements, and the topography of the service area which affects the energy required for pumping. The price of energy will also influence energy costs (NRC, 2012).

2.8.6 System Failures

A major concern relates to mechanical and operational failures at water treatment facilities, or anywhere along the water distribution system. The public perceives the advanced technology used in water reclamation as extremely vulnerable to technical malfunction, and have maintained attitudes that engineering technology is still incapable of treating wastewater to potable levels (Golder Associates, 2012).

If the water reclamation system is well designed, reliable and robust, effluent of higher quality than conventionally treated water can be produced (NRC, 2012).

2.9 Water Quality

Municipal wastewater includes a vast range of biological, inorganic and organic constituents. The harm which may be caused by these constituents, to a person or an ecosystem, is dependent on the concentration and duration of exposure. Some are essential nutrients at low concentrations, but may

become hazardous at higher concentrations. Water reuse has many potential applications, therefore the particular constituents of concern depend on the final use of the water. For example, certain constituents may impact human health when consumed, but have no impact when the same water is used for landscape irrigation. Other constituents may impact aquatic species but pose no threat to human health (NRC, 2012). Since, this study concerns potable reuse, concerns regarding the drinking of treated wastewater in relation to public health will be discussed.

2.9.1 Pathogens

Although wastewater may contain many microorganisms, it is only a portion of them, above a certain concentration, which are potential human health hazards. The microorganisms capable of causing infections include helminths (wormlike parasites), protozoa, bacteria and viruses. A grave concern, among the public; and officials, is that disease causing viruses to be present in untreated wastewater, including via human faeces, could still remain in the water after treatment. Pathogens can cause acute health effects which are sudden and severe (NRC, 2012).

Viruses are small infectious agents, which are of special concern in potable reuse applications due to their small size, resistance to disinfection, and their low infectious dose. The known agents of concern in water treatment and the diseases they cause have been given in Table 2.1. These viruses are usually present in untreated secondary effluent, and are capable of persisting in effluents after some advanced treatment (NRC, 2012).

Domestic wastewater contains many bacteria which are shed by human populations. Of particular importance are those bacteria which cause gastroenteritis, inflammation of the stomach and intestines, which causes vomiting and diarrhoea. Many disease outbreaks are caused by these bacteria, which are transmitted by the faecal-oral route (NRC, 2012). The associated illnesses with these bacteria are shown in Table 2.2. Due to these illnesses, and the health risks related to bacterial pathogens, monitoring systems and water quality standards have been established based on faecal bacteria, in many nations around the world. E. coli, a bacteria found in the intestines of humans, which are essential for proper digestion and nutrient uptake, are commonly used as indicators of the presence of human waste; in water quality monitoring. Although E. coli are generally harmless bacteria, and may only cause diseases in certain instances, the reason for their monitoring is that they are present in high concentrations in human faeces and sewage, and are more persistent than most bacterial pathogens. They are therefore used an indication of the adequacy of water treatment in terms of removal of bacterial pathogens (NRC, 2004).

Table 2.2: Microbial Agents and their Associated Illnesses (Asano et al., 2007)

Agent	Associated Illnesses
Viruses	
Noroviruses	Gastroenteritis
Adenoviruses	Conjunctivitis, gastroenteritis, respiratory disease, pharyngoconjunctival fever
Coxsackieviruses	Meningitis, pharyngitis, conjunctivitis, encephalitis
Echoviruses	Gastroenteritis, encephalitis, meningitis
Entiroviruses	Hepatitis A
Astroviruses	Gastroenteritis
Bacteria	
E. coli	Haemorrhagic diarrhoea, Gastroenteritis
Campylobacter jejuni	Campylobacteriosis
Salmonella	Salmonellosis
Shigella	Shigellosis
Vibrio	Gastroenteritis, wound infection, cholera
Legionella	Legionellosis
Protozoa	
Cryptosporidium	Cryptosporidiosis
Giardia	Giardiasis
Microsporidia	Microsporidiosis

2.9.2 Inorganic Constituents

A variety of inorganic constituents are found in wastewater, including metals, nutrients and salts. Generally an aggregate measure, called total dissolved solids, is provided for the amount of inorganic constituents in the water. Human and industrial activities consistently increase the total dissolved solids in water, thus water reuse will increase the total dissolved solids in the water supply (NRC, 2012).

Metals such as lead, mercury, chromium, arsenic and boron can be detrimental to human health if consumed in large amounts. However, the South African National Standard for Drinking water, SANS 241-1:2011, specifically targets toxic metals, and as a result most municipal effluents have concentrations of toxic metals within public health guidelines and standards.

The reuse of wastewater generally results in the accumulation of inorganic ions, which can result in aesthetic issues as well as infrastructure damage through corrosion (NRC, 2012). Elevated concentrations of calcium and magnesium are responsible for hardness, and damage to household appliances. 'Hard water' is water which has a high concentration of calcium and magnesium, which causes damage to equipment which uses water. There is no evidence to suggest that hard water causes adverse health effects in humans. Excess sodium and chloride concentrations in reclaimed water can be detrimental to plants, because they cause leaf burn and negatively affect soil structure. Therefore, careful control of salt concentrations is crucial to water reuse (NRC, 2012).

A large amount of nitrogeness and phosphorus compounds are present in human waste, as the human body metabolises and excretes both nitrogen and phosphorus in various forms. One of the primary forms of nitrogen, nitrate, found in drinking water, can cause public health issues, especially in infants. Although nutrients such as nitrogen and phosphorus are beneficial for irrigation, an overload of nutrients can lead to nutrient contamination of underlying aquifers, surface waters, lakes and streams, resulting in the eutrophication of open water bodies. The result of the excess nitrogen is a stimulation of the rapid growth of algae which can deplete the oxygen content in the water, alter the state of an ecological system, affect the functioning of water treatment plants and result in the production of compounds that affect taste and cause odours in water(NRC, 2012). The SANS 241-1 thus also provides limits for nutrients such as nitrogen and phosphorus in treated water.

2.9.3 Organic Constituents

Wastewater is rich in organic matter, measured in water quality tests as total organic carbon. Organic chemicals have several origins. Organics such as pesticides, personal care products and preservatives originate from domestic products and activities. Certain endocrine disruptors such as pharmaceutical residues and steroidal hormones are excreted by humans, while others are formed during the water treatment process. Although modern technology is capable of detecting even minute concentrations of these chemicals present in reclaimed water, not all may be harmful to human health in small concentrations or with intermittent exposure. Organic chemicals can, however, cause chronic health effects after extended periods of consumption (NRC, 2012).

Those chemicals originating from industrial processes need to be considered when wastewater becomes part of a domestic water supply. Common industrial chemicals include solvents, detergents, petroleum mixtures and a range of other products, some of which are not removed completely by the

water reclamation process. For example, dioxane, a common industrial solvent, has been shown to break through reverse osmosis membranes (NRC, 2012). In order to limit organic chemicals in drinking water, the SANS 241-1:2011 provides standard limits for the total organic carbon, as well as other specific organic determinands.

Recently a great deal of attention has been given to the occurrence of personal care products and pharmaceuticals in wastewater effluents. It is logical that substances such as shampoo and perfumes enter the sewer system since they are used by the majority of the population (NRC, 2012). Research indicates that continuous exposure to these organic chemicals, as well as those hormones naturally excreted by the human body, known as endocrine disrupting compounds, may cause a wide variety of physiological, behavioural and reproductive effects in animals and humans. It is also speculated that these chemicals may be linked to a variety of disorders, such as cancers of the reproductive organs as well as decreased sperm count in males. However, it must be noted that it is difficult to determine whether these chemicals are the actual cause of these disorders since there is a diverse range of potential risk factors, both environmental and genetic (Singhal *et al*., 2009). These chemicals have been widely detected in recent water tests, but the South African National Standards have not yet included limits for these substances in the regulations.

2.10 Ensuring Water Quality in Reclamation

In order to achieve a consistent reclaimed water quality, a system should be designed which incorporates appropriate treatment strategies such as high-level disinfection and process redundancy, technical controls such as alarm shut downs and frequent inspections, online monitoring devices which monitor factors such as residual chlorine concentration and effluent turbidity, and operational controls which react to system failures or variability (NRC, 2012). This section discusses those methods which are considered effective in ensuring water quality.

2.10.1 Design Principles

The main of objective of any reuse system is that public health is always protected, and that the final reclaimed water quality is acceptable to consumers. Acceptability is measured by the consumers' willingness to use reclaimed water. In order to ensure acceptability, four principles are usually the foundation of the design of the system, which are monitoring, attenuation, retention and blending (NRC, 2012).

Water quality is monitored through an online system as well as through the testing of samples in the laboratory. These practices follow the normal standards applied in drinking water systems. In terms of the production of potable water, monitoring requirements are stringent, since municipal wastewater contains many chemicals which originate from consumer products and industrial and commercial discharges. Thus monitoring programs for potable water reclamation are generally more complex than those for conventional drinking water supplies (NRC, 2012).

As will be discussed in the water treatment process section, attenuation of contaminants is achieved through the application of a multiple barrier system. A multiple barrier system ensures that if any one process fails to remove a certain contaminant there are similar processes capable of removing the same contaminant, and is an integral part of guaranteeing that the reclaimed water is safe for human consumption (NRC, 2012).

The purpose of retention is to allow additional time for the attenuation of contaminants, and to allow sufficient time to respond to system failures. Retention time can be provided by storing reclaimed water in a canal, segment of a river, conveying it through a pipeline system or storing it in a reservoir (NRC, 2012).

In accordance with South African drinking water regulations, reclaimed water must be blended with a water source other than wastewater, such as surface water or groundwater. This is because the treatment processes involved in reclamation remove most of the minerals from the water, and it is necessary to balance the water chemistry by blending to ensure public health. These factors of concern include the absence of minerals such as magnesium and calcium, prevention of downstream corrosion, and to minimize damage to soils and crops (NRC, 2012).

2.10.2 Water Quality Monitoring and Management

The Water Research Commission (2015), in their guidelines for monitoring and management of water quality in direct wastewater reclamation, propose monitoring systems for three key processes in a reclamation plant. These processes are raw water monitoring, operational and control monitoring, and compliance monitoring. The aim of this monitoring is to allow for the early detection of poor incoming wastewater quality, the maintenance of the various treatment barriers through alerts warning of a water quality malfunction, and compliance of the final water quality with the applicable standards (WRC, 2015).

The greatest health risk associated with the consumption of reclaimed water is microbial contamination, in terms of pathogens, and thus should be of primary importance. It is important that monitoring programmes prioritise the measuring of chemical contaminants. The optimal situation is that monitoring of the system should be done automatically, which requires advanced and expensive monitoring systems. Manual samples should also be taken to ensure that the monitoring system is functioning efficiently. Good protocols and communication will ensure that this can be achieved in an efficient manner (WRC, 2015).

There is a tendency to have a more extensive monitoring system for larger reclamation facilities, which serve larger communities, since the risk is considered to be higher. Smaller communities tend to have a scaled-down version of a monitoring programme. This is an incorrect approach because monitoring should be extensive regardless of the number of users (WRC, 2015). An important consideration in the design of monitoring programs is that the water quality should be communicated to all stakeholders, in order to convince them about the true reflection of water quality in the system, thereby gaining and maintaining their trust (WRC, 2015).

2.11 Direct Potable Reuse System Design

Contaminants in wastewater are removed via unit operations and processes. Unit operations involve the use of physical mechanisms, while unit processes use chemical or biological reactions. In a wastewater treatment plant there are various levels of treatment such as preliminary, primary, advanced primary, secondary, tertiary, and advanced treatment which comprise both unit operations and processes (Asano *et al*., 2007).

Potable reuse systems should be designed with treatment trains that include reliability and robustness. Redundancy ensures contaminant removal, particularly of those which pose acute health risks, and robustness employs a combination of technologies that address a broad variety of contaminants. Potable reuse systems should include redundant barriers for pathogens that cause waterborne diseases, and employ diverse processes that can function as barriers for many types of chemicals, especially considering the varied nature of chemical contaminants (NRC, 2012). As the level of human exposure increases, the higher the level of treatment that the water is required to undergo (Tram VO *et al*., 2014).

A wide range of treatment options exist to mitigate microbial and chemical contaminants in reclaimed water, which can be adapted to meet specific water quality needs (NRC, 2012). The design of the

Beaufort West Water Reclamation Plant is based on the system which has been successfully used at the Goreangab Water Reclamation Plant in Windhoek (Marais & Durckheim, 2012). The design of the Beaufort West Reclamation Plant differs from that of Windhoek in that there are fewer barriers employed. The treatment process mainly relies on two membrane filtration barriers, ultra-filtration and reverse osmosis, which are highly automated processes, and therefore easier to operate. Engineers at the Windhoek Plant did indicate that if they had to redesign their system, they would have used a reverse osmosis system like Beaufort West. The reason for this is that the Beaufort West system is highly automated, with alarms connected for monitoring purposes, and therefore does not require as many skilled personnel for the daily operation as the Windhoek system (Ivarsson & Olander, 2011).

The reclamation system used in Beaufort West has three stages: pre-treatment, main treatment, and post treatment. Pre-treatment consists of pre-chlorination, settlement in the maturation river, chlorine disinfection and rapid sand filtration. The aim of these processes is to reduce the pressure on the membranes thereby prolonging their lifetime. The replacement of the membranes is associated with high costs. After the pre-treatment, the main treatment consists of a series of membrane barriers where the majority of particles and pathogens are removed. In the post treatment stages, advanced oxidation, and final chlorination are employed as a safety barrier in ensuring that any remaining pathogens are removed (Ivarsson & Olander, 2011). Each step in the treatment process is discussed briefly below.

2.11.1 The Treatment Process

Ferric-Chloride Dosing

The first process, after the pre-treatment of the water at the wastewater treatment works, in order to prepare the water for potable reuse, is phosphate removal. In this process, Ferric-Chloride is dosed into the activated sludge (which is the biological material produced from the wastewater treatment process), to remove orthophosphates, as well as to ensure better settling of suspended solids in the next process (Marais & Durckheim, 2012). Orthophosphates are the inorganic forms of phosphates, which are used extensively in fertilisers.

Settling

The next process is settling. The maturation river acts as buffer between the original wastewater treatment works and the water reclamation plant. The final effluent leaves the existing treatment works and flows into a maturation river where the remaining suspended solids settle (Marais &

Durckheim, 2012). The total retention time of the water in the maturation river is 18 hours, to allow increased settling of particles (Ivarsson & Olander, 2011).

The maturation requires frequent cleaning to remove algae, settled particles and sludge. At times when the maturation river is being cleaned, the water is diverted to the next step in the process, which is sand filtration. Since the water is fed directly to the sand filters without prior settling, it has to be backwashed more often (Ivarsson & Olander, 2011).

Once the water has passed through the maturation river it is then fed into the reclamation plant and disinfected with chlorine (Marais & Durckheim, 2012). The aim of the disinfection process is to reduce pathogens, such as bacteria and viruses, as discussed above (NRC, 2012).

Sand Filtration

The water then undergoes sand filtration in order to remove all macro-organic matter, and any suspended solids which may not have been removed by the previous processes. The water is forced to pass through the granular media, sand, thereby removing suspended solids and particulate matter larger than the pore size. This also protects the downstream membranes from being damaged by large organic loads (Marais & Durckheim, 2012). This process does not remove any bacteria or viruses from the water (Ivarsson & Olander, 2011).

Ultra-filtration

The third barrier employed is ultra-filtration, which removes organisms by size exclusion. The water is pumped through membrane straws in order to remove particles larger than 0.05 um, such as bacteria, viruses, algae and protozoa (Marais & Durckheim, 2012). Ultra-filtration membranes are effective in the removal of micro-organisms (NRC, 2012).

Reverse Osmosis

The reverse osmosis process consists of semi permeable membranes which allow water to pass through, thereby removing the remaining organics, pesticides, hormones, aqueous salts and metal ions (Marais & Durckheim, 2012). Theoretically, the reverse osmosis membranes should remove all pathogens from the water as they are designed to remove relatively small molecules (NRC, 2012). The process requires high pressure and is therefore energy intensive (Ivarsson & Olander, 2011).

Advanced Oxidation

Although the water produced from the reverse osmosis process is suitable for consumption, advanced oxidation is employed as an extra precautionary barrier. It is a complex process which includes the dosing of peroxide, followed by the exposure of the water to Ultraviolet light. The purpose of this exposure is to destroy any remaining dissolved organic contaminants in the water, as well as kill any remaining pathogens. Furthermore, this process does not produce any hazardous by-products or air emissions (Marais & Durckheim, 2012).

Following the advanced oxidation, the pH is adjusted, and a small amount of chlorine is added to protect the water before it reaches the end user (Marais & Durckheim, 2012). The aim of this final chlorination is to prevent microbiological regrowth in the pipes, and provide protection from any pathogens which may be reintroduced. The water is then pumped to the reservoir to be blended with water from natural resources, in the ratio stipulated by regulations, and then distributed to the consumer.

2.12 Guidelines for Water Reuse

Guidelines for water reuse were initially developed in 1980 by the Environmental Protection Agency (EPA) of the USA, and updated several times, most recently in 2012. In order to develop this document and ensure that the information is current and relevant, intense stakeholder engagement was undertaken in the USA, and the document was researched, written, and reviewed by over 300 experts in the water reuse field. Currently there are no regulations developed specifically for direct potable reuse in the USA, although the EPA (2012) consider direct potable reuse as a viable option, based on advances in technology, monitoring methodology, and health effects data produced from indirect potable reuse projects, and direct potable reuse demonstration facilities.

The main points highlighted in the EPA guidelines are the inclusion of a viability assessment in any water reuse project, which examines water reuse laws, regulations, rules and policies in the area of the proposed project**.** Since dedicated design criteria for potable reuse are not available, the EPA (2012) states that the engineers should make use of the general design standards applicable to potable water, and ensure that a high standard of reliability is achieved at reclamation plants. It is also specified that public education is critical in the success of a project, especially in an area where the use of reclaimed water is not commonly practiced. Furthermore, the National Environmental Policy Act of the United States of America (NEPA) compels all projects receiving federal funds to perform an

assessment of environmental impacts, and provide mitigation measures for all significant impacts (EPA, 2012).

In 2015 the South African Water Research Commission drafted a final report titled 'Guidelines for Monitoring, Management and Communication of Water Quality in the Direct Reclamation of Municipal Wastewater for Drinking Purposes'. The main aims of this project were to document the status of water reuse for potable purposes for planning and regulatory purposes, use the outcome of the public perception research to develop effective communication methods for various stakeholders, and to provide the Department of Water and Sanitation with information that can be used to implement standards for potable water reuse in South Africa which can be included in the SANS 241 (WRC, 2015). The guidelines provided in this document have been adapted to produce Table 2.3, which will be incorporated into the sustainability study of the plant.

Table 2.3: Direct Potable Reuse Guidelines (Adapted from: WRC, 2015)

Aspect	Comment
Scheme feasibility	Political will is an important factor in determining whether the reclamation plant project will be a success
	There must be a steering committee established before a WRP is constructed. It should review the different catchments and sources to the plant and establish proper monitoring protocols
	Thorough EIA studies should be completed and the reduced return flow must be factored into the feasibility of the WRP. A minimum return flow to the environment can compete against upgrading the WRP in the future
	Financial feasibility must be established. It is also important to take into consideration that many WRP are built during extreme droughts and that the production capacity of the plant may reduce significantly once conventional water sources are no longer depleted
Water reuse plant	Proper operation and maintenance is very important for water quality over time
	Treatment process units must be thoroughly monitored. The monitoring data should be stored and reviewed in order to ensure that each of the treatment units perform as intended. Impromptu

	maintenance should also be carried out based on the monitoring results
	Filters should have a filter-to-waste option to ensure low turbidity (i.e. it should prevent particle breakthrough) after backwashing to ensure proper removal of *Giardia* and *Cryptosporidium.*

Table 2.3 Continued: Direct Potable Reuse Guidelines (Adapted from: WRC, 2015)

Aspect	Comment
Monitoring instruments	On-line monitoring is not optional for potable water reuse plants.
	The feed and final water of each of the treatment units must be measured at a high frequency in order to detect treatment failures.
Plant operators/process controllers	The process controllers of WRPs should have a sufficient skill level to understand each of the treatment processes that occur at the plant.
	Sufficient guidelines should be available on-site at each of the applicable treatment process units that can guide a process controller during emergencies.
	All process controllers must be able to use and calibrate hand held sampling devices
Public participation	Good analytical results and data management (archiving) is very important for public participation and motivating the use of certain technologies. The laboratory should also be promoted to set the minds of the public at ease.

2.13 Public Perception

As mentioned earlier, in addition to the technology available, public acceptance plays a significantly large role in the successful implementation of water reuse projects. Direct potable reuse is perceived as a radical change by the public, and therefore requires detailed research (Asano *et al*., 2007; Ishiia *et al*., 2015).

The first planned use of recycled water was in the 1950s, but it was only twenty years later that researchers began to examine issues such as public perception and acceptance of water reuse. This research was limited to finding methods of encouraging people to accept recycled water, since public acceptance was considered the primary obstacle to the implementation water reuse projects (Po *et al*., 2003).

2.13.1 Factors Affecting Public Perception

In a study conducted by Po *et al*. (2003), ten key factors which influence public perception towards water reuse were identified. These factors are the disgust factor; perceptions of risk associated with using recycled water; specific uses of recycled water; sources of the recycled water; issues of choice, trust and knowledge; attitude towards the environment; environmental justice issues; cost of recycled water; and socio-demographic factors. These factors are important in providing an insight into the reluctance of the public to accept the use of recycled water, and are discussed below.

Disgust Factor

The disgust factor experienced by the public is a psychological issue, which has been mentioned in literature repeatedly since the beginning of public perception studies in the 1970s (Asano *et al*., 2007; Po *et al*, 2003). This psychological barrier is formed at the thought of drinking recycled water, which is brought on for many people by their own mental image of raw sewage. A reaction of disgust to recycled water emanates from the perception that the water is 'dirty', and the fear of contamination, illness and disease, as a result of using this water (Po *et al*., 2003).

Terms used in the description of treated wastewater also affect the way people feel. It is for this reason that Singapore termed the recycled water produced at its plant as 'NEWater', and in San Diego, 'repurified water' (Po *et al*., 2003). A possible explanation for people associating recycled water with the emotion of disgust is through the 'law of contagion' (Rozin *et al*., 2015). This 'law' suggests that an object may acquire undesired properties from another object which can be considered contaminated, through brief contact. The application of this conception to recycled water is that although it has been treated to meet the quality standards, people perceive the water as contaminated and therefore 'disgusting', since it has been in contact with stimuli such as human wastes (Po *et al*., 2003).

Falkenmark (1989) confirms that people are affected negatively by the terminology which may be associated with water reclamation. He proposes that different terminology could be used to remove

the stigma which has naturally been associated with the field. Terms such as 'used water' can be substituted for 'wastewater' or 'sewage', 'water renovation plant' for 'sewage treatment plant', and 'reclaimed water' for 'treated wastewater'.

Perceptions of Risk

The perceived risk, in terms of health issues arising from the use of recycled water, has been identified as an important factor which influences public perception (Po *et al*., 2003). In many studies, participants explicitly expressed concerns regarding the safety of using recycled water, the severity of the pathogens in the water, and the unknown impacts of chemicals used in the treatment processes (Fielding & Roiko, 2014; Marks, 2006). In a study in the United Kingdom, 89% of participants responded by saying, 'I have no objection to water recycling as long as safety is guaranteed' (Jeffrey & Jefferson, 2002, as cited in Po *et al*., 2003). This response showed that as long as people are fully assured that use of recycled water does not pose any risk, they may be willing to use it.

Regardless of the constant assurance of safety from authorities, the public still perceives a great risk regarding the use of recycled water. The main factors identified as causing risk associated with drinking recycled water are that the use of this water source is not normal, it may be harmful to people, there may be unknown consequences, the decision to use the water is irreversible, and that quality and safety of the water is not within their control (Po *et al*., 2003).

Specific Uses of Recycled Water

The reuse of water for higher risk applications and domestic purposes is not preferred by the community. Instead, the reuse of water for non-potable purposes such as irrigation, including irrigated agriculture; and industry, were generally accepted by the community (Po *et al*., 2003).

Sources of the Recycled Water

According to researchers in the water reuse field, the past use of the water affects the acceptability of the recycled water (Asano *et al*., 2007; Po *et al*., 2003). People seem to perceive the reuse of their own waste as more acceptable than using waste from public or secondary sources (Po *et al*., 2003).

Issues of Choice

As illustrated by the Beaufort West case, the issue of choice is an important factor in whether the public accepts the recycled water. Since there is a severe water shortage, and no other feasible water supply solutions have yet been found, people in Beaufort West accepted the potable reuse scheme.

Increased awareness regarding water conservation in places where there was a water shortage resulted in people being more accepting of water reuse (Dishman *et al*., 1989). People tend to question the need for water reuse in those situations where an alternative water source is readily available, and will only consider reuse as viable option if other options are impracticable and uneconomical (Po *et al*., 2003).

Trust in Authorities and Scientific Knowledge

Trust in the implementing authorities to provide recycled water that has been proven to be safe and pathogen free could play a significant role in determining public acceptance of water reuse. In many studies, trust in authorities has been found to be one of the main factors which affects peoples' perception of the quality of their drinking water (Syme & Williams, 1993; Po *et al*., 2003).

In terms of institutions, people tend to lay their trust in those institutions which have been established for many years, have a good safety record, and the intentions of the institution are not politically or monetarily driven (Po *et al*, 2003).

Attitude toward the Environment

People who are aware of the need for environmental conservation, are most accepting of water reuse, since they feel that they will be able to do something positive for the environment. People are more willing to accept water reuse in cases where they have already implemented a water saving strategy in their home. People also respond to different conservation issues in a different manner. For example, certain people respond to issues regarding wildlife conservation, while other people respond to issues regarding water conservation. The literature did not point out the influences of specific environmental attitudes to the acceptance of water reuse. It is also evident that individual community members do not see themselves as being personally responsible for water conservation issues, and instead see the government as responsible for water shortage issues. This may cause implementation difficulties for water reuse projects (Po *et al.*, 2003).

Environmental Justice Issues

According to the United States Environmental Protection Agency (2015), environmental justice is the 'fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income with respect to the development, implementation, and enforcement of environmental law, regulations, and policies' (http://www3.epa.gov/environmentaljustice/).

It has been found that environmental justice issues can influence peoples' perception toward water reuse. In 1993, the City of San Diego proposed the Water Repurification Project, in order to supplement the potable water supply. The project proceeded through the planning and preliminary design phases before being cancelled in 1999. The reason for this cancellation was due to opposition from the public who felt that it was unjust to the poor and ethnic communities, which they believed would receive most of the recycled water. Although this was not the case, and the recycled water would be supplied to approximately half of the city's residents of a broad socioeconomic group, the project received a negative reaction from the public which ultimately led to the decommissioning of the project (Water Reuse Study, 2006).

Cost of Recycled Water

People generally expect to pay less for recycled water, as it is perceived as being of lower quality. Reduced tariffs can be used as a method of encouraging acceptance (Po *et al*., 2003). Since water reuse projects require a large capital investment, due to the machinery needed, some of which may have to be acquired overseas, the projects tend to increase the cost of water for the public (Asano *et al*., 2007). Although some costs may be borne by the authorities, the public generally does have to pay an increased tariff, which results in a feeling of discontent.

Socio-Demographic Factors

Although some demographic factors have been identified as being significant in the public perception of reuse projects, the outcome of studies in this area seem to be incongruent. For example, in a study undertaken by Mckay and Hurlimann (2003), it was found that objections to water reuse projects would be from people aged 50 and older, and thus specific education programs were recommended to target this age group. On the contrary, Wilson and Pfaff (2008) found that there was no variation in perception among any group, regardless of religion or age.

These findings suggest that socio-demographic factors alone cannot be used to determine public perception, and should be investigated further to determine the significance of socio-demographic factors in decision making.

2.13.2 Factors Promoting Public Acceptance of Direct Potable Reuse

Currently, many cities in South Africa and globally, incorporate recycled water indirectly into their water supply systems. Using the experiences of these communities, factors which may encourage acceptance of potable reuse have been identified (Dishman *et al*., 1989).

Water Shortage

Communities living in those areas suffering from acute water shortages tend to be more aware of the need to practice water conservation, and tend to be accepting of water reuse. Israel, a semi-arid country, uses recycled water to recharge groundwater sources, which is then pumped into the country's potable supply system. Since the public is very aware of the water shortage and knowledgeable regarding water reuse, the authorities receive no opposition (Dishman *et al*., 1989). California, another semi-arid region, employs water reuse extensively, and also receives public support. On the contrary, in Phoenix, Arizona, which is an arid region, there was public objection when reused water was proposed for watering golf courses. This illustrates that, in general, people are more willing to accept water reuse in more arid regions, where the water shortage is clearly evident (Dishman *et al*., 1989). This factor is highlighted by the Wilson and Pfaff (2008) study discussed below.

Gradual Introduction

Dishman *et al*. (1989) believe that it is possible to alter public perception regarding water reuse by the gradual progression from low to high contact uses. In this manner, the public may eventually accept the drinking of reclaimed wastewater. This gradual progression has been illustrated by the Santee California reuse project. In 1961, a lake was filled with reclaimed water, and initially only boating was allowed on the lake. After some time fishing was allowed in the lake. After about four years the town opened a public swimming pool which was filled only with reclaimed water. This gradual process allowed the public to gain confidence with the idea of using reclaimed water, and after some time, the residents expressed willingness to drink the reclaimed water (Dishman *et al*., 1989).

Professional and Expert Knowledge

The general public has little knowledge regarding wastewater reclamation. Thus it is important that authorities and experts, such as engineers, communicate information to the public regarding the safety of direct potable reuse. It is in this way that public trust and confidence can be gained (Dishman *et al.*, 1989). This factor will be discussed in the section below, using the study performed by Fielding and Roiko (2014).

2.13.3 Studies on Public Perception

The most relevant study, to the South African context was that of Wilson and Pfaff (2008), which examined public perception in the Durban area. The stages performed in this study will be examined in detail, since important insight is gained into the perception on water reuse of a diverse South African

community. In order to gain a deeper understanding of issues surrounding public perception, other studies are also reviewed. The case of multiple reuse projects being shelved in Australia and the USA, was examined to explore the importance of public perception, and to illustrate that negative public perception can ultimately result in the failure of a project. A study performed to gain insight into the perception of academics toward water reuse was also reviewed, to determine whether specific groups of people hold specific perceptions. The final study reviews the effectiveness of information provision on public acceptance. This study is examined since information provision has been highlighted as an important factor influencing public perception by several authors (Dolnicar *et al*., 2010; Fielding *et al*., 2014; Simson & Stratton, 2011).

Study in Durban, Kwa-Zulu Natal

Kwa-Zulu Natal has been facing drought conditions and water scarcity problems over the past few years. In response to the poor water situation, the eThekwini Municipality proposed water reclamation for potable purposes for Durban, South Africa's second most populous city. Since Durban is a city with diverse cultural, religious, ethnic and environmental groups, a preliminary social feasibility study was undertaken by Wilson and Pfaff (2008). This study aimed to determine if there were any deep religious or philosophical issues such that wastewater reclamation for potable purposes could not be considered as a viable option.

This study was based on a literature review, an email survey to regional and international experts, interviews with local religious councils, environmental groups and a mixed focus group.

The aim of the literature review was to identify the key factors affecting public perception. The main finding of the literature review was a consensus among researchers regarding the ten key factors, highlighted by Po et al. (2003). It must be noted that all ten key issues are ultimately relevant to acceptance, and if water reuse is to be successfully implemented, issues such as trust and health risks must be thoroughly addressed. In terms of public acceptance, published case studies indicate that people are most willing to accept potable wastewater reuse where there is a severe water scarcity crisis, and they have no other option (Wilson & Pfaff, 2008).

The email survey was sent to 50 international experts, who were identified through the literature review. The purpose of the email was to obtain personal knowledge from experts in the field regarding cultural, religious or philosophical objections to wastewater recycling, which would be used to supplement data collected through other strategies. Some experts felt that members of the Islamic

faith may be more likely to reject potable reuse than other groups. One expert exposed comprehensive research that this was not in fact the case, and potable reuse was not against the Islamic faith. Many of the experts were of the opinion that the public were affected by intractable 'emotional issues', which did not stem from religious or cultural beliefs (Wilson & Pfaff, 2008).

Qualitative interviews were conducted with leaders of eight local religious and environmentalist groups to determine if there were any objections to potable water reuse. The main finding of the interviews was that there was no evidence to support the proposition that potable reuse is against the Islamic faith. The Baptist Church also confirmed that wastewater reuse is permissible in the Christian faith, and is not a spiritual issue for Christians. Religious groups were in support of protection of the environment; and all living things, and expressed strong concern regarding the destruction of the environment. The Buddhist Centre and the International Propagation Centre revealed that according to their faith, solutions were expected to be a result of compromise and the best possible outcome. The main discussion with both groups gravitated towards the balance between positive environmental outcomes, and concerns regarding municipal competence. Discussion showed that ultimately the idea of direct potable reuse was not an issue of religion, but instead one of disgust (Wilson & Pfaff, 2008).

The focus group included people active in local political and environmental debates, people involved in issues regarding faith, ethnicity, race and gender, and two representatives of the eThekwini Water and Sanitation project team. The aim of the focus group was to bring together different perspectives, knowledge and awareness regarding potable reuse. The focus group did not identify any religious or philosophical issues with water reuse. The discussions instead tended toward issues of equity and justice in water resource allocation, and the issue of water scarcity (Wilson & Pfaff, 2008).

The overall findings of the study were that there was no evidence to support the idea of rejection of potable reuse on religious grounds. Other findings were that justice and equity concerns were high among the residents in Durban, and the best possible compromise should improve the distribution and quality of services for the poor. Important concerns included sustainability, environmental benefits, global warming, pollution and water scarcity. It was also found that people appear to be more comfortable with unplanned reuse rather than planned reuse, although people in general have not formed formal opinions. The general feeling was that people are not comfortable with potable water reuse, but expressed that it is something they would be more willing to consider with a proper

understanding and quality assurance. Most people consider water reuse as a last resort, and were of the opinion that reuse should begin with big consumers and industry, before households.

Since most people have not formed strong opinions regarding wastewater reuse, if a reuse strategy is to be implemented, efforts must be made in the preliminary phases to build a comprehensive knowledge within the community. Only after this knowledge base is built should studies be undertaken to determine peoples' attitude toward wastewater reuse (Wilson & Pfaff, 2008).

The USA and Australia

During the summer of 2003/04 residents in every capital city in Australia, except Darwin, were subject to water restrictions. Long term drought conditions and increasing water demands in Australia have urged authorities to consider a range of options, over a number of years, to be considered for wide scale implementation. Marks (2006) examines the reasons for most potable reuse projects being postponed or transformed in the USA and Australia.

Attempts to introduce potable reuse in Australia and the USA have involved some form of public engagement. The outcome of this public engagement, was that despite the assurance of safety, in all cases, potable reuse projects were met with public opposition, and were therefore withdrawn. The only exception was Orange County, who proposed a groundwater replenishment system, which gained acceptance through an intensified level of public education, and was commissioned in 2006 (Marks, 2006).

The overall findings were that public consultation efforts were fundamentally flawed in that there was a lack of transparency at the earliest planning stages, and minimal community outreach. In the majority of the eight cases examined, emphasis had been placed on marketing the proposed reclamation project, instead providing the public with the necessary information and consultation. Due to the sensitivity of the project, there was a reluctance to draw attention to existing indirect potable reuse projects already operating in the same country, the result of which was a lack of transparency, and an inability to draw on public familiarity with existing potable reuse projects (Marks, 2006).

Marks (2006) concludes that the implementation of potable reuse projects is inevitably problematic, given the risk awareness of the public. If future reuse projects are to be implemented successfully, and receive ongoing acceptance, the community should be actively involved in the decision making

process. Furthermore, in order to promote sustainable management of the resource and ensure that the public are to value the reclaimed water, the water should be priced at a rate which discourages over-use. The community should be involved in co-management of the resource, which incorporates a more active role, which is acknowledged and supported by the authorities (Marks, 2006).

Study in Four United States Cities

The most recent study obtained, motivated by technical advancements in the field of direct potable reuse, was undertaken to determine the public perceptions of direct potable reuse in four major USA cities in the states of Georgia, Texas, California, and Florida. The cities studied were chosen based on enhanced awareness of water conservation due to local water scarcity, strict wastewater effluent requirements, and water reuse projects implemented in close proximity (Ishiia *et al*., 2015).

The study consisted of a survey of 400 people in each city. In the survey, recycled water was referred to as 'purified water', and respondents were either provided with basic background information regarding purified water, or detailed information regarding National Primary Drinking Water Regulations. Contrary to the original hypothesis, which postulated that the level of information provided to the respondents would alter the response, the level of information provided did not have a significant impact on respondent perceptions. The overall outcome was that 56% of respondents agreed with reclaimed water as drinking water as being a good idea for society. Respondents were most concerned about the taste, smell, and microbial content of reclaimed water. The strongest reasons for the acceptance of purified water were water shortages, and the environmental benefits of water reuse instead of withdrawing additional water. Overall, the study highlighted that the following are significant to the public regarding direct potable reuse (Ishiia *et al*., 2015):

- The potential for direct potable reuse to improve current tap water standards
- The need for wastewater treatment facilities and officials to gain the trust of the public
- Community specific drivers of implementing direct potable reuse in a given setting

Study of Academic Perception

This study is based on a multiple choice survey that was administered to academics in a university in Portugal. The main objectives of the study were to estimate the level of opposition or support for wastewater reuse options, to reveal critical issues which concern the academic community regarding water reuse (Matos *et al*., 2014).

Twenty reuse options were considered in the survey, which were divided into three categories. The low contact options have an indirect link to the people, such as orchard and field crop irrigation.

Medium contact options may involve unintentional direct contact with humans, such as firefighting, toilet flushing and garden irrigation. The high contact options involve intensive human contact, such as vegetable irrigation and drinking water (Matos *et al*., 2014).

A total number of 146 people completed the questionnaire. The outcome of the survey was similar to the outcomes of other studies, in that there was a high level of support for the low and medium contact reuse options, and a low level of support for high contact options. Figure 2.1 shows the main outcomes of the survey regarding the respondents' opinions toward the level of contact (Matos *et al*., 2014).

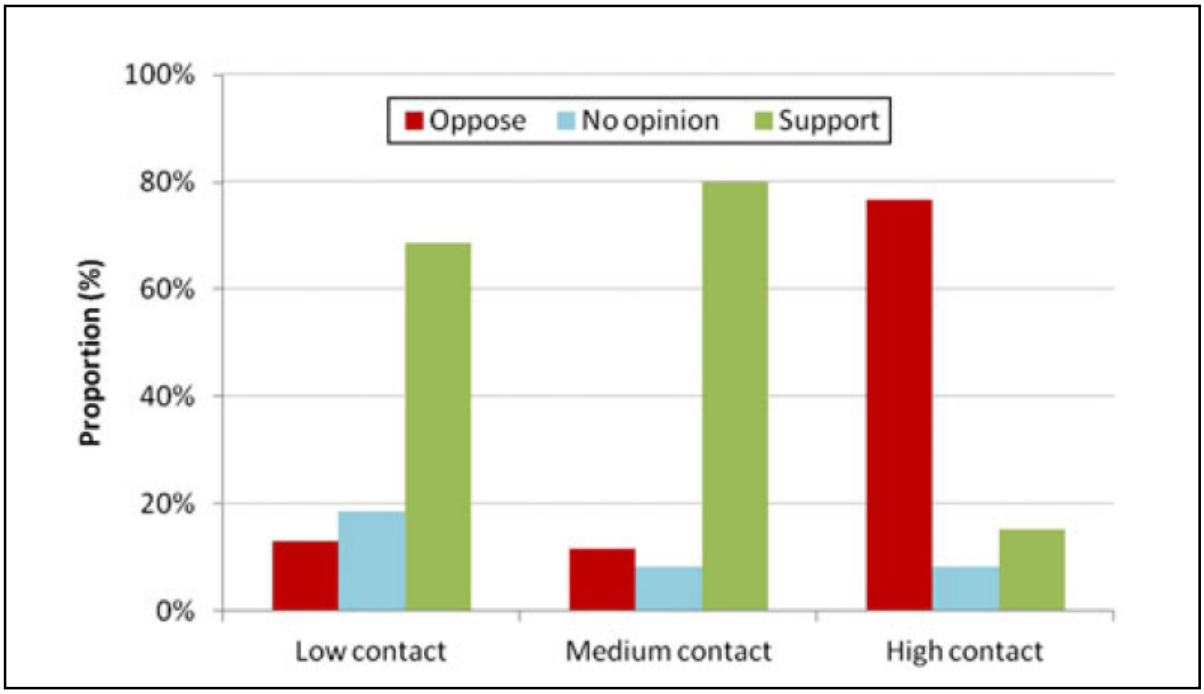


Figure 2.1: Participant Support for Low, Medium, and High Contact Reuse Options (Source: Matos et al., 2014)

The main findings of the survey were that there was a concern for public health and water reuse, which affected the level of support for reuse projects, while economic benefits and trust in authorities increases the level of support for water reuse. It was also found that the level of acceptance of water reuse within the academic community is not uniform, especially when the degree of contact increases. Although, the study did prove that in instances where there is a high level of education among the public, the level of support for reuse increases (Matos *et al*., 2014).

Study on the Effectiveness of Information Provision to the Public

To date there are only a few studies which have examined the effectiveness of information provision to the public (Fielding & Roiko, 2014). Simpson and Stratton (2011) researched the effect of providing residents of Queensland, Australia, with a 47 page online information booklet regarding water reuse. The outcome of the study was a greater acceptance of potable water reuse for drinking purposes among those who viewed the booklet, as compared to those who did not view it. In another study, performed by Dolnicar *et al*. (2010), Australians were willing to use recycled water for most purposes after receiving information about recycling water, as compared to before receiving the information.

The study by Fielding and Roiko (2014), draws on the studies mentioned above, and aimed at determining whether information provision regarding water recycling; and the safety of recycled water for consumption could improve public acceptance. Three information conditions regarding potable recycled water: basic information; basic information plus information about pollutants in the water; or information that puts the risk of chemicals in the water in perspective, were compared to a condition of no information provision. The findings of this study were in accordance with the studies by Dolnicar *et al*. (2010), and Simpson and Stratton (2011). The outcome was that the provision of information ensuring the safety of recycled water, solicited more positive responses to recycled water for potable reuse.

The main findings of the research by Fielding and Roiko (2014), was that when participants were questioned as to whether they would vote in favour of having a potable reuse scheme introduced in their area, 26% of respondents in the 'no information' category would vote in favour of a recycled water scheme. Respondent support rose to 45% in the basic information category, to 47% in the pollutant information category, and to 56% in the category which put the risks of water into perspective. The findings of the study are in contradiction with the study in four USA cities discussed above, which concludes that the level of information provided has no effect on public perception. The possible reason for this contradiction may be that in the two studies, people were approached and given the information in a different manner, which affected their perception.

2.13.4 Gaining Support for Potable Water Reuse

Based on the literature review, it is evident that the success of future potable reuse projects is largely dependent on public acceptance. Falkenmark (1989) commented that even if all other problems associated with potable reuse are resolved, the issue of public acceptance could ultimately lead to the

shelving of a project. In order to prevent this, a strategy should be developed to deal specifically with public unwillingness to consume reclaimed water.

Although the results of studies regarding the effectiveness of information provision to the public are inconclusive, this can still be considered as an important factor in gaining public acceptance, confidence and trust. Fielding et al. (2014) succeeded in providing tentative evidence that providing information about the safety of recycled water can lead to more positive responses.

2.14 Water Reclamation Plant in Windhoek, Namibia

Since 1968, the worldwide pioneer in direct potable reuse, Namibia, has been supplementing the City of Windhoek's water supply with highly treated reclaimed water. The reclaimed water produced by the Goreangab Reclamation Plant, is fed directly into the line which provides the city's potable water supply (Asano *et al*., 2007).

2.14.1 City of Windhoek

Windhoek is the capital of Namibia, which is located in the southwestern part of Africa, bordering the Republic of South Africa, as shown in Figure 2.2. It has a population of 250 000 people and is situated almost centrally in Namibia. Namibia is the most arid country in sub-Saharan Africa, and the water management issues can be attributed to its climatic conditions. Rainfall, amounting to an annual average of 360mm, only occurs for a few months a year. Annual evaporation is 3400mm per year, and is therefore the main 'consumer' of water. This factor, as well as limited groundwater resources, makes the security of water supply to the central areas of Namibia and the city of Windhoek a major challenge (Asano et al., 2007).

As a result of severe drought, and no other viable water sources for the city, the first, and until very recently, only direct potable reuse plant in the world was commissioned in 1968. Thus the City of Windhoek and the original planners involved in the water reclamation project are considered pioneers in direct potable reuse. As the first reclamation plant, considerable research has taken place in Windhoek regarding health impacts, process efficiency and water management strategies. This research continued after the commissioning of the plant, the result of which was the commissioning of the New Goreangab Plant in 2002 (WRC, 2015).

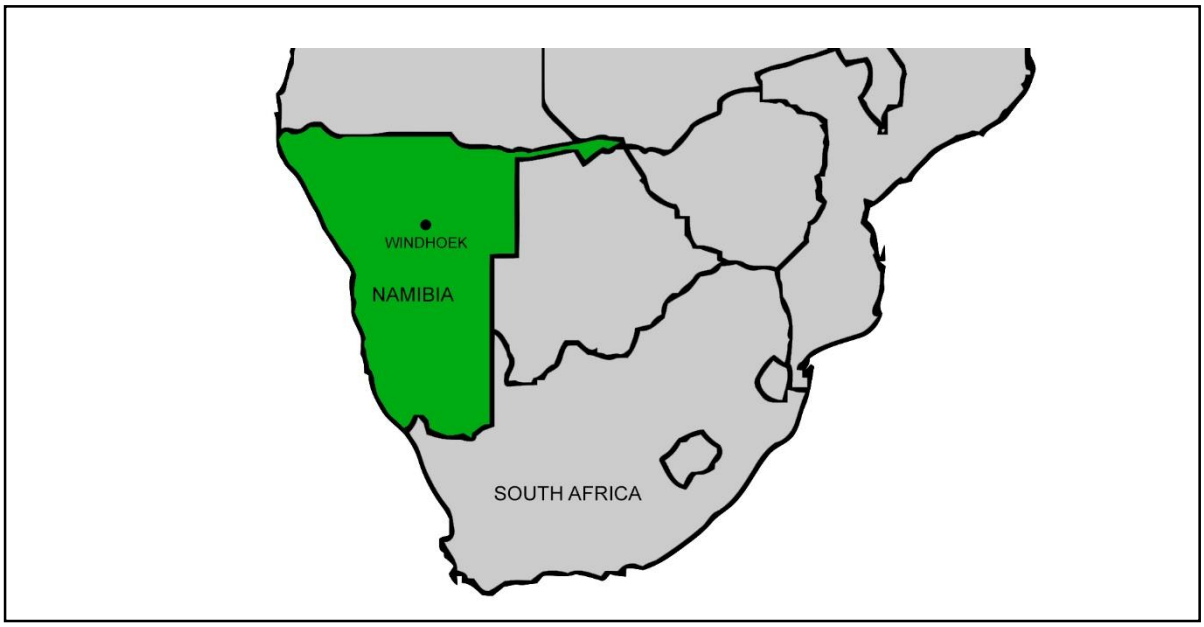


Figure 2.2: Location of Windhoek, Namibia (Author)

2.14.2 The Goreangab Water Reclamation Plant

The plant treats both the water from the Goreangab Dam and the final effluent from the city's waste water treatment plant. The plant had an initial capacity of 4.3 x 10^3 m^3/day (Asano *et al*., 2007).

One of the major factors contributing to the success of the plant was that the industrial effluent was separated from domestic effluent, and the industrial effluent diverted to a separate treatment plant. As a result of this separation, the water used for reclamation originates from domestic and business areas. The original plant, now known as 'Old' Goreangab Treatment Plant was upgraded many times, the last in 1997. The ultimate capacity of the plant is 7.5 x 10^3 m^3/day (Asano *et a*l., 2007).

2.14.3 New Goreangab Water Reclamation Plant

The demand for water increased after independence from South Africa in 1990, when the population started growing rapidly, at about 5% per annum. This rapid population growth combined with an increasing development and interest in the city, placed a great amount of pressure on the water supply. The logical choice to satisfy the increased water demand was water reclamation, since most of the easily accessible natural resources had already been fully exploited and demand management strategies had been fully implemented. A new plant, based on 30 years of experience gained from the old plant, with a capacity of 21 x 10^3 m^3/d, was constructed on the site adjacent to the old plant. This

plant, officially launched in December 2002, now provides 30% of the city's potable requirements during normal water consumption, and up to 50% during severe droughts (Asano *et al*., 2007).

2.14.4 Process Design

The design for the new plant employs a multiple barrier system, which ensures that high quality drinking water is produced. This system operates through the use of a certain number of safety barriers, which are set up based on the risk associated with a particular contaminant in the water to the user (Asano et al., 2007; du Pisani, 2006). The multiple barrier system is shown in Figure 2.3 below. Treatment barriers have been defined by du Pisani (2006) as 'continually present systems that reduce the undesired substances in the water to an acceptable level'. The new plant includes additional processes to the old plant, such as ozone and membrane ultrafiltration, which were pilot tested on site over a period of 30 months (Asano *et al*., 2007; du Pisani, 2006).

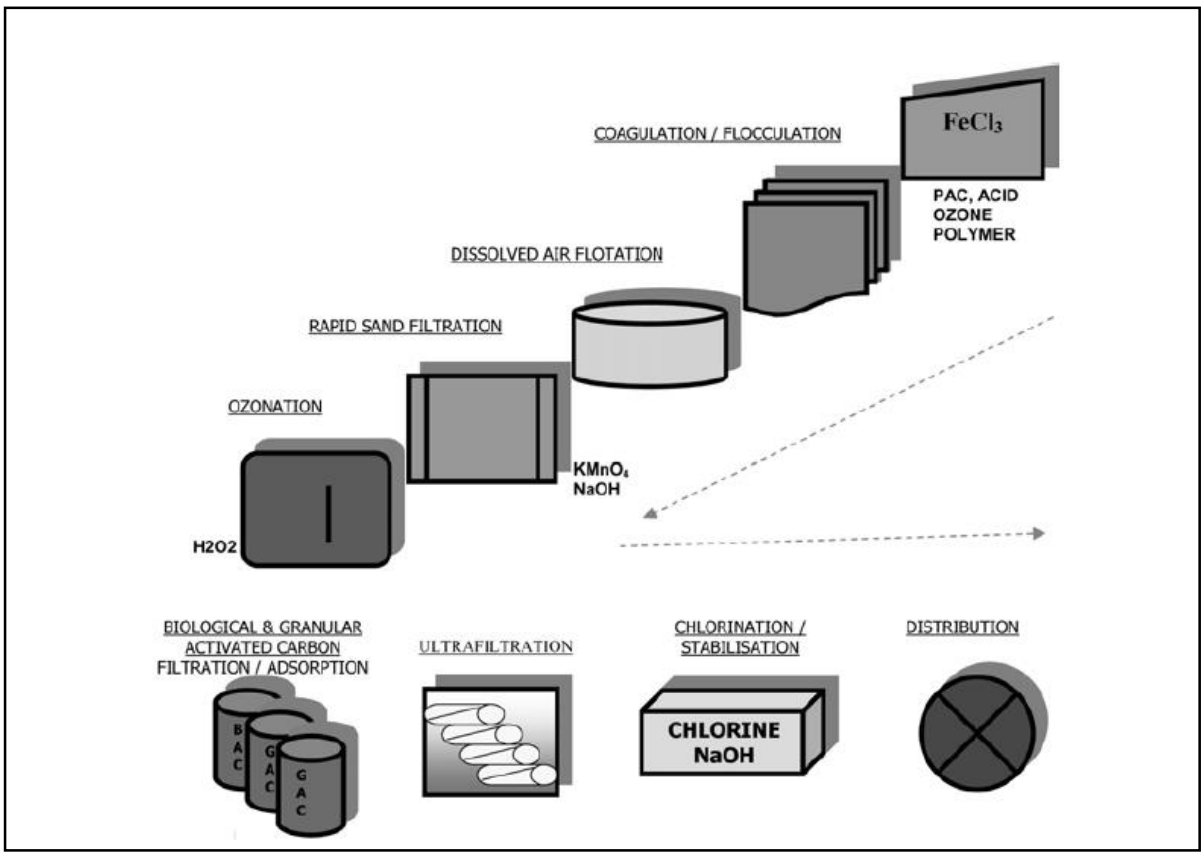


Figure 2.3: New Goreangab Process Train (du Pisani, 2006)

2.14.5 Public Perception

The greatest challenge to water reclamation and reuse for potable purposes, is gaining public confidence. Gaining public acceptance is not an easy task, therefore the City of Windhoek must

guarantee that the water quality is maintained at all times. This is ensured by a substantial investment in laboratory staff as well as equipment to exercise the required amount of control over water quality. The water quality is monitored continuously using an on-line process, as well as samples for every major unit process. The failure of any quality parameter by exceeding an absolute value, will result in the plant going into recycle mode and water not being delivered (Asano et al., 2007).

The public is informed about the necessity to save water and water reuse through local media, newsletters and visits to the plant. There is an ongoing water demand management campaign which has been successful in reducing water consumption. The citizens of Windhoek are used to the fact that reclaimed water is included in their water supply and are proud that their city is a pioneer in direct potable reuse (Asano et al., 2007). It is considered that the most important cornerstone ensuring the success of the Goreangab Reclamation Plant, is public acceptance and trust. For other plants trying to emulate this plant, the greatest task would to break down the psychological barriers toward water reclamation held by the public (du Pisani, 2006).

2.14.6 Water Quality

Since direct potable reuse is not widely practiced, specific water quality guidelines are not readily available. For this reason, the city of Windhoek has compiled guidelines using several relevant drinking water standards, which are: Namibian Drinking Water Guidelines, National Drinking Water Standards, United States Environmental Protection Agency, the European Community Guidelines for the use of water for human consumption, World Health Organisation Drinking Water Guidelines and the South African Rand Water Standards. Intermediate treated quality criteria were stipulated to ensure that final water quality requirement is met. In the event that the plant fails to meet the intermediate quality criteria, the plant goes into recycle mode until the required criteria are met (Asano *et al*., 2007).

Since direct potable reuse has been practised in Windhoek since 1968, there is a firm foundation of experience and an extensive database about the treatment train required to remove contaminants successfully. After over 40 years of operation of direct potable reuse in Windhoek, no adverse health effects related to the consumption of reclaimed water have been reported (WRC, 2015). This fact provides evidence for future reuse projects that it is possible for a direct reuse project to function successfully over a number of years.

2.14.7 Operation and Maintenance

The operation and maintenance contract for the plant has been outsourced to an internationally recognised company for a period of 20 years, beginning in September 2002. During this 20 year period, the operating manager has been responsible for the overall maintenance of the plant, all scheduled replacements, and other conditions and requirements stated in the private management agreement contract (Asano *et al*., 2007).

The private management agreement was designed in such a way that it provides maximum incentive to the manager to ensure that the water quality guidelines are adhered to, to produce water in line with the requirements of the city (du Pisani, 2006).

2.14.8 Feasibility and Costs

The value of water is calculated both in financial terms, and in the value of security of supply. If the other cost alternatives are evaluated, such as transporting water from the perennial rivers to Windhoek, the cost of water increases dramatically. It is evident that the cost of water is determined by the quantity produced, and the City ensures a maximum production of reclaimed water whenever possible (du Pisani, 2006).

2.14.9 Overall

A combination of climatic factors, combined with a lack of alternatives, has led to the need for water reclamation and reuse. Direct potable reuse is a viable option for the city of Windhoek, Namibia. Du Pisani (2006) considers the investment in water reclamation as an economically, financially and environmentally sound one. The success of the Goreangab Reclamation Plant is an excellent example of the practice of water reclamation in a country with limited resources, both naturally and financially. This example of direct potable reuse proves that it is possible to overcome public prejudice with consistent public awareness and marketing.

3. Research Method

3.1 Beaufort West Water Reclamation Plant Site Visit

The assessment of the sustainability of direct potable water reuse included a site visit to the Beaufort West Water Reclamation Plant, to observe the operation of the plant on a daily basis, and interview the process controllers. The technical manager of the plant, an employee of the Beaufort West Municipality, was interviewed to obtain information regarding the plant.

The information obtained from the technical manager includes details of feasibility studies performed by the municipality prior to the construction of the plant, the alternative water supply options investigated, and the important factors which led to the construction of the plant. The cost considerations involved in the construction of the plant, costs involved for users of reclaimed water, the construction process and the time needed for construction, were also discussed with the technical manager. Furthermore, information was obtained regarding the water monitoring processes undertaken by the municipality, the details of the agreement between the municipality and the company contracted to operate the plant, as well as their responsibilities. With regard to public participation, the processes undertaken during all project phases were discussed.

The technical manager also provided a tour of the plant, including an explanation of each of the treatment steps undertaken in the reclamation process.

3.2 Method of Assessing Sustainability

The information used in the assessment of the plant has been sourced directly from the plant, and the Beaufort West Municipality. In order to measure and calibrate the progress of water reuse toward sustainable development goals, several indicators have been chosen. Indicators are important in that they translate the information obtained through multiple sources into manageable units of information, which are able to facilitate future decision making processes.

The economic indicators chosen are; feasibility studies undertaken prior to choosing reclamation as the preferred alternative, capital costs, user costs and maintenance required. The environmental indicators are; water quality, energy requirements, environmental impact assessment, waste discharge, and pollution. The societal indicators selected are; public participation, equitable access to water supply, staffing requirements and education, community size served, and land requirements.

The indicators are chosen based on those aspects considered important by researchers, as highlighted in the literature review, as well as on relevant South African regulations. The indicators aim to assess the three pillars of sustainability: economic, environmental and societal, thereby providing a holistic assessment. Section 3.3 explains how the indicators are selected, and how they are measured in the assessment of the Beaufort West Plant. Since conducting interviews with the public is beyond the scope of this research, the assessment of the social sustainability of the plant, in terms of public perception, is performed through the literature review.

In order to assess their sustainability, the indicators are benchmarked against the relevant literature, and South African Regulatory frameworks, such as the National Environmental Management Act. Certain indicators are discussed and their sustainability assessed. The reason for this is that these indicators are site specific, as well as there being a lack of other direct potable reclamation plants to compare the information to. Since direct potable reuse is not widely practiced there is a general lack of information to which the plant can be compared.

The outcome of the assessment of each indicator was either positive, satisfactory, uncertain or negative. Positive indicates that an indicator is sustainable, satisfactory indicates that the indicator is moving toward sustainability and is potentially sustainable, uncertain is used to classify those indicators about which the sustainability could not be assessed clearly using this study, and require further research, while negative is useed for those indicators that are considered unsustainable and would require a large amount of research to move toward being sustainable**.**

3.3 Sources of indicators

Indicators were selected through an evaluation of various sources. These sources are derived from the literature review, previous studies, and South African regulations and standards.

3.3.1 Previous Studies

This study uses a similar approach to Muga and Mihelcic (2007), who developed a set of indicators which incorporated economic, environmental and societal aspects to assess the sustainability of different wastewater treatment technologies. These technologies included a mechanical system, a lagoon system and a land treatment system. This study was chosen as it makes use of a balanced set of indicators for a holistic evaluation of the sustainability of different wastewater treatment technologies.

Indicators are crucial to the decision-making process, as they assist in making informed decisions, and function as a suitable measure of progress towards sustainable development goals (DiSano, 2002). Indicators should be selected on a scientific basis, transparent in that their meaning must be obvious even to non-experts, relevant in terms of considering the crucial aspects of sustainable development, quantifiable, and limited in number (UNDPCSD, 1995). These criteria, developed by the United Nations Department of Policy Co-ordination and Sustainable Development (1995), were used by Muga and Mihelcic (2007) to select a set of indicators for use in evaluating wastewater treatment technologies, which are shown in Table 3.1.

Table 3.1: Set of Indicators Developed for Sustainability Assessment (Muga & Mihelcic, 2007)

Category	Indicator
Economic	Capital costs
	Operation and maintenance
	User Cost
Environmental	Energy use
	Biochemical oxygen demand
	Total suspended solids
	Nitrogen
	Phosphorus
	Pathogens
Societal	Public participation
	Community size served
	Aesthetics
	Staffing required to operate plant
	Level of education
	Open space availability

Another study which is drawn upon, is the basic assessment report performed by Golder Associates (2012) for the proposed direct potable reuse scheme in eThekwini, South Africa. This study highlights important aspects to be investigated for a water reuse scheme. This study is also relevant in obtaining indicators, since it has also been performed within the South African context.

3.3.2 National Environmental Management Act

The National Environmental Management Act 107 of 1998 is the document which serves as the core of South Africa's policy on matters affecting the environment and co-operative environmental governance.

The National Environmental Management Act (NEMA), serves as the framework within which environmental management and implementation plans must be formulated, and therefore requires consideration when determining the indicators to be used in the assessment. This Act requires that development must be socially, environmentally and economically sustainable. The sustainable development factors, presented in NEMA, can be summarised as follows:

- The disturbance of ecosystems and loss of biological diversity are preferably avoided, or minimised and remedied
- Pollution and degradation of the environment are preferably avoided, or minimised and remedied
- The disturbance of landscapes and sites that constitute the nation's cultural heritage is preferably avoided, or is minimised and remedied
- Waste is avoided, minimised and reused or recycled where possible, and otherwise disposed of in a responsible manner
- The use and exploitation of non-renewable natural resources is responsible and equitable, and takes into account the consequences of the depletion of the resource
- The development, use and exploitation of renewable resources and the ecosystems of which they are part do not exceed the level beyond which their integrity is jeopardised
- A risk-averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions
- Negative impacts on the environment and on people's environmental rights should be anticipated and prevented, and where they cannot be altogether prevented, are minimised and remedied (NEMA Act 107 of 1998, s. 4a)

Other relevant legislation is also drawn upon in the process of defining the chosen indicators.

3.4 Sustainability Indicators

The chosen indicators are discussed below, and the method by which they are evaluated. Certain indicators which reflect South African regulations have been included, thus the compliance of the plant with the regulations is discussed.

3.4.1 Economic Indicators

Economic sustainability incorporates the financial cost and benefits of the process. This includes costs incurred initially, such as the capital costs, as well as ongoing costs such as operation and maintenance. Affordability to the user also plays a role in the economic sustainability (Popovic *et al.*, 2013).

Feasibility Studies

Financial feasibility of the proposed direct potable reuse plant must be established. It must also be taken into consideration that many water reclamation plants are built during extreme droughts, and that the required production capacity of the plant may reduce significantly once conventional water sources are no longer depleted (WRC, 2015).

As considered in the Basic Assessment study for the proposed direct potable reuse scheme in eThekwini it is important to investigate viable alternatives to a scheme. The basic assessment performed did not initially include a study of the alternatives, but when the project was communicated to stakeholders, their first response was regarding other viable alternatives to supplement the water supply (Golder Associates, 2012). Thus, a study into alternatives had to be undertaken.

Cost Considerations

The capital costs involved in water reclamation include the design and construction of the plant, associated distribution pipelines, related administrative costs, as well as other costs discussed in the literature. This cost is, as previously stated, context specific and cannot be compared to the cost of other treatment facilities. Since this plant is only the second in the world, after Namibia, there are also no other plants with a similar capacity that the costs can be compared to. This indicator, although it is an important factor, cannot be measured against norms or standards, therefore the assessment of the capital costs will be based on empirical evaluation.

User Costs

The costs of the treated water to the user are based on a combination of the type of treatment technology used, its efficiency, waste discharged and the population size served (Muga & Mihelcic, 2007). In order to determine whether the costs of the reclaimed water are affordable to the user, the price of water prior to the commissioning of the plant can be compared to the price of water after the commissioning of the plant, as well as to neighbouring municipalities.

This study uses the municipality of George as a comparison. The tariffs in George are used as a comparison as George has experienced similar water shortages to Beaufort West and is investigating water saving strategies and the possible introduction of a water reclamation plant (George Municipality, 2013). This allows the water costs to be compared to a municipality in a similar predicament.

Maintenance

The operation and maintenance is assessed against the applicable guidelines provided by the Water Research Commission (2015), as discussed in the literature review, section 2.12. The study of the plant excludes the costs of operation and maintenance, since it is against the policy of the plant to provide such information to the public.

3.4.2 Environmental Indicators

Environmental sustainability addresses the impact of the treatment processes and human activity on the natural environment. Indicators which can be used to assess the environmental sustainability of the reclamation process are greenhouse gas emissions, waste discharge, and energy consumption. The waste discharged by a process is a good indication of its efficiency and potential harm to the environment (Popovic *et al*., 2013). In order to achieve sustainable environmental outcomes, environmental management must recognise that all elements of the environment are interrelated, and it must take into account the effects of decisions on all aspects of the environment and all people in the environment through the selection of the best practicable environmental option (NEMA Act 107 of 1998, s. 4b).

Water Quality

The methods used to determine whether water is suitable for human consumption vary according to the different guidelines and standards. In simple terms, the water should be safe, palatable and aesthetically pleasing (WRC, 2015). The quality of drinking water in South must comply with the specifications in the South African National Standard for drinking water quality, SANS 241-1: 2011, as stipulated in the Water Services Act (No. 108 of 1997)**.** SANS 241-1 specifies the quality of acceptable drinking water, in terms of microbiological, physical, aesthetic, and chemical determinands at the point of delivery. Water that complies with the specified parameters in the guidelines is considered to present an acceptable health risk for lifetime consumption (WRC, 2015). The primary objective of these regulations is the production of safe drinking water, in order to protect public health. The SANS 241: 2011 limits can be found in Appendix C.

In order to acknowledge excellence in drinking water quality management in South Africa, the Department of Water Affairs has implemented an incentive-based Blue Drop Certification Programme. The main aims of this programme are to recognise those service providers who are maintaining standards of best practice, promote transparency and accountability, introduce incentive-based regulation of drinking water quality management, as well as to provide reliable information to the public. For the Blue Drop Assessment, compliance is tested against main five criteria, which are:

- water safety planning
- drinking water quality process management and control
- drinking water quality compliance
- management, accountability, and local regulation
- asset management (DWA, 2012)

The Blue Drop scorecard, which outlines the key requirements of the Blue Drop assessment has been placed in Appendix C.

An important aspect in ensuring water quality over time is the proper operation and maintenance of a plant. The Water Research Commission (2015) has stated that on-line monitoring is not optional for potable water reuse plants. Also, treatment processes must be thoroughly monitored, and the final output of each treatment process must be measured to detect treatment failures. The monitoring data should be stored and reviewed, by management, in order to ensure that each of the treatment units is functioning correctly (WRC, 2015).

Energy Requirements

A large portion of maintenance costs may be attributed to energy consumed by machinery during the treatment process. In the production of energy a large amount of carbon dioxide as well as other harmful substances are produced, which have been quantified by Eskom, as shown in Table 3.2. In South Africa electricity is generated from coal and nuclear power. Coal is a non-renewable resource and moreover, South Africa has had an insufficient supply of energy since 2006, with the price of electricity in South Africa steadily increasing due to limited resources and pressure due to climate change. The amount of energy being produced needs to decrease since the burning of coal releases chemicals into the air which causes acid rain, which damages plants and animals. The burning of coal also releases carbon into the atmosphere, which causes climate change (CoCT, 2011).

Table 3.2: Environmental Implications of Using 1kWh of Electricity (Eskom, 2011)

Parameter	Use per 1kWh
Coal use	0.53 kg
Water use	1.4 *l*
Ash Produced	155 g
Particulate emissions	0.33 g
CO_2 emissions	0.99 kg
SO_2 emissions	7.75 g
Nox emissions	4.18 g

Table 3.2 can be used to calculate the resources consumed by the plant, as well as the emissions, on a monthly basis. In assessing this indicator the energy requirements of water reclamation can be compared to other alternatives for obtaining additional water. The alternatives which are used as a comparison are the importation of water, the use of local surface water and groundwater, desalination and non-potable reuse.

Environmental Impact Assessment (EIA)

Prior to the construction of the plant, in the initial planning phases, thorough EIA studies should be completed (WRC, 2015). An environmental assessment is required by the National Environmental Management Act 107 of 1998, Chapter 5, for certain listed activities. An EIA is the ongoing process of identifying and mitigating the biophysical, social and other relevant effects of development proposals prior to decisions being taken. It is a pro-active process where potential environmental impacts associated with an activity, both positive and negative, are assessed, investigated and reported. The process contributes to the objectives of integrated environmental management, as decision makers are informed of the impacts of an activity, and on the conditions which authorisation of the activity should be subject to, if necessary (National Environmental Management Act 107 of 1998).

Certain activities, as noted in each of the three listings in NEMA, require varying levels of impact assessments. Listing notice 1 stipulates the activities requiring a basic assessment report. These are typically activities that have the potential to impact negatively on the environment, but these impacts are generally known due to the nature and scale of such activities. Listing notice 2 identifies the activities requiring both scoping and an Environmental Impact Report. These are typically large scale

or highly polluting activities and the full range of potential impacts need to be established through a scoping exercise prior to being assessed. Listing notice 3 contains activities that will only require an environmental authorisation through a basic assessment process if the activity is undertaken in one of the specified geographical areas indicated in that listing notice. Geographical areas differ from province to province (National Environmental Management Act 107 of 1998).

The main objectives of an EIA are to improve the environmental design of a proposal by ensuring that resources are used appropriately and efficiently. An EIA must also identify appropriate measures for mitigating the potential impacts of the proposal. This is intended to facilitate informed decision making, avoid irreversible changes and serious damage to the environment, and safeguard valued resources and natural ecosystems (National Environmental Management Act 107 of 1998).

Waste Discharge

Waste management guidelines have been laid out in the National Environmental Management Waste Act (2008), which states that in order to achieve sustainable development the generation of waste should be avoided, or where it cannot be avoided, that it is reduced, reused, or recycled, and only as a last resort safely disposed of. The Act provides that pollution and the consumption of natural resources should be minimised through vigorous control measures, cleaner technologies and production practices, in order to ensure that the environment is protected from the impact of waste. Other objectives of this Act are to protect public health and prevent ecological degradation, through the promotion of integrated waste management (National Environmental Management Waste Act 107 of 1998, s. 2a).

Certain activities that are likely to have a detrimental effect on the environment and require the performance of an environmental assessment in order to obtain a waste management licence, have been listed in Schedule 19(2) of the National Environmental Management Waste Act.

Pollution

In accordance with NEMA, an environmental management plan, if required for a project, must include a description of how to modify, remedy, control or stop any action, activity or process which causes pollution or environmental degradation. If pollution or degradation is unavoidable, the migration pollutants must be remedied (National Environmental Management Act 107 of 1998, s. 2g). The environmental assessment practitioner, in preparing the report, must propose measures which can

be taken to prevent and mitigate any pollution resulting from the activity (National Environmental Management Act 107 of 1998, s. 24O, ss. 1 a ii bb).

South Africa relies on the National Environmental Management Air Quality Act, for guidelines regarding air pollution. The main objective of this Act is to protect the environment by providing reasonable measures for the protection and enhancement of the quality of air in the Republic, the prevention of air pollution and ecological degradation, and to ensure that peoples human rights are protected in terms of the Constitution of the Republic of South Africa, by providing ambient air quality that is not harmful to the health of people. Considering this document, the SANS 1929: 2011 Edition 2 has been developed, which outlines the limits for common pollutants regarding ambient air quality. These common pollutants include sulphur dioxide, nitrogen oxide, particulate matter, ozone and lead.

3.4.3 Societal Indicators

The final aspect of sustainability to be considered is societal. The societal aspect considers the end users, all stakeholders, and the staff involved in the plant. Societal indicators determine cultural acceptance of the wastewater treatment processes through public participation, worker satisfaction through a better education, and increased opportunities for employment (Muga & Mihelcic, 2007).

Public Participation

A comprehensive public participation programme is necessary to ensure the success of all water reuse projects. Emphasis is placed on stakeholder engagement in international guidelines, such as the US Environmental Protection Agency 2012 Guidelines for Water Reuse, and the World Health Organisation Drinking Water Quality Guidelines, as well as local guidelines, such as those produced by the Water Research Commission (WRC, 2015).

Chapter 4 of the Local Government Municipal Systems Act 32 of 2000 outlines the responsibilities of a municipality in terms of public participation. This Act requires that municipalities develop a culture of participatory governance by putting in place mechanisms and procedures that allow for public participation in the affairs of the municipality. Central to this is the need for community members to be well informed about the affairs of the municipality at all times, and to take part in the decision-making processes of council. The main requirements of a municipality, as stated in the Local Government Municipal Systems Act, in terms of public participation, have been outlined Table 3.3.

Table 3.3: Requirements of a Municipality in terms of Public Participation

(Adapted from the Local Government Municipal Systems Act 32 of 2000)

Requirement	Main Elements
Development of culture of community participation	A municipality must develop a culture of municipal governance that complements formal representative government with a system of participatory governance, and must for this purpose encourage the local community to participate in the affairs of the municipality. A municipality must also contribute to building the capacity of the local community to enable it to participate in the affairs of the municipality.
Mechanisms, processes and procedures for community participation	A municipality must establish appropriate mechanisms, processes and procedures to enable the local community to participate in the affairs of the municipality, and must for this purpose provide for: (a) the receipt, processing and consideration of petitions and complaints lodged by members of the local community (b) notification and public comment procedures (c) public meetings and hearings by the municipal council and other political structures and political office bearers of the municipality (d) consultative sessions with locally recognised community organisations and, where appropriate, traditional authorities (e) report-back to the local community. When establishing mechanisms, processes and procedures the municipality must take into account the special needs of: (a) people who cannot read or write (b) people with disabilities (c) women (d) other disadvantaged groups

Table 3.3 Continued: Requirements of a Municipality in terms of Public Participation

Requirement	Main Elements
Communication of information concerning community participation	A municipality must communicate to its community information concerning: (a) the available mechanisms, processes and procedures to encourage and facilitate community participation (b) the matters with regard to which community participation is encouraged (c) the rights and duties of members of the local community (d) municipal governance, management and development.
Public notice of meetings of municipal councils	The municipal manager of a municipality must give notice to the public, in a manner determined by the municipal council, of the time, date and venue of every meeting of the council
Admission of public to meetings	Meetings of a municipal council are open to the public, including the media, and may not exclude the public, including the media, from a meeting, except when it is reasonable to do so due to the nature of the business being transacted
Communications to local community	When anything must be notified by a municipality through the media to the local community in terms of this Act or any other applicable legislation, it must be 50 done: (a) in the local newspaper or newspapers of its area (b) in the newspaper or newspapers circulating in its area and determined by the council as a newspaper of record; or (c) by means of radio broadcasts covering the area of the municipality.

The importance of public participation is emphasised in NEMA, which states that the law should establish procedures and institutions to facilitate and promote public participation in environmental governance. Public participation plays a crucial role in the EIA process in providing stakeholders with information and opportunities to comment on the proposed project. It also provides project team and the authorities with a better understanding of public issues regarding the proposed project (National Environmental Management Act 107 of 1998).

The Act states that the participation of all stakeholders in environmental governance must be promoted, and all people must have the opportunity to develop the understanding, skills and capacity necessary for achieving equitable and effective participation. The Act goes further to state that participation by vulnerable and disadvantaged persons must be ensured (National Environmental Management Act 107 of 1998, s. 4f). The decisions made by the authorities must take into account the needs and values of all interested and affected parties (National Environmental Management Act 107 of 1998, s. 4g). Community wellbeing and empowerment must be promoted through environmental education, the raising of environmental awareness, and the sharing of knowledge (National Environmental Management Act 107 of 1998, s. 4h).

The main elements of the public participation process, which were used in the basic assessment for the proposed eThekwini direct potable reuse project as required by Government notices GNR 385, 386 and 387 under the National Environmental Management Act of 1998, have been summarised in the table below.

Table 3.4: Main Elements of Public Participation in Environmental Assessment (Author)

Phase	**Requirements**
Planning	Allow the community to receive information about the proposed project and its components, to raise issues of concern, make suggestions for enhanced project benefits and reasonable alternatives, and contribute relevant local knowledge and information to the environmental assessment.
Environmental Assessment	Verify that the comments raised during the planning phase have been considered in the specialist studies. Comment on the findings of the specialist assessments, and raise additional issues and suggestions.
Decision Making	When the lead authority has made a decision on whether or not the project may proceed, registered stakeholders must be informed of the decision, and allowed the opportunity to appeal the decision.

There are several stakeholders involved or related to a water reuse scheme that may need to be consulted. The stakeholders have different levels of involvement with the project as well as varied

interactions with the system. A study by Salgot (2008) has identified the following stakeholders in a reuse scheme:

- Politicians
- Civil servants such as health, water and waste authorities
- Managers
- Operators
- End users
- Neighbours
- Indirectly related groups such as facilitators, lawyers and researchers

Equitable Access to Water Supply

The fundamental issue that has to be addressed in South Africa in the water sector is that of equity. The goal of the Department of Water Affairs and Forestry is to ensure that everyone has equal access to basic water supply services (DWAF, 1994). NEMA declares that the state must respect the rights of everyone, and strive to meet the basic needs of previously disadvantaged communities.

The Department of Water Affairs and Forestry, in the White Paper on Water Supply and Sanitation, has defined basic water supply as a quantity of 25 litres per person per day, which is considered the minimum requirement for direct consumption, for the preparation of food and for personal hygiene. The maximum distance from an outlet, over which a person should have to cart water to their dwelling, is 200m. In terms of availability, the flow rate of water should not be less than 10 litres a minute and the water should be available on a regular, daily basis (DWAF, 1994).

Staffing Requirements and Education

Increased education of the local community is considered an important indicator for sustainability. With regard to water treatment, the level of mechanisation of a system is often indicative of the number of operators required to run the plant, as well as their level of education. An operator that has been well trained in the functioning of the plant, can reduce the risk of a system failure, protect worker safety, and respond quickly to any problems. Even the most perfectly designed plant will not perform adequately without well informed responsible operators (Muga and Mihelcic, 2007). The guidelines produced by the Water Research Commission (2015) provide the following instruction regarding process controllers at the plant:

- The process controllers of a water reclamation plant should have a sufficient skill level to understand each of the treatment processes that occur at the plant

- Sufficient guidelines should be available on-site at each of the applicable treatment process units that can guide a process controller during emergencies
- All process controllers must be able to use and calibrate hand-held sampling devices

Community Size Served

The size of the community dictates the required treatment capacity of the plant. A predicted future increase in population means that a larger plant capacity, which is more costly is required. A system must therefore be designed to cater for current and future water needs, without becoming too costly and consuming large amounts of resources. To prevent this situation from arising, in the planning stages, engineers will have to model the reclamation plant in conjunction with the predicted population as well as external factors which affect the water supply, such as climate change, to decide the optimal plant size. This may be a complex process which will yield approximate values and no exact answers, since the effects of climate change and other factors can only be estimated.

Land Requirements

Smaller land requirements for a water reclamation plant are beneficial in that it will allow land to be used for other economic or environmental purposes. This is especially important in urban areas, where land is expensive and in demand. Thus, a minimum land requirement can be seen as a benefit to the community, especially in urban areas where land is at a premium. In urban areas there is a need for open green spaces which provide ecological and social benefits. Open land can also serve as a natural buffer between a community and the aesthetic concerns generally associated with water treatment (Muga & Mihelcic, 2007).

3.5 Final Set of Indicators

The final set of sustainability indicators selected, as well as their source, to be used for the purposes of this study, are summarised in Table 3.5 below.

Table 3.5: Final Set of Sustainability Indicators (Author)

Indicators	Source	Benchmark	Comment
Economic			
Capital Cost	Manager of technical services at the Beaufort West Municipality, Literature	Discussion	The initial costs incurred in start up. These costs include planning, building, machinery and equipment, training of staff
Maintenance	Process controllers at the plant, Manager of technical services at the Beaufort West Municipality	Literature - WRC Guidelines	Is the plant meeting the maintenance requirements specified in the literature?
User Costs	Beaufort West Water Services Audit	Water tariffs in George, Previous tariffs in Beaufort West	Are the users paying for the total cost of the treated water or is the cost supplemented by the municipality?
Feasibility Studies	Manager of technical services at the Beaufort West Municipality	Discussion, eThekwini Basic Assessment	Cost analysis type studies performed by the municipality prior to the building of the plant. Were these studies adequate? What alternatives were considered and what would have been the cost of these alternatives?
Environmental			
Water Quality	Water quality tests	Sans 241: 2011, WRC Guidelines	Water quality is assessed by the percentage removal of conventional water quality constituents such as BOD, TSS, NH_3, Phosphorus and Pathogens
Energy Requirements	Plant, Literature	Literature, Eskom	What processes are used to measure energy use?
Waste Discharge	Plant	SA Regulations	Includes the nature of waste, quantity produced, constituents, and disposal site
Pollution	Site visit	SA Regulations	Is the plant polluting the environment?
Environmental Impact Assessment	Western Cape Department of Environmental Affairs	NEMA Regulations	An assessment of the feasilbility studies done by the plant wrt the environment. Was an environmental management plan produced?
Societal			
Equitable Access to Water Supply	Beaufort West Municipality Water Services Development Plan	Department of Water Affairs and Forestry:White Paper on Water Supply and Sanitation Policy	Does the construction of the plant increase equity in terms of access to a water supply?
Public Participation	Manager of technical services at the Beaufort West Municipality	NEMA Regulations	The extent to which the public was involved in the planning phases as well as ongoing involvement
Staffing Requirements	Process controllers at the plant	Discussion	Were the staff sourced from the local community?
Staff Education	Process controllers at the plant	Discussion	The training received by the staff for this particular project. Has the training been effective in skilling up labourers? Since the project is a first for South Africa the staff would require a very specific education
Community Size Served	Beaufort West Water Services Audit	Discussion	What is the size of the community being supplied with reclaimed water?
Land Requirements	Google Earth	Discussion	Are there large land requirements?

4. Results and Discussion

In order to assess the sustainability of water reclamation for direct potable reuse, the selected indicators are applied to the Beaufort West Water Reclamation Plant. Information regarding each indicator is drawn from the visit to the plant, data sourced about the plant, and relevant literature on water reclamation.

4.1 Economic Indicators

4.1.1 Feasibility Studies

The Beaufort West Integrated Development Plan 2007 identified the scarcity of water as limiting the potential for the further development of the town. In order to address the issue, the municipality explored several options for additional water sources. The options identified include water reclamation, the development of ground water sources, rainwater harvesting and demand side management. Although water reclamation emerged as the most immediate solution, it is likely that a suite of these options would be developed further to support the continued growth and development of Beaufort West (Ninham Shand, 2009).

Prior to the selection of water reclamation as the chosen alternative, one of the main options investigated was the transferring of water from the Orange River Scheme to Beaufort West. The findings of the investigation were that there was an insufficient quantity of water in the scheme to supply Beaufort West, in addition to the areas currently being supplied. An additional limiting factor was that 380 km of pipeline would have to be built to transport the water, which would be too expensive (Ninham Shand, 2009).

According to the head engineer of the current plant operators, Water & Wastewater Engineering, all other possible alternatives investigated were not viable or already had already been developed (Mattheus, 2013). As decided by the municipality, the most efficient way to construct the plant was to invite tenderers, who had to provide a proposal showing the most feasible way to construct a water reclamation plant (Wright, pers. comm, 2015).

4.1.2 Capital Cost

The funding for the Beaufort West Water Reclamation Plant, in terms of capital, was provided by the National Treasury. A total sum of R42 million was provided, for the upgrading and optimisation of the

existing wastewater treatment works, construction of the water reclamation plant, and the new rising main to the existing reservoir (Holloway *et al*., 2012).

The water treatment works and reclamation facilities are located next to each other, therefore the cost of pumping the water from the treatment works to the reclamation plant is minimal. Significant pumping costs incurred are for the running the machinery in the reclamation plant, and pumping of the reclaimed water to the reservoir to be distributed to the end consumer (Wright, pers. comm, 2015).

Since the wastewater treatment plant was upgraded when the water reclamation facility was constructed, the quality of the effluent produced is of a suitable standard. This helps to reduce costs of reclamation, since the lower the level of treatment the water requires, the lower the costs (Wright, pers. comm, 2015).

4.1.3 User Costs

4.1.3.1 Prior to the Plant

Table 4.1 shows the block step tariff structure from 2009, prior to the construction of the water reclamation plant, until 2014. The first 6 kl of water is provided free to those consumers who are poor, and qualify for indigent relief. The block tariff system provides an affordable tariff for up to 20kl of water usage per month, and has been structured to discourage the inefficient or wasteful use of water. It must be noted that the tariffs up to 20 kl of water do not recover the cost of purification and distribution of the water. Higher tariffs are charged for excessive water consumption in order to balance the under recovery (BWM, 2014).

Table 4.1: Beaufort West Municipality Block Tariff Structure for 2009 to 2014 (BWM, 2014)

Description	Block (kl/month)	2013/14 (R/kl)	2012/13 (R/kl)	2011/12 (R/kl)	2010/11 (R/kl)	2009/10 (R/kl)
Indigent Households	0 - 6	R0.00	R0.00	R0.00	R0.00	R0.00
Other Households	0 - 6	R8.93	R8.20	R6.08	R4.00	R3.64
	7 – 20	R10.23	R9.39	R6.96	R4.58	R4.17
	21 – 50	R11.13	R10.31	R7.64	R5.03	R4.58
	> 50 Kl	R12.18	R11.17	R8.28	R5.45	R4.96

The costs shown in table 4.1 are the normal charges. These tariffs were influenced by the different drought phases, and the costs rose substantially as the drought intensified during 2010. Severe penalties for over consumption were imposed as the drought worsened.

Prior to the plant, using the conventional system, the cost of the production of drinking water was approximately 90c/m^3 (BWM, 2011). By comparison, treatment using water reclamation doubles the cost involved in the production of drinking water (Wright, pers. comm, 2015). The water tariff after the construction of the reclamation plant, in 2011/12 has not increased by an amount that would cover the treatment of the water, which could be because this is included in the basic charge shown in the table, which has increased substantially since 2010, or because the municipality pays for most of the cost of the water reclamation process.

Table 4.2: Beaufort West Municipality Basic Monthly Charge (BWM, 2014)

Description	2013/14	2012/13	2011/12	2010/11
Basic Charge per month	R104.40	R93.00	R68.90	R45.35

The costs of water can be compared to a nearby town, George. The cost of water, shown in Table 4.3 is much higher in George, which like Beaufort West, is also in the arid Karoo region, and therefore faces a water shortage. Even though the cost of water is higher, the first 6 kl of water is provided free to all consumers, not just indigent houses, as in the case of Beaufort West. This implies that higher consumption blocks are charged at a rate greater than the cost in order to generate a surplus to cater for consumers who use up to 6 kl per month. The water usage block tariff has been structured for a basic affordable tariff for up to 20 kl per household per month. Punitive tariffs are in place for excessive water consumption and to cross-subsidise under-recovery. It must be noted that even though the costs of water are higher, the basic charge in 2014 was R63.45, which is nearly half that of Beaufort West (George Municipality, 2013). As mentioned, this large basic charge in Beaufort West might be due to the need to pay for the cost of the reclamation of the water, as the technical director at the Beaufort West Municipality did indicate that the consumers bear some of the cost of the treatment, and the remainder is subsidised by the municipality.

Table 4.3: George Municipality Block Tariff Structure for 2009 to 2014 (George Municipality, 2013)

Block (kl/month)	2013/14 (R/kl)	2012/13 (R/kl)	2011/12 (R/kl)	2010/11 (R/kl)	2009/10 (R/kl)
0 - 6	R0.00	R0.00	R0.00	R0.00	R0.00
7 -12	R 11.11	R9.53	R8.82	R8.32	R7.30
13 - 1 5	R12.79	R10.96	R10.15	R9.58	
16 - 20					R8.40
21 - 30	R15.34	R13.15	R12.18	R11.49	
31 - 50	R18.41	R15.79	R14.62	R13.79	R10.08
> 50	R21.00	R18.00	R16.67	R15.73	R12.10

4.1.4 Maintenance

The municipality invited tenders for the design, construction and operation of the plant, based on a 20-year service-level agreement. The tender was awarded to Water and Wastewater Engineering. Since they are stationed in Cape Town, the head engineer of the company visits the plant once a month to perform a routine inspection and ensure that the plant is operating efficiently (Wright, pers. comm, 2015). The monitoring data is recorded by the process controllers and submitted to Water and Wastewater engineering for their records (Process Controller, pers. comm, 2015).

Service Level Agreement

The Beaufort West Municipality has a 20-year public-private partnership concession agreement to design, build and operate the plant, with Water and Wastewater Engineering. The contract is performance based, and if the water does not meet the required standard, the plant will automatically shut down. Water and Wastewater Engineering's responsibilities include daily monitoring, routine maintenance, and specialised maintenance on membranes. The company is paid per kilolitre of water that is delivered to the town, which ensures that the municipality is able to meet its service delivery mandate. The reason for this is if the plant shuts down and lower volumes of reclaimed water are produced, a financial penalty will automatically be incurred. This ensures that Water & Wastewater Engineering maintain the required standard in the maintenance of the plant. The major maintenance of the plant includes replacing the reverse osmosis pumps every 3 years, and replacing the ultra-filtration membranes every 5 years. This is an expensive process as the membranes are imported while the pumps are obtained locally. The cost of replacing parts, and maintenance of the plant, is included in the price paid to Water and Wastewater Engineering per kilolitre (Wright, pers. comm, 2015).

Failures

There have been no operational failures since the plant was commissioned in 2011. When there is load shedding the plant shuts down, but there is still sufficient water supply to the town. Once the load shedding is over, the system has to be reset, which can be done by the on-site plant operators. If there is a problem which the operators cannot fix, they call the technician, who is able to view and fix the system remotely. In the event that the problem cannot be fixed remotely, the technician who lives in Beaufort West will visit the site (Wright, pers. comm, 2015).

Back-up System

The plant is closed for 3 days every month for maintenance. During this time the Gamka Dam is opened fully to ensure that Beaufort West has an adequate water supply (Wright, pers. comm, 2015).

4.2 Environmental Indicators

4.2.1 Water Quality

There are no heavy industries in Beaufort West, thus all the wastewater produced is fed to the wastewater treatment works. This wastewater consists of domestic sewage as well as wastewater from abattoirs. Since the quality of water discharged from abattoirs is not monitored, the municipality has made a commitment to put a monitoring system in place, to test whether the quality of the discharge complies with the standards (BWM, 2011). The design of the multi-barrier system in the water reclamation plant ensures the optimal removal of organics, harmful pathogens, and physical and aesthetic determinands (Marais & Durckheim, 2012).

Prior to the construction of the reclamation plant, the majority of Beaufort West's water was obtained from boreholes. This water was hard, which means it had a high mineral content, and could cause damage to machinery. The hardness was not regulated since there is no standard regarding hardness in SANS 241. The final effluent from the wastewater treatment works and the final reclaimed water from the water reclamation plant are tested daily at the laboratory on site, as well as on a monthly basis, by an independent laboratory, to ensure that it consistently meets the criteria laid out in the drinking water standards. It has been found that by mixing the reclaimed water with the water from natural sources, the water quality at Beaufort West has actually improved, and the hardness decreased. (Wright, pers. comm, 2015).

Once the final water is produced at the reclamation plant, it is pumped to the existing reservoir, using the new 5 km pipeline which was constructed for the project, and mixed with the water from the

boreholes and the treated dam water. The town's water is made up of 20% reclaimed water. According to SANS 241-1 (2011), it is not permissible for the reclaimed water to constitute more than 25% of the final water supplied to the town, since it lacks essential nutrients. The mixed water is then pumped to the town using the existing pipe network (Wright, pers. comm, 2015).

Monitoring

The literature review identified water quality monitoring as an extremely important process in direct potable reuse. After the commissioning of the plant, Beaufort West began an extensive sampling process, which they continue to do. On a daily basis, a final water sample taken from the outlet of the reclamation plant which is tested for strategic chemical components. The final water supplied to the town is monitored twice weekly at 13 different places in the town. If the analysis at any point shows that the water does not meet the requirements, the supply to the town is immediately shut off (Wright, pers. comm, 2015). The table below provides an overview of the parameters sampled, and the number of samples taken over the 2011/2012 financial year.

Table 4.4: Number of Water Quality Samples Taken (BWM, 2014)

Parameter Sampled	No of Samples
Free Chlorine	96
Conductivity	96
turbidity	97
pH	96
Iron	96
Manganese	96
Aluminium	96
E. Coli	136
Total	809

The water reclamation plant delivers water which complies with the SANS 241-1: 2011 (Edition 1) Drinking Water Standards. The compliance of the plant with these standards is summarised in Table 4.5, and detailed results of final water quality tests can be found Appendix D.

Table 4.5: Summary of Beaufort West Reclamation Plant Final Water Quality Results (Metcalf et al., 2014)

Determinand	Unit	Sans 241-1: 2011	Final Water (Average)
Total Dissolved Solids	mg/l	<1200	34
Turbidity	mg/l	<1	0.2
Ammonia as N	mg/l	<1.5	<0.1
Nitrate and Nitrite as N	mg/l	<11.9	1.4
Faecal Coliforms	Count/100ml	Not detected	0
E.coli	Count/100ml	Not detected	0
Dissolved Organic Content	mg/l	<10	<1.0

It must be noted that the performance, in terms of drinking water quality management and Blue Drop Status, has improved significantly for the Beaufort West Municipality. The Blue Drop Status in 2010, prior to the commissioning of the water reclamation plant, was 83.8, and in 2012, one year after the construction of the plant, the score was 94.91. This placed the municipality at 24th on the National Log Position. The table below shows the scores of the municipalities in the Western Cape that are in close proximity to Beaufort West. Beaufort West attained 12th position, out of a total of 26 municipalities (BWM, 2014).

Table 4.6: Blue Drop Scores in the Western Cape (DWA, 2012)

Water Services Authority	Blue Drop 2012	Blue Drop 2011	Blue Drop 2010
City of Cape Town	98.14	97.61	98.2
Eden District Municipality	98.12	-	-
George	98.12	96.32	96.9
Bitou	97.74	96.12	97.7
Witzenberg	97.63	97.56	93.3
Overstrand	96.82	90.56	71.6
Drakenstein	96.29	95.72	91.7
Mossel Bay	95.68	95.27	84.5
Stellenbosch	95.56	95.74	94.9
Saldanha Bay	95.40	87.69	80.8
Swartland	95.24	92.89	68.6
Beaufort West	94.91	92.01	83.8

Table 4.6 Continued: Blue Drop Scores in the Western Cape (DWA, 2012)

Water Services Authority	Blue Drop 2012	Blue Drop 2011	Blue Drop 2010
Knysna	92.00	89.76	75.2
Bergrivier	90.60	85.2	62.7
Breede Valley	89.02	85.93	74
Cape Agulhas	86.64	73.01	78.6
Swellendam	85.16	80.5	67.3
Cederberg	80.39	51.05	60
Theewaterskloof	71.50	75.41	49
Laingsburg	71.16	80.54	63.9
Matzikama	70.29	32.98	30.1
Prince Albert	70.08	70.72	55
Oudtshoorn	64.58	36.88	44.8
Langeberg	51.62	32.39	0
Hessequa	35.59	14.1	46.2
Kannaland	28.47	55.05	19.4

Since the commissioning of the plant there have been no reported incidents of water-borne diseases, and the plant continues to deliver water that is in full compliance with SANS 241 (Wright, pers. comm, 2015). The Water Research Commission (2015), in their guidelines for monitoring and management of water quality in direct wastewater reclamation, propose monitoring systems for three key processes in a reclamation plant. These processes are raw water monitoring, operational and control monitoring, and compliance monitoring. In accordance with this, it is evident from that Beaufort West has incorporated all three of these aspects into the design and running of the plant (WRC, 2015).

The maturation river acts as a failure mechanism and ensures that the effluent entering the reclamation plant is of sufficient quality to be treated further. If there is a failure at the wastewater treatment works, the maturation river can be closed so that no water enters the reclamation plant. The waste contained in the effluent can then settle, and if the water is of sufficient quality the river can be re-opened and the water allowed to flow into the reclamation plant. This river is monitored constantly, and if the water does not reach the desired pre-treatment quality it can be diverted to the waste pond. The maturation river is cleaned regularly to ensure that waste does not accumulate and thereby lower the quality of the water entering the plant (Wright, pers. comm, 2015).

The objectives of operational monitoring, performed by the process controllers and automated system, are to monitor each control measure in a timely manner to allow effective system management, and ensure that health-based targets are being achieved. It has been ensured that the necessary data capturing and record keeping systems are in place to satisfy the requirements of the Water Services Act (BWM, 2011).

Compliance monitoring is the final process in ensuring that the water reaching the end-users meets the stipulated requirements. The water quality samples are loaded electronically onto the Department of Water Affair's Blue Drop System. Once entered, the water quality data is automatically compared to the SANS 241 Standard. These real-time systems allow the immediate detection of any water quality problems, which enables the use of immediate intervention to correct any problems (BWM, 2011). It has not been necessary thus far to warn consumers of any health risks regarding the water supply, but should a problem arise, safety management procedures are in place should it become necessary.

4.2.2 Energy Requirements

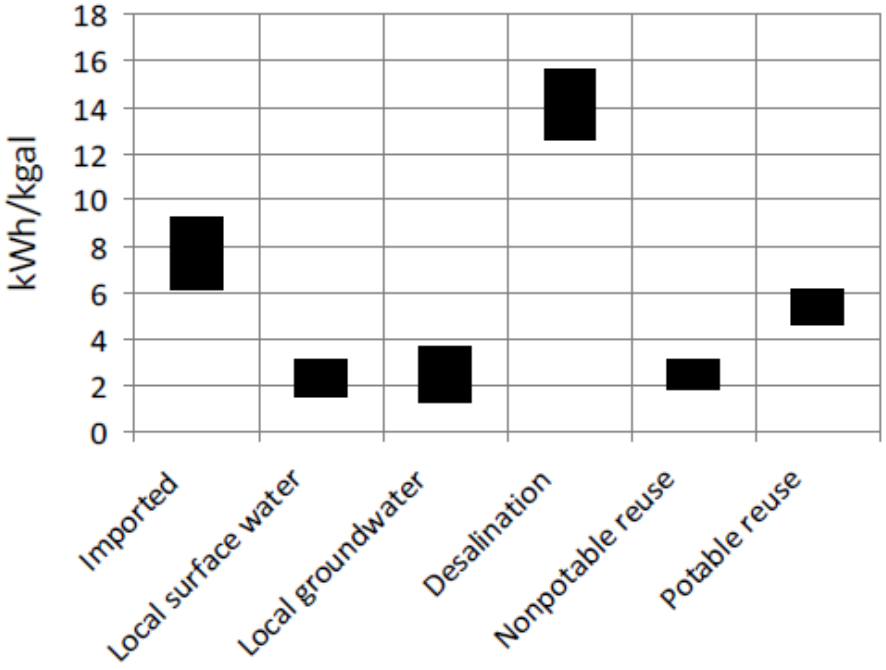
The municipality is billed directly for the energy usage of the plant. The plant consumes approximately 77 245kWh of energy per month (Wright, pers. comm, 2015). As stipulated in the literature, the energy demands of direct potable reuse are relatively high. Using the information provided by Eskom (2011), the environmental implications of the Beaufort West Plant's monthly energy usage have been calculated, to provide an indication of the resources being consumed and the harmful substances being emitted.

Table 4.7: Environmental Implications of Beaufort West Plant's Monthly Energy Usage (Adapted from Eskom, 2011)

Parameter	Use per 1kWh	Plant/month
Coal use	0.53 kg	40 940 kg
Water use	1.4 *l*	108 143 *l*
Ash Produced	155 g	11 973 kg
Particulate emissions	0.33 g	25 kg
CO_2 emissions	0.99 kg	76 472 kg
SO_2 emissions	7.75 g	599 kg
Nox emissions	4.18 g	323 kg

Energy usage is an important factor not only for energy demand but because of the implications for greenhouse gas emissions. A study performed in San Diego County, California, has quantified the energy requirements for different water reuse scenarios (Equinox Centre, 2010).

Table 4.8: Power Consumption for Water Supply alternatives for San Diego County (Equinox Centre, 2010)



From Table 4.8 it is evident that potable reuse is less energy intensive that desalination and importing water, but it takes double the amount of energy as extracting groundwater or treating water for non-potable purposes (Equinox Centre, 2010).

In the planning phases of the reclamation plant, it was confirmed by the Beaufort West Municipality that they did have sufficient capacity to provide the required 315 kW to run the reverse osmosis machinery, and the pumps required to transfer the reclaimed water to the reservoirs. It was thus concluded that the proposed activity would not have a cumulative impact in terms of strain on the power capacity. The proposed pipeline is slightly larger than required for the capacity in order to reduce friction, enabling water to be transported using less energy (Ninham Shand, 2009).

4.2.3 Environmental Impact Assessment

An environmental impact assessment was carried out in accordance with the National Environmental Management Act of 1989. In order to obtain environmental authorisation for the project a basic

assessment was conducted by Ninham Shand Consulting Services, and submitted to the Western Cape Department of Environmental Affairs and Development Planning (Ninham Shand, 2009). Since the plant and pipeline fall under listing notice 1 of the National Environmental Management Act of 1998, a basic assessment report was required in order to obtain environmental authorisation for the project.

The pipeline, which carries reclaimed water from the plant to the existing reservoirs, has a diameter of approximately 250mm, and a length of 3 700m. At the reservoirs, reclaimed water is mixed with water from other sources and fed into the bulk supply system of Beaufort West (Ninham Shand, 2009). A map of the town, showing the proposed pipe route from the reclamation plant to the reservoir can be found in Appendix E.

As required in an environmental impact assessment, alternatives to the proposed activity were investigated. Alternative 1 proposed the introduction of the reclaimed water to the treated water at the potable water supply reservoir, thereby resulting in the greatest dilution. Alternative 2 proposed to introduce the reclaimed water directly into the nearest connection of the water reticulation network, resulting in a higher concentration of reclaimed water for residents closest to the input point. This alternative would have been the most economically viable option for the municipality's proposed water reclamation facility. However, it would be less equitable to the residents of Beaufort West as the concentration would be greater in closer communities. The no-go option was also investigated but would have resulted in 1 200m^3 of additional potable water per day not being available to support the development of Beaufort West. Thus alternative 1 was chosen for the construction of the plant (Ninham Shand, 2009).

In terms of alternative site options, the environmental assessment practitioner found that the proposed project would have similar impacts on the biophysical environment, predominantly due to there being no alternative sites as a result of the inherent link with the existing wastewater treatment works, and potable supply mains. The preferred alternative was identified due to its equitable distribution of reclaimed water, and efficiency in energy and infrastructure use by keeping effluent within the boundary of the wastewater treatment works (Ninham Shand, 2009).

The main findings of the assessment were that the construction of the pipeline on commonage would not be expected to have a negative impact on the community, as the site is already disturbed and the new pipeline would lie adjacent to an existing pipeline. The reclamation plant would be constructed on the existing wastewater treatment works site, and would therefore not require a detailed impact

assessment. An environmental management plan was provided for the construction, operational and decommissioning phases. The chosen site has additional benefits in that water reclamation is permitted in terms of the property's existing land use rights, as it is within the boundary of the existing wastewater treatment works (Ninham Shand, 2009).

4.2.4 Waste Discharge

During the construction phase, 30m^3 of solid waste was produced, which was disposed of at the municipal waste facility. In the operational phase no solid waste is expected to be produced (Ninham Shand, 2009).

The reclamation process will produce effluent which will amount to a reduction in current licensed effluent capacities, due to its being the same effluent produced by the existing wastewater treatment works, with additional water extracted by the reclamation process. Effluent will be disposed of in the manner it is currently being dealt with by the municipality. The existing wastewater treatment works has a series of waste ponds where the waste from the process is deposited. Effluent that results from the reclamation process is directed to the existing waste ponds, keeping the waste in a closed system (Ninham Shand, 2009).

All the phosphates, dissolved salts and waste produced by the reclamation process flow out into the waste ponds. The solid matter and sediment in the water then settles, and the remaining water is pumped, free of charge, to the town, for irrigation purposes. Due to the water shortage, the municipality had already been using all of the water that was treated at the wastewater treatment works to irrigate sports fields, parks and other municipal lands (Ninham Shand, 2009). The reclamation process is based on the principle of recycling, hence optimising the use of resources (Ninham Shand, 2009).

The waste pond allows for the accumulation of waste to about 1m in depth before it has to be cleaned, and the sludge disposed of. According to the manager of technical services at the Beaufort West Municipality (Wright, pers comm, 2015), the waste pond has not been cleaned since the commissioning of the plant, and it will not require cleaning anytime soon. He confirmed that an amount of residual sludge of 1m in depth would take an extended period to accumulate, thus they have not planned how this will be disposed of. This lack of planning may pose a problem in the future, when the waste pond has been filled to capacity and the waste must be disposed of.

This is an efficient method of recycling as it minimises the waste produced. However, according to Asano et al. (2007), since this water is being reused for irrigation, if the capacity for the vegetation to take up the nutrients present in the water is exceeded, then the groundwater and surface water can become overloaded with nutrients. This can in turn lead to human health effects and environmental impacts, such as eutrophication and algal bloom. Excess salinity, as a result of nutrients in the water, can be detrimental to plant growth, and high levels of sodium can adversely impact soil structure.

Since the treatment of wastewater or effluent is not classified as a listed activity, according to the National Environmental Management Waste Act (2008), a waste management licence is not required for the plant.

4.2.5 Pollution

It is a general perception that wastewater treatment facilities, regardless of how well designed they may be, generate odour as a by-product of the wastewater collection and treatment process (Muga & Mihelcic, 2007). On visiting the plant it was clear that there was no noise pollution, air pollution or smell produced by the water reclamation plant. This could be due to the wastewater treatment works removing any smell that the wastewater had, prior to its entering the water reclamation plant.

With regard to noise pollution, all pumps and mechanical equipment is housed in the reclamation plant, and noise is within the acceptable SANS limits for the current zoning of the property. Disturbance of neighbours is not an issue since the nearest neighbour is 480m away (Ninham Shand, 2009).

In terms of air pollution, the reclamation process does not produce any emissions that are disposed of into the atmosphere (Ninham Shand, 2009).

4.3 Societal Indicators

4.3.1 Public Participation

The public participation was performed according with the NEMA Environmental Impact Assessment Regulations Guideline and Information Document Series.

Planning Phase

Although the initial response of the residents toward the plant was negative, about the reuse of sewage for drinking purposes, once they received education regarding the plant their initial

perceptions were altered. The construction of the water reclamation plant was communicated to everyone and there were no complaints. The public was enthusiastic about the plant, especially because their current water quality would increase (Marais & Durckheim, 2010).

In order to ensure that all members of the community were aware of the construction of the plant and pipeline posters were placed around the town. A presentation was also given to the community which provided information regarding the drought experienced in Beaufort West and the construction of the plant (Wright, pers. comm, 2015).

EIA Phase

During the EIA process, importance was placed on informing all community members of the proposed construction of the plant. It was clearly communicated to the community that the treated effluent from the wastewater treatment works would undergo further treatment and then be used for potable water purposes. Awareness was created in the community through the publication of newspaper articles and the handing out of leaflets from door to door. Community committee meetings were held by Water and Wastewater Engineering in conjunction with the municipality, in which questions surrounding the plant were answered as transparently as possible. In these meetings no major objections were received from the public, thus the EIA process was considered complete (Marais & Durckheim, 2010). The greatest concern expressed by the community in these meetings was that they all would not receive water, since they had been exposed to the drought conditions experienced in Beaufort West over the previous years. The public were assured that they would all receive equal access to water supplies (Wright, pers. comm, 2015).

The public participation undertaken for the project, included in the basic assessment report, has been summarised in Table 4.9.

Table 4.9: Public Participation Undertaken During the EIA Phase

(Adapted from Ninham Shand, 2009)

Requirement	**Engagement**
Notice Board	Fixed at a place conspicuous to the public at the boundary or on the fence of the site where the activity is to be undertaken and any alternative proposed site
Written notice	Written notice given to: • the owners and occupiers of land within 100 m of the boundary of the site or alternative who are or may be directly affected by the activity • the municipal councillor of the ward in which the site or alternative site is situated and any organisation of ratepayers that represents the community in the area • the municipality which has jurisdiction in the area • any organ of state having jurisdiction in respect of any aspect of the activity
Advertisement	Local newspaper
Register of I & AP	A register of I & AP was maintained and made available to any person requesting access to the register
Access to Information	All I & AP were given access to the basic assessment reports and any other related reports
Comments	All I & AP, stakeholders that have direct interests in the site and municipalities and other organs of state were informed of the project and provided an opportunity to comment

Notices in English, Afrikaans and Xhosa were placed along the pipeline where vehicle and pedestrian crossing was obvious, and at the entrance to the water reclamation plant and wastewater treatment works. The notices advertised that a basic assessment process was underway and invited interested and affected parties to register. Copies of the basic assessment report were placed at the local library, municipal offices and on the environmental assessment practitioner's website, for public viewing (Ninham Shand, 2009).

Continuous Education

Public participation is an ongoing process, and there have been no complaints about the plant since its commissioning. People are encouraged to visit the plant, to see how it operates, whenever they wish. On a yearly basis, during Water Week, schools are encouraged to visit the plant. They are taken on a tour through the plant where each process is explained, and they are able to taste, smell and touch the reclaimed water. This has a positive impact on the community, and children are encouraged to inform their parents regarding what they learn at the plant. In addition to these tours, test results are made available to the public through their publishing in the local newspaper (Wright, pers. comm, 2015).

The public engagement process involved in the different phases of the project has been summarised in the table. The comments are regarding the strengths and drawback of the participation undertaken in that particular phase of the project.

Table 4.10: Public Engagement Involved in the Project (Author)

Phase	Engagement	Comments
Planning Phase	The community received information about the proposed project and its components, and was able to raise issues of concern. Presentations given and posters placed around town.	The community were simply informed about the project. It seems that they did have an opportunity to discuss alternatives, and contribute relevant local knowledge and information to the environmental assessment. This could be because the municipality had already conducted feasibility studies and found that water reclamation was the only viable alternative.

Table 4.10 Continued: Public Engagement Involved in the Project (Author)

Engagement	Comments
Emphasis placed on informing all community members of the proposed construction of the plant. It was clearly communicated to the community that the treated effluent from the wastewater treatment works would undergo further treatment and then be used for potable water purposes. Awareness was created in the community through the publication of newspaper articles and pamphlets	The environmental impact assessment report is unavailable electronically, at the Beaufort West Municipality or library or through any other source. This document should be readily available to the public.
Committee meetings were held to answer questions from the community as transparently as possible.	Although the questions asked by the community were answered, it seems like they were not directly involved in the decision making process. A top-bottom approach was used.
The plant has an ethos of continuing education. Schools are encouraged to visit the plant. Water quality test results are made available to the public through their publishing in the local newspaper. A public complaints register is kept on site to allow the public to record any complaints regarding the operation on the facility and water quality concerns.	The attitude adopted by the plant, post construction has helped to make the plant a success, and maintain public acceptance and trust.

Equitable Access to Water Supply

As stated in the basic assessment report, the project would not address all the water requirements but rather contribute to the current need. Furthermore, it was intended that the project would contribute to the municipality's initiative to speed up the delivery of water to the remaining households which do not have basic access to water supply (Ninham Shand, 2009).

Table 4.11: Table Showing Percentage of BWM without Access to Basic Water Supply (Adapted from DWAF, 2015)

Basic Water Supply	2011/12	2012/13	2013/14
Below Minimum Service Level	1%	2%	2%

From the table it can be concluded that BWM has not met its target of providing all households with basic water supply. The percentage of those without access to basic supply has actually increased from 2011 to 2014, suggesting that the roll-out of water supply to households is not meeting population growth.

4.3.2 Staffing Requirements

According to the IDP (2007), 35.06% of the economically active population in Beaufort West is unemployed, and the average income per household against national standards in 2007 was low, R800 versus R2 400 per month nationally. During the construction phase there were approximately 26 employment opportunities created, with a value of R400 000, but it is unknown what percentage of this accrued to previously disadvantaged individuals (Ninham Shand, 2009).

Three permanent employment opportunities have been created during the operational phase of the activity, with an expected value of R4 219 000 during the first ten years, R1 547 750 of which will go to previously disadvantaged individuals (Ninham Shand, 2009).

There are three process controllers, sourced from the local community, who operate the plant on a daily basis. Their daily duties are to monitor the plant, analyse the final water produced in the on-site laboratory, ensure that the pumps are functioning correctly, and manually clean the sand filters. The monitoring of the plant is automated, which allows the water to be checked after each process. The automated system also allows the process to be monitored by Water and Wastewater Engineering at their offices in Cape Town (Wright, pers. comm, 2015).

The plant has been effective in skilling up some members of the local community. However, since the plant is highly automated, it does not have a great potential to impact social and economic development in the community. Only general labourers for construction were sourced from within Beaufort West. The design team had to be sourced outside of Beaufort West since there were no sufficiently qualified engineers to do the design, operation and maintenance of the plant. It would be more efficient if the engineering company that runs the plant were from Beaufort West, as they would not have to travel every month to do the routine inspection, and the plant would generate greater economic gain for the Beaufort West community.

4.3.3 Staff Education

The process controllers were initially involved in the construction of the plant, and were then approached to be trained as process controllers. The prior qualifications required for the post of process controllers was a matric certificate. They received three months of on-the-job training prior to the commissioning of the plant regarding the functioning of the plant and how to use the system. After the commissioning of the plant they also received three months of on-the-job training. If there are any changes to the plant system, the head engineer of Water and Wastewater Engineering visits the plant to update and educate the technicians regarding the changes (Process Controller, pers. comm, 2015).

Although the process controllers did receive on-the-job training, they did not undergo any formal training (Process Controller, pers. comm, 2015). It is evident, from discussions with them that they do not fully understand the functioning of the plant, and are just doing what they were told to. Although, it must be noted that one of the process controllers is now undergoing part time formal university training in water treatment.

4.3.4 Community Size Served

The plant serves all 41 000 inhabitants of Beaufort West Municipality, which is approximately 8 800 households (Wright, pers. comm, 2015). The plant treats 1.5 Ml/day of final effluent from the wastewater treatment works, resulting in 1.2 Ml/day of additional potable water, to cater for the needs of the community (Ninham Shand, 2009).

4.3.5 Land Requirements

In addition to the existing wastewater treatment works and waste ponds, the main land requirements are the site of the reclamation plant itself and the maturation river which feeds the effluent from the wastewater treatment works into the reclamation plant. It is evident that the waste ponds require the most land, which may be a problem for the construction of water treatment works in urban areas.

In addition to the area of the treatment facility, the new pipeline constructed; to transport water to the bulk supply reservoir, results in the disturbance of a width of approximately 5m, while the pipeline length is 3 700m. The total disturbance footprint is 18 500m^2 (Ninham Shand, 2009).

Table 4.12: Land Requirements of the Beaufort West Water Reclamation Plant (Author)

Land Use	Area (m2)	Percentage
Water Treatment Works	3500	9,4
Water Reclamation Plant	640	1,7
Maturation River	1242	3,3
Waste Ponds	31964	85,6
Total	37346	100

The layout of the wastewater treatment works and water reclamation plant are shown in Figure 4.1.

Figure 4.1: Image Showing Layout of Beaufort West Water Treatment Facility (Google Earth, Version 6.2)

4.4 Sustainability Discussion

4.4.1 Water Availability

Water conditions in Beaufort West stabilised in March 2011, after the commissioning of the plant (Holloway *et al*., 2012). Prior to the drought, the town extracted water from 17 boreholes, and obtained water from the Gamka Dam, which was suffering from over-extraction. In addition to the construction of the plant, seven boreholes were upgraded and ten new boreholes drilled, with the additional funding of R10.5 million received from the National Treasury (Holloway *et al*., 2012). With the introduction of the plant the water level in the dam can be maintained (Wright, pers. comm, 2015).

Beaufort West can be commended for the measures implemented, since they have secured their water supply situation. Although they did not have the money to build the plant, they took the initiative to secure the funds, and build the first direct reclamation plant in South Africa.

4.4.2 Non-monetised Costs and Benefits

There are costs and benefits which are significant, but cannot be directly quantified. Some of the economic, environmental and societal considerations, in relation to the Beaufort West Reclamation Plant, that are of relevance and have not been monetised are summarised in the tables below.

Table 4.13: Non-monetised Benefits of Direct Potable Reuse
(Adapted from Asano et al, 2007; EPA 2008)

Non-monetised Benefits	Description
Improved reliability	Wastewater reuse provides a reliable, local supply of water during regional shortages. The Beaufort West Municipality is more able to meet the needs of its water users and the environment in both wet and dry periods and under other stresses.
Enhanced self-sufficiency	By reducing dependence on imported water and providing a local water supply, water reuse has increased the community's self-sufficiency.
Enhanced reputation for environmental stewardship	By embracing water reuse, Beaufort West has gained international recognition for their environmental stewardship.
Enhanced regional economic vitality	By meeting increased water demands with new sources, the community is able to maintain local economic growth.
Increased water for the environment	If some existing surface or groundwater supplies are replaced by water reuse, more water can be made available to meet environmental needs (e.g., instream flows for environmental restoration, reducing withdrawals of over-tapped aquifers).

Table 4.14: Non-monetised Costs of Direct Potable Reuse

(Adapted from Asano et al, 2007; EPA 2008)

Non-monetised Costs	Description
Effects on the overall carbon footprint of water supplies	Unless offset by low-carbon energy sources, water reuse may increase the overall carbon footprint of a water supply compared to existing supplies.
Public health effects	Inadequate protection against equipment failures could expose the public to pathogens causing acute gastrointestinal illness or low levels of hazardous chemicals.
Public perception of reduced quality	Public concern over the perceived lower quality of the drinking water supply could lead to increased stress among some individuals and increased expenditures on bottled water.
Effects on downstream flows	Water reuse will reduce downstream flows, with potential adverse ecological effects.

4.4.3 Final Assessment of Indicators

In Table 4.15 each indicator has either been classified as positive, satisfactory, uncertain or negative. As discussed in the research method chapter, the asessment of each indicator is based on the background obtained in the literature review, the assessment of the plant, as well as the opinion of the author. 'Positive' indicates that an indicator is sustainable, 'satisfactory' indicates that the indicator is moving toward sustainability and is potentially sustainable, 'uncertain' is used to classify those indicators about which the sustainability could not be assessed and require further research, while 'negative' is used for those indicators that are considered unsustainable and would require a large amount of research to move toward being sustainable.

Table 4.15: Table showing Assessment of Final Indicators (Author)

Indicators	Evaluation	Comment
Economic		
Capital Cost	Uncertain	Since the costs are site specific, and there are no similar reclamation plants to compare to, it cannot be determined if the capital costs were reasonable. See section 4.1.2 and section 5.5.3
Maintenance	Satisfactory	The plant is being well maintained and the monitoring process is extensive. Membranes for the machinery have to be imported which has an extremely high cost. See section 4.1.4 and 5.5.4
User Costs	Satisfactory	Although the price of water has not increased excessively, the basic monthly charge is quite high. Also, by the water tariff not reflecting the water scarcity situation, consumers may be encouraged to waste water. See section 4.1.3
Feasibility Studies	Positive	Extensive studies were performed by the Beaufort West Municipality with direct potable reuse emerging as the most viable alternative. National Water Research Instutue considers direct potable reuse as the preferable solution to water scarcity. See section 4.1.1
Environmental		
Water Quality	Positive	The quality of the reclaimed water meets all the requirements stipulated in the SANS. The reclaimed water has actually improved the final quality of the drinking water in Beaufort West. The multi barrier system has been effectively designed to include redundancy and reliability, and includes an online monitoring programme. See section 4.2.1
Energy Requirements	Negative	The energy requirements for direct potable reuse are very large. In South Africa, this is a problem, as Eskom cannot meet the current energy requirements. If more plants a built the pressure on the power grid and power stations will increase drastically. See section 4.2.2
Waste Discharge	Uncertain	The waste discharged is reused for irrigation purposes. The outcome has been classified as uncertain since a notable author in the subject, Takashi Asano, has warned that the nutrients in the water may have a negative effect on the soil and plants. See section 4.2.4
Pollution	Positive	The visit to the plant revealed that there was no obvious pollution. This includes noise, air and smell. See section 4.2.5
Environmental Impact Assessment	Positive	The Environmental Assessment Practitioner confirmed that the project would not have a negative impact on the environment, and environmental authorisation was given. See section 4.2.3

Table 4.15 Continued: Table showing Assessment of Final Indicators (Author)

Indicators	Evaluation	Comment
Societal		
Equitable Access to Water Supply	Negative	The construction of the plant has not improved equity in terms of access to water supply.
Public Participation	Satisfactory	Although the public were educated and informed about the plant, they were not involved in the decision making process. See section 4.3.1 and section 5.5.2
Staffing Requirements	Negative	Although the staff were sourced from the local community, since the plant is automated only three process controllers are required. See section 4.3.2
Staffing Education	Satisfactory	The staff did not receive a formal education, and instead received on the job training. However, they have been offered fromal university training after the commissioning of the plant. See section 4.3.3
Community Size Served	Uncertain	Since the plant has only been functioning for a short period of time it is uncertain as to whether it has been effeiciently designed in catering for the changing needs in the Beaufort West community as well as the environment. See section 4.3.4 and section 5.5.3
Land Requirements	Satisfactory	Although the plant itself does not require a large area, the land needed to discharge the waste produced requires a measurable amount of land, which would pose a serious problem in urban areas. See section 4.3.5

Figure 4.2 has been produced in order to provide a simple visualisation of the sustainability outcomes presented in Table 4.15. This 'circle of sustainability' allows the progress of each indicator towards sustainability to be judged by looking at the colour of the corresponding segment of the circle. The circle shows that the main barriers regarding the implementation of direct potable reuse projects are the societal aspects.

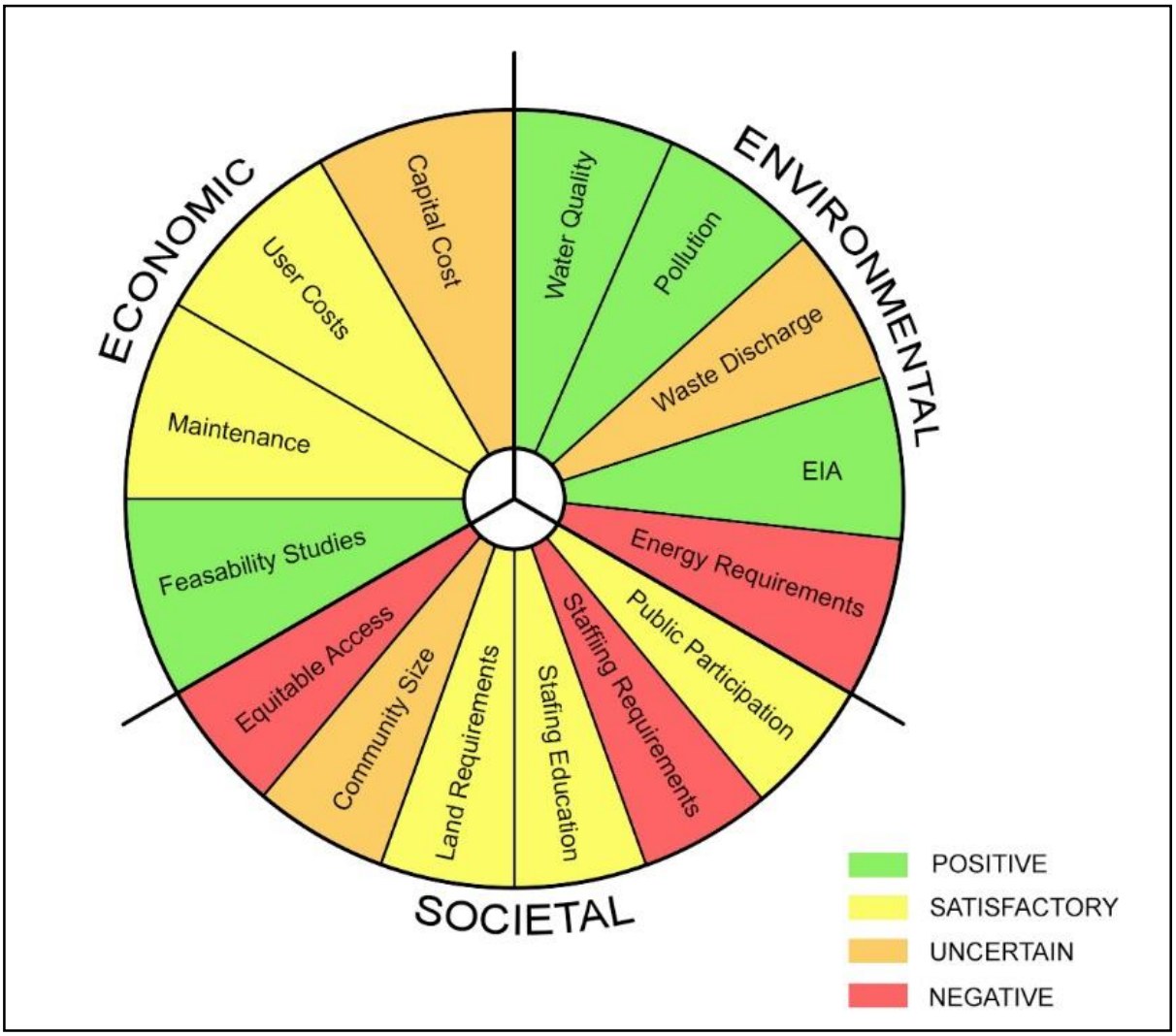


Figure 4.2: Evaluation of Sustainability Indicators (Author)

5. Conclusion and Future Research

The study set out to determine the sustainability of water reclamation for potable purposes through an assessment of the Beaufort West Reclamation Plant, as well as an examination of the relevant literature. In order to achieve this, economic, environmental and societal indicators were selected to determine the sustainability of direct potable water reuse. Furthermore, through the assessment of the plant, and the study of the relevant theoretical literature, the study sought to determine whether potable water reuse can be employed as a viable solution to the problem of water scarcity.

This chapter has two main objectives. Firstly, it aims to provide a condensed analysis of the findings of the literature study, as well as the main findings regarding the chosen indicators, with special regard to the Beaufort West Water Reclamation Plant. Secondly, the chapter outlines future research needs, which will aid in assisting decision makers regarding the implementation of potable reuse projects.

5.1 Economic Indicators

Feasibility Studies

The outcome of the feasibility studies performed prior to the construction of the plant was that direct potable reuse is the most sustainable solution to the water supply problem in Beaufort West. In addition to this, many experts in the field consider reuse as the most viable alternative.

However, the literature review and the study of the plant showed that the feasibility of a reclamation project is site and context specific. Prior to a decision being taken regarding the construction of a reclamation plant, a multitude of factors must be investigated, including the water history of a region and alternative supply measures.

Capital Cost

Although the capital cost of a particular reuse project is site specific, the research suggests that potable reuse projects tend to be more expensive than most water conservation options, and the use of existing water sources, but less expensive than seawater desalination. Since there are no other direct potable reuse plants in South Africa to which the capital cost of the Beaufort West Plant can be compared, it is uncertain as to whether the cost involved was reasonable. It must be noted that the only other option for acquiring additional water to meet demands in Beaufort West, was a water transfer scheme. This option would involve a very large cost, surpassing that of water reclamation, due to the infrastructure required, as well as pumping needs. It must also be noted that in South

Africa, water is a scarce resource, thus transfer schemes have reached capacity, and are unable to supply any additional areas with water.

Costs in terms of future water reuse projects are widely variable, because they are dependent on site-specific factors. These factors are size, location, incoming water quality, regulatory requirements for water quality, treatment process, waste disposal, pumping requirements, costs of energy, and the complexity of the approval process. The lowest-cost water reuse systems supply non-potable reclaimed water to irrigation or industrial cooling operations located in close proximity to the wastewater treatment plant.

User Costs

Since water reclamation is a costly process, reclaimed water rates may not return the full cost of treating and delivering reclaimed water to end users. Thus, larger consumers may have to be charged more, to subsidise the cost of treatment, as is done in Beaufort West. The cost of water to the consumers in Beaufort West illustrates that with sufficient support from the government and efficient budgeting by the municipality concerned, a reclamation plant can be constructed without consumers having to pay an exorbitant price for the water. However, the price of water does not reflect the value of the treatment that it has undergone, which may result in a lack of appreciation for the water by consumers, and subsequent wastage. The price of water needs to be set at a sustainable value.

Maintenance

In terms of maintenance, the Beaufort West Plant illustrates that with suitably qualified engineers and well-trained process controllers, the plant can be well maintained, ensuring that the desired water quality is achieved consistently. Unlike in the Beaufort West case, where the engineering company contracted to operate the plant is situated a considerable distance away, it would be more efficient if they were located closer to the plant. This would allow immediate response in the case of an emergency, closer monitoring, as well as reduced travel distances for routine maintenance.

Although the exact cost of the major maintenance of the plant could not be disclosed, it was indicated that it is very costly, as the membranes for the machinery have to be imported. This indicator was therefore deemed ‘satisfactory’ as this may not be sustainable in the long term. If reclamation facilities are to become more common in South Africa, the machinery required should ideally be produced locally.

5.2 Environmental Indicators

Water Quality

Although, the origin of wastewater means that any substance used or excreted by humans has the potential to be present in the final reclaimed water, the literature reviewed indicates that current technology is capable of removing all contaminants to such a level that the water can be considered safe for extended periods of human consumption. The study of the Beaufort West Plant has been successful in proving that the quality of reclaimed water is capable of consistently meeting the criteria specified in South African water quality regulations.

Like the Beaufort West Plant, reclamation facilities should develop sufficient monitoring and operational plans to respond to variability, equipment malfunctions, and operator errors, to ensure that reclaimed water meets the appropriate quality standards for its use. This is critical in ensuring the sustainability of water reclamation in the future, and maintaining public acceptance and trust.

Energy Requirements

The level of energy consumption involved in direct potable reuse may be insignificant to consumers because the energy cost of delivered water to a home is minimal, but, collectively it influences regional and national energy policy strategies regarding future energy requirements. This includes whether to expand power grids, build new power generation facilities, and how to meet greenhouse gas emission targets.

Although technology has advanced sufficiently to allow the production of water which surpasses the drinking quality requirements, this technology requires a large energy input. If reclamation is to be fully sustainable, technology will need to develop such that it has a lower energy requirement. If this is achieved, it is possible that direct potable reuse will be favoured over other water supply alternatives.

Environmental Impact Assessment

In terms of site location and environmental impact, there is a greater chance of achieving sustainability if the reclamation plant is built within the boundary of the existing wastewater treatment works. This location is preferable since a detailed impact assessment would not be required, and reclamation would be permitted in terms of the property's existing land use rights.

For future projects, it is essential that in the planning phases a detailed environmental impact assessment is undertaken, and an environmental management plan produced. This will ensure that the predicted impacts are mitigated, and if they cannot be mitigated, they are reduced.

Waste Discharge

Since the waste from the Beaufort West Plant is reused for irrigation purposes, it can be concluded that the plant is achieving sustainability in terms of this indicator. Also, the reclamation plant uses the output of the wastewater treatment works, as its input, which reduces the total waste produced. However, it is concerning that it has not been planned how the waste will be disposed of once the waste pond has reached capacity, which may pose a problem in the future. This aspect should have been handled in the environmental management plan.

Pollution

Depending on the specific designs and pumping needs, which in turn relates to energy requirements, reuse projects may have a larger or smaller carbon footprint than existing supply alternatives. During the physical reclamation process, there is no air pollution and minimal noise pollution, thus this indicator has been declared sustainable.

5.3 Societal Indicators

Staffing Requirements and Education

Since reclamation plants are highly automated, they lack the ability to provide job opportunities to the local community on a long term basis. Although general labourers can be employed for the construction period, once the construction has been completed there are limited job opportunities, in terms of daily work. The Beaufort West plant was successful in providing three process controllers with an on-the-job education as well as an opportunity for long term employment. These controllers were then offered an opportunity to obtain a higher education.

Land Requirements

The plant itself does not have a large land requirement, but the waste ponds require a large area, which may pose a problem regarding the construction of water treatment works in urban areas. This problem can be overcome by constructing reclamation facilities adjacent to existing wastewater treatment works, which already have waste ponds. Thus the effluent from the wastewater treatment works can be re-routed from the waste ponds to the reclamation plant for further treatment, and the final waste directed to the ponds.

Equitable Access to Water Supply

The plant has not had any impact on reducing the number of people without access to water. Thus, it can be concluded that the plant does not have any impact on equity of water supply.

Public Perception

Based on the literature review, public perception has proven to be a determining factor in the success of a reuse project, since the lack of public acceptance has been the cause for the failure of several reuse projects. In order to encourage public acceptance and allow informed decision making among authorities, knowledge of water supply and treatment must be enhanced. The public, and decision makers must be provided with scientific and technical material in order to understand water reclamation, and to allow them to evaluate proposals. As illustrated in the Beaufort West case, it is possible to gain public acceptance, especially if the effects of water scarcity are affecting their daily lives.

5.4 Final Conclusion

Based on the literature review and the assessment of the plant, it is evident that there are no technological hurdles hindering the application of potable reuse projects. Although reclamation technology is quite advanced, technology will no doubt, be constantly upgraded due to the increased interest in water reclamation.

In determining the most sustainable option, it is important to consider non-monetised costs and benefits of water supply alternatives, which are frequently overlooked when assessing proposed projects. Although it is evident from the study that water reuse is an attractive solution to the water scarcity problem, it can also be concluded that assessment of the sustainability of this solution is context specific. The applicability of sustainability of direct reuse has to be addressed based on the geographical, societal and political context, existing infrastructure, and availability of funds, among other context specific factors.

Water scarcity is a pressing issue, which requires solutions which are sustainable and can be implemented immediately. In order to achieve overall sustainability, water reclamation would have to be employed in conjunction with other water conservation strategies.

5.5 Future research

5.5.1 Production of Water Quality Standards

In conjunction with the views of the Water Research Commission (2015), to ensure the sustainability of reuse projects, and the production of safe drinking water, the Department of Water and Sanitation should regard the production of standards for water reuse in South Africa as a high priority, since there are no specific guidelines. These standards should be included in the SANS 241 as a separate section, for water reclamation plants which produce drinking water.

5.5.2 Public Perception Studies

To generate achievable development targets, with regard to water reuse, there is need for further studies, especially at a local level, which explore significant factors such as public perception, public health, and environmental impacts. Since public perception studies in South Africa have revealed inconclusive results, further studies will allow experts to gain a broader understanding of the subject.

An issue highlighted in the review as not being fully understood by researchers is trust in the implementing authority. Since trust in the implementing authority has a considerable effect on how the public perceives the quality of the water, further research is required to determine the role of trust in how people make decisions regarding the reuse of recycled water. In this way, institutions which are capable of gaining public trust can be built.

The public perception study performed in the City of Durban draws the conclusion that there were no religious objections to water reclamation for potable purposes, but, allegedly the City of Durban has opted for the construction of two desalination plants, due to public objections and religious concerns. Since desalination is considered to be a more expensive, energy intensive process, further research should be undertaken to determine how the community of Durban truly perceives wastewater reuse.

It is evident that public perception surrounding water reuse is an intricate and sensitive subject which requires extensive future research. This research and possible understanding of public perception will assist implementing authorities to introduce reuse projects with a greater chance of public acceptance, and therefore success.

5.5.3 Life Cycle Costing

Life cycle costing should also be undertaken to determine whether reclamation projects are financially sustainable. This will aid decision makers in assessing which water conservation strategies to implement.

5.5.4 Local Machinery Production

Although the membranes for the machinery are available internationally, dedicated research should be performed into producing these membranes locally. Should this be achieved, direct potable reuse will become more affordable as a long term solution, since the membranes have to be replaced every few years.

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Appendices

Appendix A: Interviews

A1: Interview with Mr C Wright, technical Manager at the Beaufort West Municipality

20 July 2015

1. Who owns the plant?

Beaufort West Municipality

2. Prior to constructing the plant, was an investigation into building a pipeline to transfer water from elsewhere to Beaufort West performed?

Yes, in depth studies into all possible alternatives were conducted. The nearest water scheme is the Orange River Scheme, which does not have the capacity to provide water to Beaufort West, and even if it could supply Beaufort West, the length of pipeline required would be 380km, which would be very expensive.

3. Does the wastewater treatment work treat all the wastewater produced by the town?

Yes, all the town's wastewater is directed to the plant. This is possible because there are no heavy industries within the town.

4. Is the stormwater also fed to the plant?

No

5. How many households does the plant receive wastewater from?

8888 households, which is approximately 40 000 people.

6. How is the reclaimed water delivered to consumers?

It is pumped by the new pipeline to the existing reservoir, where it is blended with water from the Gamka Dam and boreholes, and then delivered to consumers using the existing pipelines.

7. How often and by whom is the water tested?

The final effluent from the wastewater treatment works and final reclaimed water is tested on site daily by the process controllers. The final reclaimed water is also tested once a month by an independent laboratory.

8. Have there been any failures since the commissioning of the plant?

No there haven't. When there is loadshedding the system has to be reset, but there is still water supply to the town. If there is any problem the technician, in Beaufort West, is called to fix it.

9. How does the service-level agreement work?

The municipality pays Water and Wastewater engineering per kl supplied to the town. This price paid per kl includes any maintenance to the plant that the company has to perform.

10. Is there any major maintenance required?

The reverse osmosis membranes have to be replaced every three years, and the ultra-filtration membranes every five years. These have to be imported from overseas. Maintenance is included in the service-level agreement with Water and Wastewater Engineering therefore they have to replace the parts required.

11. How often is maintenance performed?

The plant is shut down for three days a month to clean the reverse osmosis and ultra-filtration membranes. During this time the Gamka Dam is opened fully to ensure a supply of water to Beaufort West.

12. How many staff are required for the operating of the plant?

There are three process controllers from the town of Beaufort West.

13. What are the duties of the process controllers?

They monitor the plant on a daily basis, and check that the pumps are functioning correctly. They analyse the water produced by the plant, daily, in the on-site laboratory.

14. What is the total monthly energy usage of the plant?

11 245kWh. The electricity cost is paid by the municipality, and does not form part of the service-level agreement with Water and Wastewater Engineering.

15. Have there been any complaints from the public since the commissioning of the plant?

No, there have not.

16. Is there any ongoing public participation?

Yes, people are able to visit the plant whenever they want to, and the water quality tests for the final water are published in the local newspaper every month. During water week, schools are encouraged to visit the plat. They are taken on a tour through the plant, where each process is explained. This has a positive impact on the community, and the children inform their parents about the plant.

A2: Interview with Process Controllers, Beaufort West Water Reclamation Plant

20 July 2015

1. Do you live in Beaufort West

Yes

2. How were you selected as process controllers?

We were employed as general construction labourers on the site. We then gave our CV to the head engineer at Water and Wastewater Engineering, for selection as process controllers.

3. What qualifications do you have?

Our highest qualification is a matric certificate.

4. What training did you receive?

We received three months of training prior to the opening of the plant, on how the plant operates, our daily duties which include water quality testing in the on-site laboratory, and how to use the online system.

5. Have you received any further training?

After we started working we received three month of in-job training. We are currently undertaking part-time studies in plant operation theory, wastewater treatment, maths, and science. These studies are sponsored by Water and Wastewater Engineering.

Appendix B: Potable Reclamation Plants across the World

Table B1: List of Potable Reclamation Plants across the World (WRC, 2015)

Plant Name	Country	State/ Province	ML/d	Commissioned	Status	Treatment train	System
Montebello Forebay	USA	CA	165	1962	Operational	Media filtration -> Cl	IPR: Groundwater recharge via soil-aquifer treatment
'Old' Goreangab Water Reclamation Plant	Namibia	Windhoek	7	1968	Superseded	Clarification -> DAF -> sand filtration -> GAC -> Cl	DPR: Blending prior to treatment
Water Factory 21	USA	CA	60	1976	Superseded	LC -> air stripping -> RO -> UV/AOP -> Cl	IPR: Groundwater recharge via seawater barrier
Upper Occoquan Service Authority	USA	VA	204	1978	Operational	LC -> media filtration -> GAC -> IX -> Cl	IPR: Surface water augmentation
Hueco Bolson Recharge Project	USA	TX	38	1985	Operational	LC -> media filtration -> O_3 -> GAC -> O_3 -> Cl	IPR: Groundwater recharge via direct injection
Clayton County	USA	GA	66	1985	Operational	Cl -> UV	IPR: Surface water augmentation via land application/wetlands
West Basin Water Recycling Plant	USA	CA	47	1993	Operational	MF RO -> UV/AOP -> Cl	IPR: Groundwater recharge via direct injection
Scottsdale Water Campus	USA	AZ	53	1999	Operational	Media filtration -> MF -> RO -> Cl	IPR: Groundwater recharge via direct injection
Gwinnett County	USA	GA	227	1999	Operational	UF -> O_3 -> GAC	IPR: Surface water augmentation
Toreele Reuse Plant	Belgium	Wulpen	7	2002	Operational	UF -> RO -> UV	IPR: Groundwater recharge via infiltration ponds
'New' Goreangab Water Reclamation Plant	Namibia	Windhoek	21	2002	Operational	PAC -> O_3 -> C/F -> DAF -> sand filtration -> O_3/AOP -> BAC -> GAC -> UF -> Cl	DPR: Blending prior to treatment
NEWater	Singapore	Kranji	55	2003	Operational	UF -> RO -> UV	IPR: Surface water augmentation
NEWater	Singapore	Bedok	86	2003	Operational	UF -> RO -> UV	IPR: Surface water augmentation
Alimitos Barrier	USA	CA	10	2005	Operational	MF -> RO -> UV	IPR: Groundwater recharge via direct injection
Chino Basin Groundwater recharge Project	USA	CA	69	2007	Operational	Media filtration -> SAT -> Cl	IPR: Groundwater recharge via soil-aquifer treatment

Appendix C: South African Water Quality Standards

Table C1: Microbiological Determinands (SANS 241:2011)

Determinand	Risk	Unit	Standard Limits
E. coli [a] or faecal coliforms [b]	Acute health – 1	Count per 100 mL	Not detected
Cytopathogenic viruses [c]	Acute health – 2	Count per 10 L	Not detected
Protozoan Parasites [d]			
Cryptosporidium spp	Acute health – 2	Count per 10 L	Not detected
Giardia spp	Acute health – 2	Count per 10 L	Not detected
Total coliforms [e]	Operational	Count per 100 mL	≤ 10
Heterotrophic plate count [f]	Operational	Count per mL	≤ 1 000
Somatic coliphages [c, g]	Operational	Count per 10 mL	Not detected

[a] Definitive, preferred indicator of faecal pollution.

[b] Indicator of unacceptable microbial water quality, could be tested instead of *E. coli*, but is not the preferred indicator of faecal pollution. Also provides information on treatment efficiency and after growth in distribution networks.

[c] Confirms a risk of human infection and faecal pollution, and also provides information on treatment efficiency. The detection of selected viruses confirms faecal pollution of human origin.

[d] Confirms a risk of infection and faecal pollution, and also provides information on treatment efficiency. The detection of selected protozoan parasites confirms a human health risk.

[e] Indicates potential faecal pollution and provides information on treatment efficiency and after growth.

[f] Process indicator that provides information on treatment efficiency, after growth in distribution networks and adequacy of disinfectant residuals.

[g] Process indicator that provides information on treatment efficiency.

Table C2: Physical, Aesthetic, Operational and Chemical Determinands (SANS 241:2011)

Determinand	Risk	Unit	Standard Limits [a]
Physical and aesthetic determinands			
Free chlorine	Chronic health	mg/L	≤ 5
Monochloramine	Chronic health	mg/L	≤ 3
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Odour or taste	Aesthetic	—	Inoffensive
Total Dissolved Solids	Aesthetic	mg/L	≤ 1 200
Turbidity [b]	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 C [c]	Operational	pH units	≥ 5 – ≤ 9.7
Chemical determinands — macro-determinands			
Nitrate as N [d]	Acute health - 1	mg/L	≤ 11
Nitrite as N [d]	Acute health - 1	mg/L	≤ 0,9
Sulfate as SO_4^{2-}	Acute health - 1	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F^-	Chronic health	mg/L	≤ 1,5
Ammonia as N	Aesthetic	mg/L	≤ 1,5
Chloride as Cl^-	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical — micro-determinands			
Antimony as Sb	Chronic health	µg/L	≤ 20
Arsenic as As	Chronic health	µg/L	≤ 10
Cadmium as Cd	Chronic health	µg/L	≤ 3
Total Chromium as Cr	Chronic health	µg/L	≤ 50
Cobalt as Co	Chronic health	µg/L	≤ 500
Copper as Cu	Chronic health	µg/L	≤ 2 000
Cyanide (recoverable)	Acute health - 1	µg/L	≤ 70
Iron as Fe	Chronic health	µg/L	≤ 2 000
	Aesthetic	µg/L	≤ 300
Lead as Pb	Chronic health	µg/L	≤ 10
Manganese as Mn	Chronic health	µg/L	≤ 500
	Aesthetic	µg/L	≤ 100
Mercury as Hg	Chronic health	µg/L	≤ 6
Nickel as Ni	Chronic health	µg/L	≤ 70
Selenium as Se	Chronic health	µg/L	≤ 10

Table C3: Blue Drop Scorecard (DWA, 2011)

Key Performance Area		Key Performance Indicator	
1	**Water Safety Planning**	1.1	Water Safety Planning Process
		1.2	Risk Assessment and Review of Control Measures
		1.3	Risk-Based Monitoring Programmes
		1.4	Credibility and Submission of Drinking Water Quality Data
		1.5	Incident Management
2	**Drinking Water Quality Process Management & Control**	2.1	Compliance with Regulation - Works Classification
		2.2	Compliance with Regulation - Process Controller Registration
		2.3	Availability of signed WTP logbook
3	**Drinking Water Quality Compliance**	3.1	Compliance per Determinand (according to Monitoring Programme)
		3.2	Risk Assessment Defined Health Index
		3.3	Operational Efficiency Index
4	**Management, Accountability & Local Regulation**	4.1	Management Commitment
		4.2	Publication of Performance
		4.3	Service Level Agreements / Performance Agreements
5	**Asset Management**	5.1	Annual Process Audit
		5.2	Asset Register
		5.3	Availability & Competence of Maintenance Team
		5.4	Operations and Maintenance Manual
		5.5	Maintenance and Operations Budget and Expenditure
		5.6	Design Capacity versus Operational Capacity

Appendix D: Beaufort West Reclamation Plant Water Quality Tests

Table D1: Detailed Water Quality Tests for Beaufort West Reclamation Plant (Water & Wastewater Engineering, 2011)

Determinant	Unit	SANS 241: Class I	Final Water	Compliance
Physical and organoleptic requirements				
Colour (aesthetic)	mg/L Pt	< 20	5	Passed
Conductivity	mS/m	< 150	4	Passed
Total Dissolved Solids (Calculated)	mg/L	< 1000	24	Passed
Odour	TON	< 5		
pH value	pH units	5,0 – 9,5	6.1	Passed
Taste	FTN	< 5		
Turbidity	NTU	< 1	0.3	Passed
Chemical Requirements – macro determinant				
Ammonia as N	mg/L	< 1,0	0.1	Passes
Calcium as Ca	mg/L	< 150	< 0.5	Passed
Chloride as Cl^-	mg/L	< 200	6.9	Passed
Fluoride as F^-	mg/L	< 1,0	< 0.1	Passes
Magnesium as Mg	mg/L	< 70	< 0.1	Passed
Nitrate plus Nitrite as N	mg/L	< 10	0.3	Passed
Potassium as K	mg/L	< 50	< 2.0	Passed
Sodium as Na	mg/L	< 200	6.2	Passed
Sulphate as SO_4	mg/L	< 400	0.3	Passed
Zinc as ZN	mg/L	< 5,0	0.03	Passed
Chemical Requirements – micro determinant				
Aluminium as Al	mg/L	< 0,3	< 0.02	Passed
Antimony as Sb	mg/L	< 0,01	< 0.01	Passed
Arsenic as As	mg/L	< 0,01	< 0.01	Passed
Cadmium as Cd	mg/L	< 0,005	< 0.005	Passed
Total Chromium as Cr	mg/L	< 0,1	< 0.01	Passed
Cobalt as Co	mg/L	< 0,5	< 0.01	Passed
Copper as Cu	mg/L	< 1	0.04	Passed
Cyanide as CN^-	mg/L	< 0,05	< 0.05	Passed
Iron as Fe	mg/L	< 0,2	< 0.01	Passed
Lead as Pb	mg/L	< 0,02	< 0.02	Passed
Manganese as Mn	mg/L	< 0,1	< 0.01	Passed
Mercury as Hg	mg/L	< 0,001	0.001	
Nickel as Ni	mg/L	< 0,15	< 0.02	Passed
Selenium as Se	mg/L	< 0,02	< 0.02	Passed
Vanadium as V	mg/L	< 0,2	0.01	Passed
Chemical Requirements – organic determinant				
Dissolved Organic Carbon	mg/L	< 10	5.5	Passed

Appendix E: Map Showing Proposed Pipeline

Table E1: Map Showing Beaufort West Proposed Pipeline (Wright, 2015)