A DECISION SUPPORT SYSTEM FOR ASSESSING THE FEASIBILITY OF IMPLEMENTING WASTEWATER REUSE IN SOUTH AFRICA

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A thesis submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2011

DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

(Signature of candidate)

...................day of 2011

ABSTRACT

South Africa is a semi-arid country with low volumes of rainfall (average of 500 mm per annum) and high evaporation (approximately 85 percent of mean annual precipitation). The highly variable and spatial distribution of rainfall across the country adds to the sparse availability of fresh water. Stream flows in most South African rivers are at relatively low levels for most of the year, and the infrequent high flows that do occur happen over limited and often unpredictable periods. Coupled with this problem is continuous pollution of surface water with wastewaters generated from domestic, institutional and industrial activities. Community concerns about environmental pollution resulting from the quality of wastewater disposed to sensitive environments have led to pressures on the water industry to treat wastewater to higher qualities before discharging to water. As a result of the above, wastewater reuse for potable and non-potable uses increases globally.

In South Africa, the shortage of water can significantly abated by the reuse of treated municipal wastewater through dual water reticulation systems. However, it is very likely that a water reuse project may fail if all the factors governing its implementation are not well addressed prior to its implementation. To achieve this goal, there is need to develop a decision support tool that would enable a balance between the social, economic, technical and environmental attributes involved in implementing wastewater reuse via dual reticulation. The aim of this research work is to develop a Decision Support System (DSS) for assessing the feasibility of implementing wastewater reuse systems for non-potable uses in South Africa.

The DSS is classified into quantitative and qualitative modules. The quantitative modules consist of technical and economic assessment criteria while qualitative modules consist of environmental and social assessment criteria. Under quantitative assessment, technical assessment starts with the estimation of the volume of non-potable water needed for agricultural irrigation, urban, domestic, mining and industry and in other uses. This module therefore, provides the basis to justify a reuse project economically by quantitative estimation of the volume of recycled water needed for various activities. Other quantitative assessments include pollutant removal efficiency to meet reuse water quality, capital and O&M costs of the 33 unit processes from which the DSS can form a diversity of wastewater treatment

trains. Treatment train qualitative is classified into technical (i.e. reliability, adaptability to upgrade, varying flow rate, change in water quality, ease of O&M and ease of construction) and environmental (i.e. power and chemical requirements, odour generation and impact on groundwater) criteria.

The social qualitative module of the DSS contains simplified questionnaires that were developed based on the implications of the results obtained from the application of the Theory of Planned Behaviour (TPB) for potential domestic and institutional users at Limpopo (Capricorn and Vhembe) and Cape Town (City of Cape Town) provinces to determine factors influencing intention to accept/reject wastewater reuse for non-potable water uses. The Triple Bottom lines of sustainability (TBL) were also used to investigate the ability of the service providers to manage reused facilities successfully. The results of the TPB study show that *attitude towards wastewater reuse*, *control over the source of water and its application, advantages of reuse on the environment* and *trust in the service provider* are the factors influencing respondent's intention to accept reuse. These factors were then incorporated into a simplified module of the DSS.

Testing of the developed DSS using a case study of the Parow wastewater treatment works in Cape Town showed it to be versatile and to provide a good assessment of both qualitative and quantitative criteria of the selected treatment trains. When the actual performance of the Parow wastewater treatment works was compared to the result of the DSS, Chemical Oxygen Demand and faecal coliforms removal was similar at average and maximum values. However, the DSS over estimates the Total Suspended Solids and under estimates Total Nitrogen and Total Phosphorus. In the current WWTWs monitoring procedure, plant personnel do not have performance data on the unit process pollutant removal efficiency (i.e. minimum, average or maximum). Hence, selecting operating efficiency for an existing treatment train requires good knowledge of each unit's process performance. The DSS thus provide a suitable information when data of this nature is not available.

The DSS quantitative assessment for Parow WWTW shows that the treatment and distribution cost wastewater that meets the quality requirement of all users has a payback of less than 3 years with annual revenue of R1 095 000.00. The qualitative assessment score for the same treatment configuration was calculated as 0.73 out of a maximum score of 1.00. This is interpreted as a good qualitative score. Further testing of the DSS perception module using questionnaires administered at the Goldfields gold mine, Driefontein shows that there is *high potential for reuse to be viable* if implemented.

DEDICATION

To the cherished memory of my late uncle,

Prof Joseph Odeleye Ajayi

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Distinction

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LIST OF SYMBOLS AND ABBREVIATIONS

AFFI	Adjusted Goodness of Fit
AGR	Artificial Groundwater Recharge
AHP	Analytical Hierarchy Process
AVWR	Annual Volume of Water Reclaimed
BOD_5	5-day Biochemical Oxygen Demand
CFI	Comparative Fit Index
CoCT	City of Cape Town
COD	Chemical Oxygen demand
CRD	Capital Regional District
CRF	Capital Recovery Factor
DNHPD	Department of National Health and Population Development
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWEA	Department of Water and Environment Affairs
DWRS	Dual Water Reticulation System
EM	Electromechanical works
ESCWA	Economic and Social Commission for Western Asia
FC	Faecal Coliforms
GIS	Geographic Information System
GUI	Graphic User Interface
LCC	Life Cycle Cost
MDGs	Millennium Development Goals
MSPWR	Minimum Selling Price of Water Reclaimed
NFI	Normalized Fit Index
NNFI	Non-normalized Fit Index
NPV	Net Present Value
NSER	National State of Environmental Report
O&M	Operation and Maintenance
pH	Power of hydrogen

RDP	Reconstruction and Development Program
RFI	Relative Fit Index
RMSEA	Root Mean Square Error of Approximation
SAT	Soil Aquifer Treatment
SEM	Structural Equation Modelling
SPWR	Selling Price of Water Reclaimed
TBLs	Triple Bottom Lines
TC	Total Coliforms
TDS	Total Dissolved Solids
TN	Total Nitrogen
TOC	Total Organic Carbon
TOD	Total Oxygen Demand
TP	Total Phosphorus
TPB	Theory of Planned Behaviours
TS	Total Solid
TSS	Total Suspended Solids
Turb	Turbidity
UKEA	UK Environmental Agency
USEPA	United State Environmental Protection Agency
USGS	United State Geological Survey
WHO	World Health Organisation
WWTWs	Wastewater Treatment Works

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CHAPTER 1
INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

The scarcity of water resources is one of the most challenging constraints that militate against economic growth, social justice, and ecological integrity in many developed and developing countries. The information on availability of water resources worldwide shows that 40 percent of the world's population in over 80 countries experience water scarcity, where water reserves are exploited faster than they are replenished (Wallace and Austin, 2004). Rapid growth in population, urbanization, agriculture, industrial development and natural occurrences like drought, have increased the demand for water resources in many parts of the world and water resources planners are continually looking for additional sources of water to supplement the limited resources available to their region. Also, as both industry and populations continue to increase, there is a corresponding increase in wastewater generation in urban areas raising concerns about environmental pollution resulting from the quality of wastewater disposed to sensitive environments. To promote sustainable and efficient water use, recent efforts have centred on wastewater reuse for non-potable uses via dual reticulation. A dual water reticulation system is an urban water reuse scheme where non-potable water (e.g. treated wastewater, saline water, or greywater) is provided to households and/or other consumers for non-potable water uses via a reticulation system that is separate from the drinking water supply.

Water reuse has become an attractive option for conserving and extending available water supplies and at the same time presents an opportunity for pollution abatement when water reuse replaces effluent discharge to sensitive surface waters bodies. Other benefits of reuse include the decrease in diversion of freshwater from sensitive ecosystems, replenishment of soil nutrients in agriculture due to irrigation, enhancement of groundwater recharge, delay in future expansion of water supply infrastructure and the creation or sustenance of wetlands (Angelakis and Bontoux, 2001; Joksimovic, 2006). Despite the benefits mentioned above, there are some challenges affecting the implementation of reuse projects. These challenges include public acceptance which is driven by general lack of knowledge or other individuals\ group specific concerns, diverse technical and economical efficiencies, potential health risks to the public and the lack of suitable standards, guidelines and/or legislation (Weizhen and

Andrew, 2003). Sources of water for reuse include rainwater, stormwater, salinewater, brackish water, greywater and wastewater. Reuse of these water sources are practiced in diverse parts of the world and at different scales. However, managing each system varies according to the types of pollutants present and their concentrations (Booker, 2000) and the maintenance requirements of each system. In this thesis, the source of reuse water is limited to municipal wastewater generated within an urban setting. It is also imperative to note that the basic condition that must be met before implementing municipal wastewater reuse is that the area must be sewered (Joksimovic, 2006).

Treated municipal wastewater represents a significant potential source of reclaimed water for some beneficial reuses. In developed countries, approximately 73 percent of the population is served by wastewater collection and treatment facilities. Yet only 35 percent of the population of developing countries is served by wastewater collection (USEPA, 2004). This situation presents a good opportunity for the inclusion of wastewater reuse in many sewerage planning projects within developing communities. As developing country populations continue to move from rural to urban areas, the number of centralized wastewater collection and treatment systems will also increase, creating significant opportunities to implement water reuse systems to augment water supplies and, in many cases, improve the quality of surface waters (USEPA, 2004).

1.2 Problem Statement

In comparison with other forms of water (e.g. salinewater and fossil water), freshwater has traditionally been the main source of potable water to communities as a result of the lower costs associated with its treatment, accessibility, conveyance and storage. Freshwater scarcity, which is being experienced globally, needs conservative measures to maximize usage. Water demand already exceeds supply in many parts of the world, and many more areas are expected to experience this imbalance in the near future (Wikipedia Encyclopaedia, 2007). In order to meet an ever increasing demand for freshwater, past efforts have centred on the development of additional water resources schemes i.e. water supply interventions such as the exploitation of distant surface water and deeper groundwater sources, construction of new dams and desalination (Friedler and Hadari, 2006). However, implementation of these measures usually requires significant capital investment (planning, construction, operation, maintenance, and replacement) and is frequently accompanied by negative long term environmental effects such as the depletion of renewable water resources, deterioration of water quality, seawater intrusion, and alteration of ecosystem dynamics. Efforts to augment existing water supply have gone a long way to mitigate the negative effects of freshwater scarcity. However, other feasible and more environmentally attractive initiatives have been developed to complement water supply interventions. The separation of potable and non-potable water for various uses has increasingly been investigated in many parts of the world as a means to meet the growing demand for non-potable water requirements that have traditionally used potable water (Hurlimann and Mckay, 2007).

Some of the obstacles to water reuse mentioned in section 1.1 (i.e. combination of prejudiced beliefs, fear, attitudes, lack of knowledge and general distrust) led to the failure of the San Diego water repurification and San Gabriel valley groundwater recharge projects in the United State of America (Po et al., 2004). To reduce potential risks to public health and promote public acceptance, there is a well established guideline for water reuse for agricultural irrigation by the World Health Organization (WHO, 2006) while the US Environmental Protection Agency (USEPA, 2004) has standards for various non-potable applications. Also, there are standards available in many developed (e.g. Australia; Dettrick and Gallagher, 2002 and USA; USEPA, 2004) and developing (e.g. Mexico and Indonesia, Blumenthal *et al*., 2000) countries. In Europe, some member states or autonomy regions have their own standards/guidelines/regulations as shown in Table 1.1.

Table 1.1: Existing water reuse criteria within the European Union (Bixio *et al.*, 2005)

Member State	**Type of criteria**	**Comment**
Belgium: Flemish regional Authority	Aquafin Proposal to the Government (2003)	Based on Australia EPA Guidelines
Cyprus	Provisional standards	Quality criteria for irrigation stricter than WHO standards but less than Californian Title 22 (TC <50/100 ml in 80% of the cases on a monthly basis and <100/100 ml always)
France	Art. 24 decret 94/469 3 juin 1994 Circulaire DGS/SD1.D/91/n^{o}51	Both refer as water reuse for agricultural purposes. Essentially follow the WHO standards, with the addition of restrictions for irrigation techniques and setback distances between irrigation sites and residential areas and roadways
Italy *Regional authority:* Sicily, Emilia Romagna and Puglia	Decree of Environmental Ministry 185/2003	Quality requirements are required for the three water reuse categories defined: Agriculture, non-potable urban and industrial. possibility for the Regional Authorities to change some parameters and implement stricter norms
	Guidelines	The proposed microbiological standards are similar to those of the title 22 regulation for Pugila and Emilia Romangna and to WHO standards for Sicily
Spain	Law 29/1985, BOE n.189, 08/08/85 Royal Decree	In 1985, the Government indicated water reuse as a possibility, but no specific regulation followed.

Member State	Type of criteria	Comment
Regional authorities: Andalucia, Balearic Is and Catalonia	2473/1985	Draft legislation has been issued in 199, with a set of standard for 14 possible applications of treated water. The proposed microbiological standards range is strongly similar to those of the Title 22 regulations
	Guidelines from the Regional Health Authorities	Developed their own guidelines concerning wastewater recycling, in particular in the field of the irrigation, based on the WHO guidelines in 1989

However, guidelines on the use of non-potable water (i.e. wastewater, greywater and salinewater) are still in its infancy in South Africa and currently there are no national regulations and guidelines on the implementation of wastewater reuse systems.

In fulfilling the fundamental principles and objectives of the current South African water law (DWAF, 1998), priority has been given to providing basic water needs for human use and water allocation for ecological requirements in order to preserve natural ecosystems. In line with this principle, aggressive campaigns and programs in support of potable water supply for all South Africans was initiated (i.e. the 6 KL per household per month of free basic water supply). As a result, many low-income rural communities have benefited immensely from water supply and distribution systems. However, it has been predicted that unless the water consumption patterns in South Africa change significantly, the country would not be able to meet the growing demand for water, and the problem could be extremely severe within 20-25 years (DWAF, 1997). As shortage increases, allocation of water to irrigated agriculture, for example, may result in downstream urban areas facing water shortages leading to water use restrictions and increased general discontent. It is thus within the context of freshwater constraints that the South African government is faced with the challenge of implementing sustainable alternatives including the use of non-potable water for non-potable requirements especially in previously deprived communities. This alternative has been shown to facilitate economic development and job creation (Barbara and Dhesigen, 2000).

In the past, wastewater and salinewater reuse have been viewed with unfavourable conclusions i.e. high treatment costs and technical constraints. With recent advances in wastewater treatment technologies to treat wastewater for reuse in non-potable applications in many developed and developing countries, it has become imperative to visit this subject matter as a viable alternative in the drive towards overcoming the challenges of current and future water shortages in South Africa. Treatment technologies for wastewater reuse systems are already well established with varied degrees of success in many countries such as Singapore, Israel, Jordan, Namibia, United States of America (USA), Australia, Germany and many European countries (Po *et al*, 2004). In South Africa, research on and practice of non-potable water use for diverse non-potable uses has grown in the last 5 years (Carden, *et al.*, 2007 (b)). However, wastewater reuse systems in South Africa is still in its infancy and as such, there is a paucity of reliable information relating to the costs and benefits, public opinion and decision support tools for assessing the feasibility of implementing wastewater reuse systems in different South African communities. This research is therefore focused on developing a decision support tool for assessing the feasibility of implementing wastewater reuse for various non-potable uses in South Africa.

1.3 Research Aim and Objectives

It is evident from the discussion in the previous sections that wastewater reuse will provide a viable and sustainable option in water demand management as the nation's industries and populations continue to grow. In light of this, there is need to develop tools that can assist the decision makers during the assessment of the critical factors that govern the implementation of reuse.

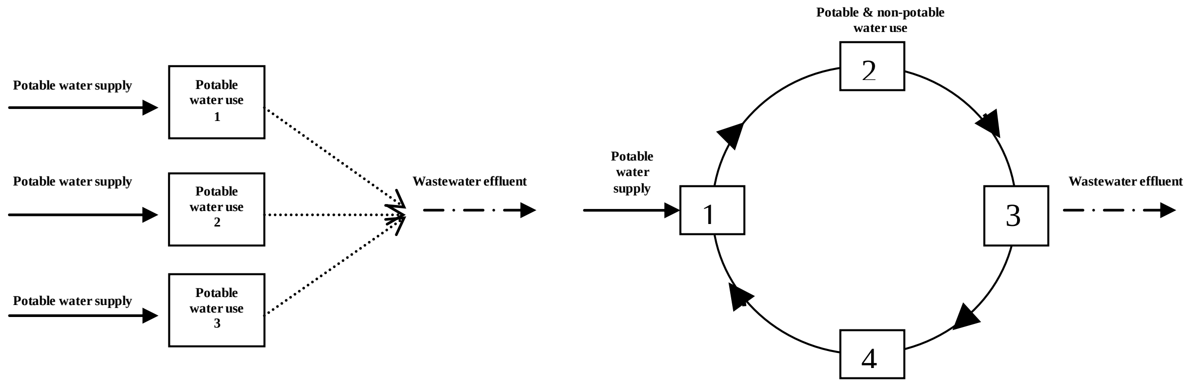
The primary aim of this research is to develop a decision support system for assessing the feasibility of implementing wastewater reuse systems in South Africa. This tool will assist decision makers in the water industry to achieve a balance between social, economic, and environmental attributes involved in implementing wastewater reuse. In this way, a more balanced view of all critical factors that could influence the implementation of wastewater reuse as a water demand management alternative is created.

The aim of this research will be achieved through the following objectives:

i. To investigate from local and international experience, the critical parameters and processes that influenced the feasibility and sustainability of implementing wastewater reuse systems;
ii. Based on these critical parameters and processes, to develop a framework for assessing the feasibility of implementing wastewater reuse in South Africa;
iii. To develop a decision support system based on objective ii;
iv. To test the developed decision support system; and
v. To suggest operational guidelines that will guide service providers and consumers of reclaimed water.

1.4 The relevance of this study.

Water and sanitation management in a typical urban city consists of water and wastewater systems. The water supply subsystem consists of natural freshwater sources (surface and groundwater), water treatment plant, and specified water quality and quantity requirements. The wastewater subsystem consists of wastewater discharge by the users as an input, a series of wastewater treatment plants, and the specified effluent standards. Traditionally, after water use, wastewater is treated to a certain quality before being discharged into receiving water bodies. This is a one way system as shown in Figure 1.1 (a). This method of wastewater management has proven to be unsustainable as a result of the increase in pollution to the environment. However, an interaction between both subsystems will inevitably result in treated wastewater reuse as indicated in Figure 1.1 (b). This method offers more sustainable management of scarce water resources and pollution abatement.



(a) Schematic of a traditional one-way system (b) An integrated water and wastewater system

Figure 1.1: One-way system and integrated water reuse system (Zang, 2004)

Despite the fact that wastewater reuse has been implemented in many countries, different reuse projects have failed due to the absence of thorough preliminary investigations. Preliminary investigations (also called feasibility study) involve detailed studies of the proposed project and its implications. These investigations are conducted to assist decision-makers in determining whether or not to implement a particular project. They are based on extensive research on the current practices and the proposed project and its impact (Urkiaga, *et al.*, 2006).

Feasibility studies on wastewater reuse systems to be implemented are also conducted in order to evaluate the capability of municipal wastewater utilities to implement water reuse. A detailed feasibility study will typically involve the following (Florida, 2005; Urkiaga, *et al.*, 2006):

i. assessment of monetary costs and benefits for several levels and types of reuse;
ii. assessment of water savings, if reuse is implemented;
iii. assessment of rates and fees necessary to implement reuse;
iv. assessment of environmental and water resource benefits associated with reuse;
v. assessment of economic, environmental, social and technical constraints;
vi. assessment of available source of funding for the project; and
vii. a schedule for implementation of reuse (phased implementation must be considered).

In this research, a decision support system for assessing the feasibility of implementing wastewater reuse systems was developed to assist different stakeholders (administration, service providers, engineering companies, water management bodies, etc.) involved in the planning of a water reuse program in South Africa. A thorough feasibility study should be tackled from a multidisciplinary approach by considering several diverse aspects of the proposed project such as technical (e.g. operational efficiency), economic (e.g. life cycle costs), environmental (including public health and safety) and social (including legislation) issues. These factors contribute to the final decision that could lead to the success or failure of any wastewater reuse project and their due consideration should reliably lead to correct decisions. Accordingly, within the scope of this research work, the different aspects of a feasibility assessment are addressed.

1.5 Layout of Dissertation.

This thesis contains 8 chapters. Figure 1.2 depicts the flow chart for the report's layout. The first chapter (this chapter) contains the introduction, background to the study, motivation and problem statement. Other information in this chapter includes the research aim and objectives, as well as the need for the study.

The second chapter starts with the current South African water resources situation, water use and wastewater generation. It provides a detailed literature survey of reclaimed water use for non-potable activities. The sources of reclaimed water and its applications in agricultural and landscape irrigation, urban, industrial and groundwater recharge are well discussed in this chapter.

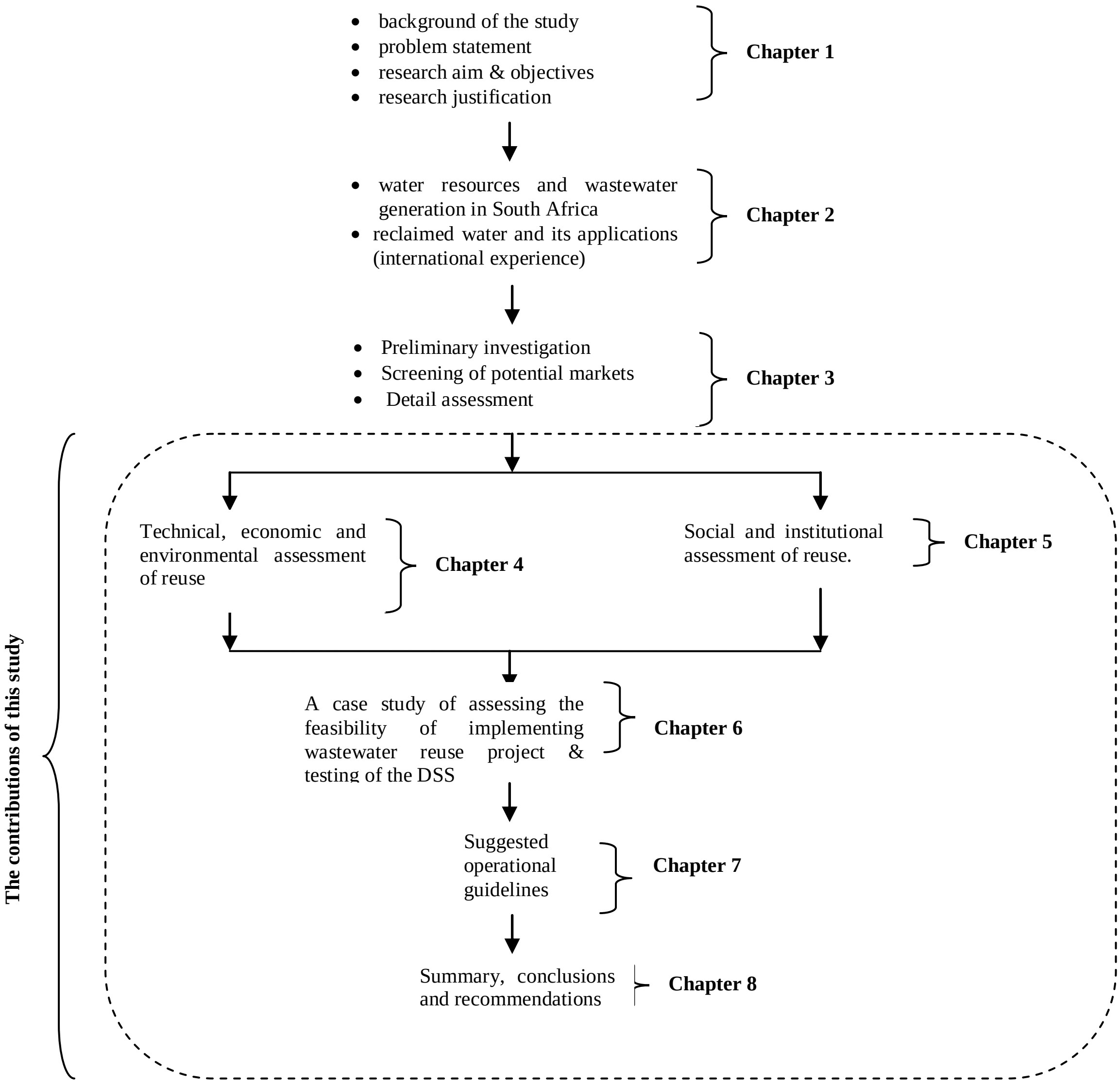


Figure 1.2: Flow chart of the dissertation layout

The third chapter contains planning procedures for wastewater reuse as reported in USEPA (2004) and other literature. This chapter discuss the preliminary investigation, screening of the selected market and detail assessment of the selected market for reuse water.

The fourth chapter focuses on the technical, economic and environmental assessment framework for the wastewater treatment process of the reuse scheme. This chapter highlights the methodologies used in the development of the treatment train of the decision support tool developed in this project. It describes information contained in the knowledge base for each unit process and their technical and economic quantitative criteria (i.e. pollutant removal efficiencies, costs, land requirement, labour requirements, sludge and concentrate production and energy consumption) and qualitative criteria (i.e. reliability, adaptability to upgrade, adaptability to varying flow, ease of construction, ease of operating and maintenance, chemical requirement, power requirement, odour generation and impact on groundwater) This chapter also describes treatment train selection procedure and rules.

Chapter five contains social (i.e. public perception) and institutional assessment methodology and its application in the development of the DSS. Factors that influence the respondent's intention to use non-potable water are modelled and incorporated into the DSS.

Chapter six contains the development and testing of the DSS. This chapter discusses the results of the technical, economic, environmental and social assessment of the DSS.

Chapter seven provides suggested guidelines for the operation, inspection and regulation of water reuse in South Africa while Chapter eight summarises this research work with conclusions and recommendations for future research.

CHAPTER 2

WATER RESOURCES IN SOUTH AFRICA AND RECLAIMED WATER FOR NON-POTABLE REUSE

2.1 Introduction

South Africa is a semi-arid country due to the low volumes of rainfall (average of 500 mm per annum) and high evaporation (approximately 85 percent of mean annual precipitation). The highly variable and spatial distribution of rainfall across the country adds to the sparse availability of fresh water (Figure 2.1). Stream flows in most South African rivers are at relatively low levels for most of the year, and the infrequent high flows that do occur, happen over limited and often, unpredictable periods. The country has no navigable rivers, and the combined flow of all the rivers in the country amounts to approximately 49 000 million m^3 per year (DWAF, 2004).

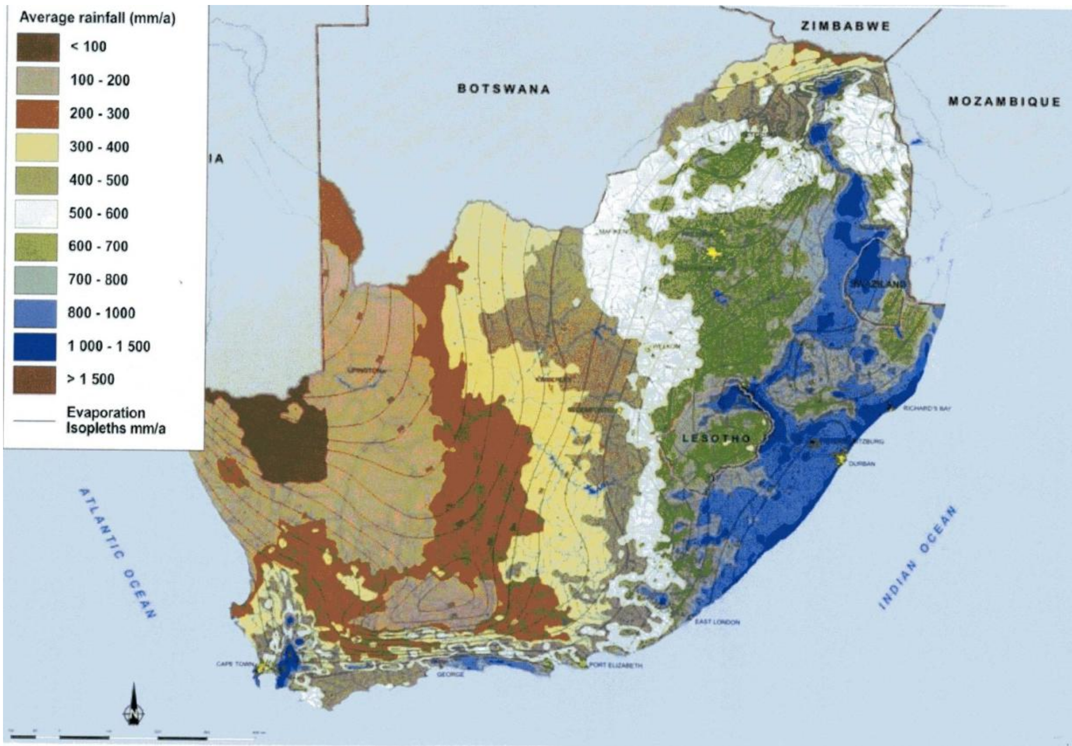


Figure 2.1: National Rainfall and Evaporation

South Africa depends on surface water for most of its urban, industrial, and agricultural requirements with About 320 major dams, each with a full supply capacity exceeding 1 million cubic metres, have a total capacity of about 32 400 million cubic metres (DWAF, 2004). Groundwater plays an important role in most rural water supply schemes given that there are only a few groundwater aquifers that can be utilised on a large scale due to poor geological formations and groundwater intrusion, especially in the coastal areas of the country (Mukheibir, 2005).

To manage existing water resources, the country's hydrological basins are divided into 19 water management areas (Figure 2.2) with mean annual runoff of approximately 49 000 million m^3/a. This includes water inflows of about 4 800 million m^3/a and 700 million m^3/a originating from Lesotho and Swaziland respectively (DWAF, 2004). The available yield from each water management area is shown in Table 2.2.

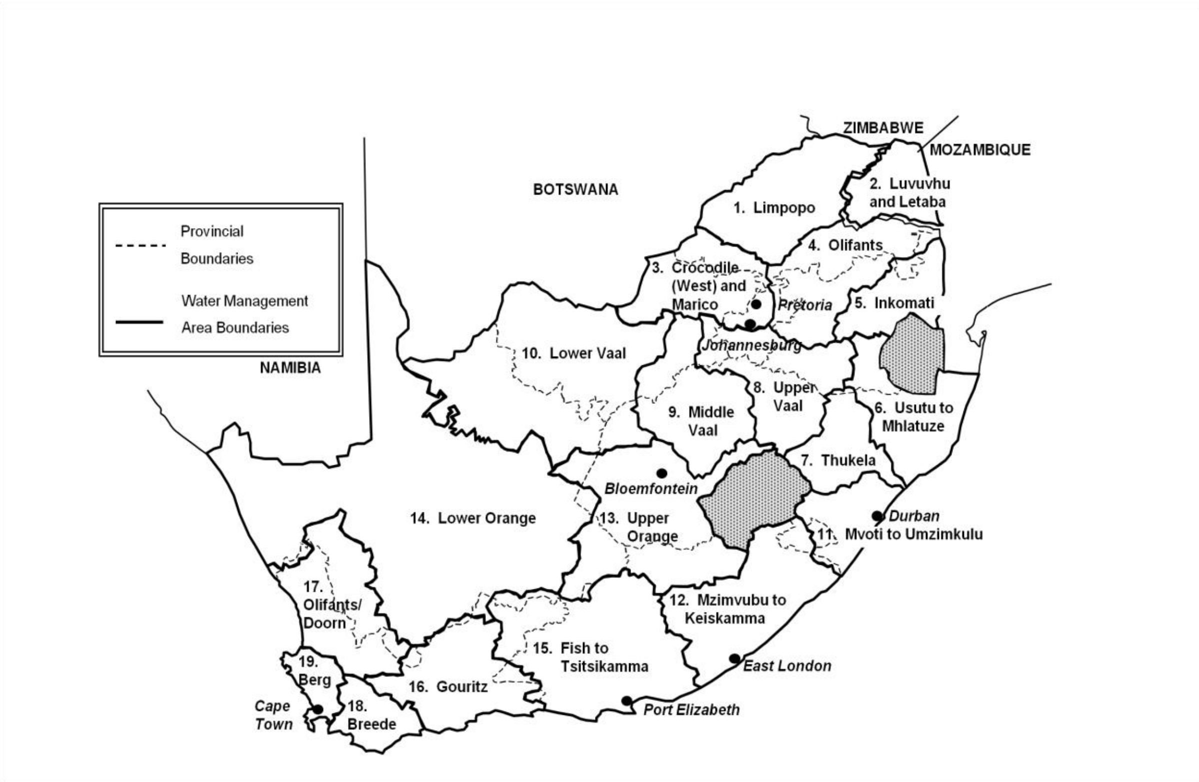


Figure 2.2: Map of South Africa showing its water management areas (DWAF, 2004).

Table 2.1: Available yield from water management area in 2000.

Water management area	Freshwater source (million m³/a)		Exploitable return flows (million m³/a)			Total local yield (million m³/a)
	Surface water	Groundwater	Irrigation	Urban	Industrial/ mining	
Limpopo	160	98	8	15	0	281
Luvuvhu/Letaba	244	43	19	4	0	310
Crocodile West and Marico	203	146	44	282	41	716
Olifants	410	99	44	42	14	609
Inkomati	816	9	53	8	11	897
Usutu to Mhlatuze	1019	39	42	9	1	1110
Thukela	666	15	23	24	9	737
Upper Vaal	598	32	11	343	146	1130
Middle Vaal	(67)	54	16	29	18	50
Lower Vaal	(54)	126	52	0	2	126
Mvoti to Umzimkulu	433	6	21	57	6	523
Mzimvubu to Keiskamma	777	21	17	39	0	854
Upper Orange	4311	65	34	37	0	4447
Lower Orange	(1083)	24	96	1	0	(962)
Fish to Tsitsikamma	260	36	103	19	0	418
Gouritz	191	64	8	6	6	275
Olifants/Doring	266	45	22	2	0	335
Breede	687	109	54	16	0	866
Berg	403	57	08	37	0	505
Total	**10 240**	**1 088**	**675**	**970**	**254**	**13 227**

(Source: DWAF, 2004)

In the northern parts, both surface and groundwater resources are almost fully developed and utilized with over-exploitation occurring in some areas. The reverse applies in the well-watered south-eastern region of the country where there are still significant undeveloped resources (Figure 2.3).

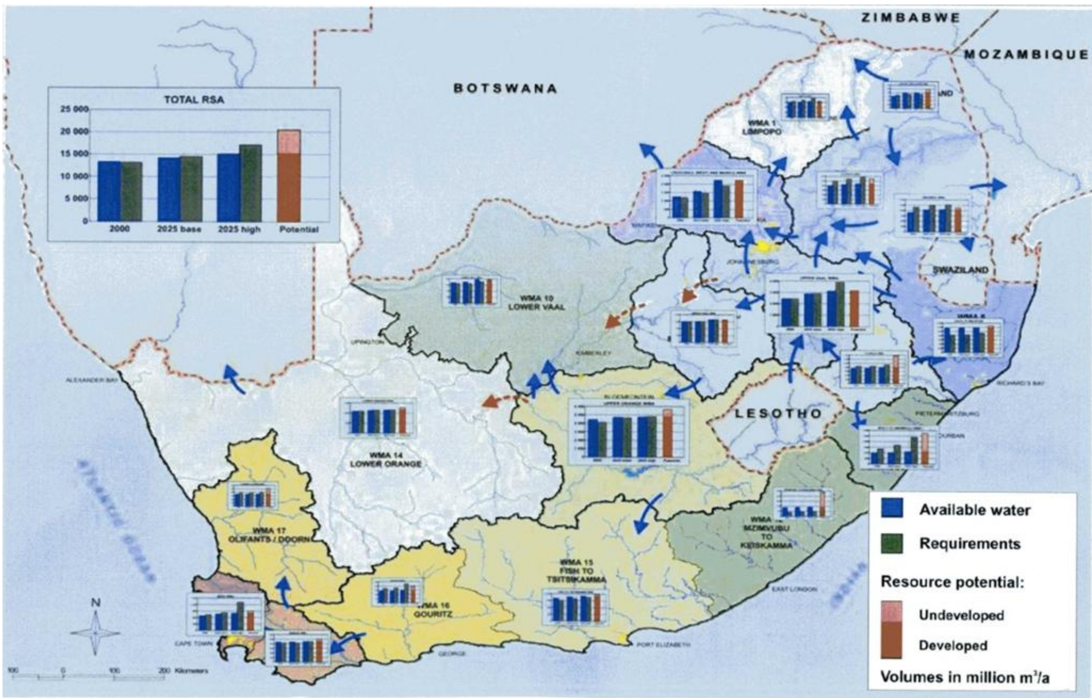


Figure 2.3: Water balance in water management area

In the past, government's efforts have focused mainly on the development of new water resources as demand increased because of the availability of large, unused raw water sources in some water management area, hence large transfer of water from areas with surplus into water management areas with deficit as shown in Figure 2.4.

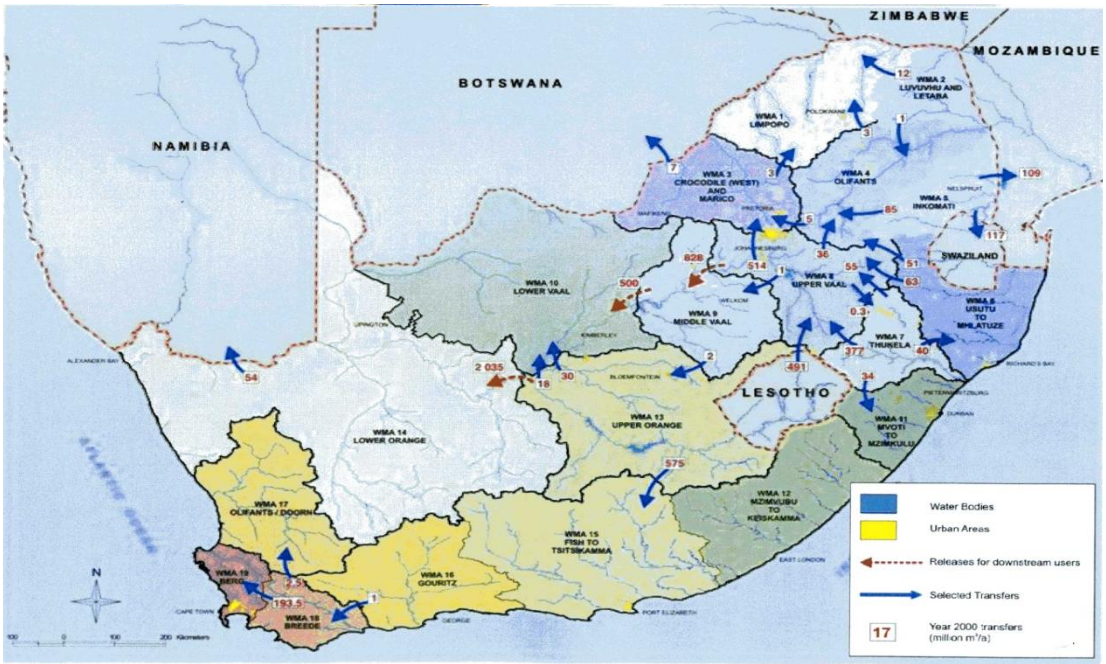


Figure 2.4: Inter-water management area water transfer

However, with the scarcity of water and incessant pollution of surface and groundwater resources, it has become imperative that efficient water use management be developed and sustained. Further industrialization of the economy and urbanization of the population will likely result in exacerbated scarcity and deterioration of the country's rivers. Waters used for irrigation, toilet flushing and a variety of industrial processes do not require the same quality as water used for drinking. Hence, much of the wastewater generated from various water sectors may be reused in the same or different environment after some level of treatment. In doing this, the country can maximize on water extracted from its freshwater sources, thereby reducing the need to develop new water schemes.

2.2 Water Use and Wastewater Generation in South Africa

In South Africa, water use is grouped into 6 categories with total water requirements in 2000 (i.e. 12 871 x 10^6 m^3/a) close to the estimated available resources of 13 227 x 10^6 m^3/a. These categories are rural (domestic and stock watering requirements), urban (domestic, commercial, and public requirements), mining and industry, power generation, irrigation, and afforestation. Irrigation makes up 62 percent of the total water used (Table 2.2).

The demand for water does not necessarily coincide with the spatial distribution of water. This indicates that many of the country's urban and industrialized areas such as Cape Town, Port Elizabeth, East London, Pietermaritzburg, Bloemfontein, Pietersburg, Johannesburg and Pretoria are the most likely water stressed areas, and these will become more so as the populations increases - a development that will be accompanied by a rise in the demand for water in the urban and domestic sectors.

Table 2.2: Water requirements (million m^3/a) in the various sectors in 2000

Water Management Area	Irrigation	Urban	Rural	Mining & Industry	Power Generation	Afforestation	Total Requirement
Limpopo	238	34	28	14	7	1	322
Luvuvhu/Letaba	248	10	31	1	0	432	333
Crocodile West and Marico	445	547	37	127	28	0	1 184
Olifants	557	88	44	94	181	3	967
Inkomati	593	63	26	24	0	138	844
Usutu to Mhlatuze	432	50	40	91	0	104	717
Thukela	204	52	31	46	1	0	334
Upper Vaal	114	635	43	173	80	0	1 045

Water Management Area	Irrigation	Urban	Rural	Mining & Industry	Power Generation	Afforestation	Total Requirement
Middle Vaal	159	93	32	85	0	0	369
Lower Vaal	525	68	44	6	0	0	643
Mvoti to Umzimkulu	207	408	44	74	0	65	798
Mzimvubu to Keiskamma	190	99	39	0	0	46	374
Upper Orange	780	126	60	2	0	0	968
Lower Orange	977	25	17	9	0	0	1 028
Fish to Tsitsikamma	763	112	16	0	0	7	898
Gouritz	254	52	11	6	0	14	337
Olifants/Doring	356	7	6	3	0	1	373
Breede	577	39	11	0	0	6	633
Berg	301	389	14	0	0	0	704
Total for country	**7 920 62 %**	**2 897 23 %**	**574 4 %**	**755 6 %**	**297 2 %**	**428 3 %**	**12 871**

(Source: DWAF, 2004)

In many catchments, water requirements exceed the available supply because of the spatial variability of water resources and the scarcity of water in the country. In general, deficits exist in more than half of the water management areas when Tables 2.1 and 2.2 are compared. In many cases, the deficits shown do not imply that present use exceeds available resources, but rather that ecological water requirements are not fully met (DWAF, 2004). Inter basin transfers are often employed to address water supply shortfalls on a regional scale. However, this supplementation is not often economically feasible (Mukheibir, 2005).

Since water demand in the country is likely to exceed availability in the near future, the challenge is to use appropriate management mechanisms to improve water use efficiency. Many municipalities, for instance, have implemented demand management mechanisms to curb growing demands in the face of declining freshwater availability. These mechanisms include water restrictions, pressure management, timely identification and repair of leaks, efficiency in handling customer complaints, monitoring of water usage, water meter management, installation of water efficient devices, the planting of water efficient plants, promoting retrofitting, capacity building programmes, communication and education, and the promotion of alternative technologies (especially reuse) (CoCT, 2006).

The total amount of wastewater generated from industrial, domestic and agricultural activities which is disposed into surface waters is presently unknown. Nonetheless, the list of DWEA registered wastewater treatment works is shown in Table 2.3. The numbers of these wastewater treatment works (WWTWs) will likely increase in the future as populations and industries grow.

Table 2.3: Distribution of Wastewater Treatment Works in South Africa (DWEA, 2010)

Province	**No of Registered WWTWs**
Eastern Cape	112
Free State	105
Gauteng	64
Kwazulu-Natal	209
Limpopo	84
Mpumalanga	94
Northern Cape	80
North West	48
Western Cape	112
Total	**908**

As all these WWTWs are spread across the country, it is difficult to estimate the magnitude of the pollution problems resulting from indiscriminate disposal of wastewater. It is clear, however, that streams/rivers in the Western Cape, Eastern Cape, KwaZulu-Natal and the Vaal have major problems with Total Dissolved Solids (TDS), and most of South Africa's rivers have eutrophication problems (NSER, 2007). Community concerns about environmental pollution resulting from the quality of wastewater disposed into sensitive environments has led to pressures on the water industry to treat wastewater to higher quality levels before discharging into receiving rivers or streams. As this trend continues, in South Africa wastewater reuse continues to gain popularity as an unconventional source of non-potable water in different countries around the world. While the nutrients in wastewater can assist plant growth when reused for irrigation, wastewater disposal, in extreme cases, is detrimental to the ecosystems of the receiving environment.

In the face of continuous pollution and diminishing freshwater sources, a truly secure and sustainable water future can be realized only by managing the ever-increasing and complex water demands of societies, rather than ceaselessly striving to meet it. The shortage of water can be overcome or reduced by the reuse of treated wastewater from domestic, industrial and institutional sectors. Treated wastewater is a preferred unconventional water source, since the supply is increasing because of population and industrial growth. Reuse of treated wastewater will help in maintaining environmental quality and at the same time, relieve the unrelenting pressure on conventional, natural freshwater sources.

2.3 Wastewater Reuse

Unregulated wastewater reuse has been in practice for centuries in many parts of the world. However, the concept of integrated wastewater reuse has received increase attention in recent times due to a number of factors i.e. (WHO, 2006; Ilemobade *et al.*, 2009):

i. degradation of freshwater resources resulting from improper disposal of wastewater;
ii. drought and prediction of further droughts from climate change in many arid areas;
iii. increasing competition for freshwater resources and therefore, the need to conserve higher quality water for suitable uses;
iv. growing industrial, agricultural and domestic needs;
v. growing demands for greener water strategies and water conservation;
vi. a growing recognition of the resource value of wastewater especially in supplementing freshwater for non-potable uses and irrigation; and
vii. the high costs of supplying sufficient quantities of potable water to arid areas. This is especially true for communities distant from urban centres and currently within very limited public water infrastructure.

Wastewater reuse is an important component of both wastewater management and water resource management. It offers an environmentally sound option for managing wastewater that dramatically reduces environmental impacts associated with discharge of wastewater effluent into surface waters. In addition, reuse provides an alternative water supply for many activities that do not require potable quality water and as such, permits the saved potable water to be used elsewhere. In arid regions where there has traditionally been scarcity of water, wastewater reuse technology has been successfully implemented, namely in Jordan (Al-Jayyousi, 2003; 2004), Israel (Friedler and Hadari, 2006; Brenner *et al.*, 2000), Spain (March et al, 2004), Australia (John, 1996; Eric, 1996; Diana *et al.*, 1996; Dillion, 2000), Namibia (Ben, 2006), and some parts of South Africa (Marilyn, 2006). In contrast to the above, water scarcity experienced globally has led to the embracing of wastewater and other sources of non-potable water in many large urban areas in regions previously considered to have sufficient water sources like China (Junying et al, 2004, Weizhen and Andrew, 2003), Japan (Dixon et al, 1999), Canada (Exall, 2004), Germany (Nolde, 1999), United Kingdom

(UKEA, 2000) and the United States of America (Okun, 1996). Some existing wastewater reuse projects in some countries are summarized in Table 2.4.

Table 2.4: Existing wastewater reuse projects in some selected countries (adapted from Metcalf and Eddy, 2004; USEPA, 2004 and AQUAREC, 2006)

S/No	Country	Location	Level of treatment	Application (s)
1	Argentina	Campo Espejo, Mendoza	Secondary treatment	Unrestricted irrigation
2	Australia	Aurora, Melbourne	Tertiary treatment	Toilet flushing and irrigation
		Mawson lakes, North of Adelaide	Tertiary treatment	Toilet flushing, irrigation and car washing
		Bolivar and Virginia Project, South Australia	Tertiary treatment	Groundwater recharge for unrestricted irrigation
		South East Queensland	Tertiary Treatment	Unrestricted irrigation
		Hunter Water	Tertiary treatment	Coal washing and power generation
		East irrigation Scheme	Tertiary treatment	Unrestricted irrigation, toilet flushing and garden irrigation
		McClaren Vale	Tertiary treatment	Irrigation
		Rose Hill	Tertiary treatment	Toilet flushing and garden irrigation
		Georges River Program	Tertiary treatment	Toilet flushing and garden irrigation
		Northern Shoalhaven	Tertiary treatment	Urban irrigation
		Sydney Olympic Park	Tertiary treatment	Irrigation, water fountains and domestic/residential uses
		City of Wagga Wagga	Tertiary treatment	Landscape irrigation
3	Belgium	Wulpen	Tertiary treatment	Groundwater recharge and saltwater intrusion barrier
		Waregem	Tertiary treatment	Industrial uses
4	Brazil	Sao Paulo	Tertiary treatment	Irrigation, industrial and toilet flushing
5	Chile	Santiago	Secondary treatment	Irrigation
6	China	Taiyuan	Tertiary treatment	Industrial uses
7	Cyprus	Cyprus	Tertiary treatment	Irrigation
8	Egypt	Egypt	Secondary treatment	Irrigation of tree crops
9	France	Aubergenville	Tertiary treatment	Groundwater recharge
		Clermont Ferrand	Tertiary treatment	Irrigation
		Noirmoutier Island	Tertiary treatment	Irrigation
10	Greece	Levadia	Tertiary treatment	Irrigation of cotton
		Amfisa	Tertiary treatment	Olive tree irrigation
		Palecastro	Tertiary treatment	olive tree irrigation
		Chalkida	Tertiary treatment	Landscape and Forestry irrigation
		Karistos	Tertiary treatment	Landscape and Forestry irrigation
		Lerisos	Tertiary treatment	Landscape and Forestry irrigation
		Agios Konstantnos	Tertiary treatment	Landscape and Forestry irrigation
		Kentarchos	Tertiary treatment	Landscape and forestry irrigation
		Chalkida	Tertiary treatment	Irrigation and industrial uses
11	India	Hyderabad	Secondary treatment	Irrigation
12	Israel	Dan Region Scheme	Secondary treatment	Groundwater recharge for irrigation
		Kishon Scheme	Secondary treatment	Irrigation
		Jeezrael valley	Secondary treatment	Irrigation
		Gedera	Secondary treatment	Irrigation
		Getaot Kibbutz	Secondary treatment	Irrigation
		City of Arad	Secondary treatment	Irrigation
13	Italy	Emilia Romagna	Secondary treatment	Irrigation
		Grammichele	Tertiary treatment	Irrigation

S/No	Country	Location	Level of treatment	Application (s)
		Palermo and Gela	Tertiary treatment	Irrigation
		Turin	Tertiary treatment	Irrigation and industrial uses
14	Japan	Tokyo	Tertiary treatment	irrigation, Toilet flushing, industrial uses
		Chiba Prefecture Kobe City	Tertiary treatment	irrigation, Toilet flushing, industrial uses
		Fukuoka City	Tertiary treatment	irrigation, Toilet flushing, industrial uses
15	Jordan	City of Jordan	Tertiary treatment	Environmental enhancement, irrigation and industrial uses.
16	Kuwait	Ardhiya, Reqqa, and Jahra,	Tertiary treatment	Irrigation
17	Mexico	Mexico city	Tertiary treatment	Irrigation
		Monterrey metropolitan area	Tertiary treatment	Industrial uses
18	Morocco	Ben Slimane	Secondary treatment	Irrigation of golf courses.
		Casablanca	Secondary treatment	Irrigation of crops
		Drarga Prject	Tertiary treatment	irrigation
19	Namibia	City of Windhoek	Tertiary treatment	Potable reuse
20	Oman	City of Muscat	Tertiary treatment	Irrigation
		City of Dhofar	Tertiary treatment	Irrigation
		City of Al-Batinat	Tertiary treatment	Irrigation
		City of Salalah	Tertiary treatment	Groundwater recharge
21	Pakistan	City of Faisalabad	Secondary treatment	Irrigation
22	Peru	Riyadh North	Tertiary treatment	Irrigation and industrial uses
		Lima	Secondary treatment	Irrigation
		Tacna	Secondary treatment	Irrigation
23	Saudi Arabia	Riyadh	Tertiary treatment	Irrigation and industrial uses
		Jeddah	Tertiary treatment	Irrigation and industrial uses
24	Singapore	City of Singapore, NEWater	Tertiary treatment	Industrial and potable water augmentation.
25	Spain	Girona, municipality of Portbou	Tertiary treatment	Landscape irrigation, street cleaning and fire protection
		Costa Brava (Title 22 reclamation treatment trains)	Tertiary treatment	Landscape irrigation, street cleaning and industrial use
		Aiguamolls de l'Emporda natural Preserve	Tertiary treatment	Environmental Enhancement
		City of Victoria	Tertiary treatment	Irrigation
26	Tunisia	Great Tunis Area	Secondary treatment	Irrigation
27	United Arab Emirate	Abu Dhabi	Tertiary treatment	Irrigation
		Al-Ain	Tertiary treatment	Restricted irrigation
28	United Kingdom	Water Resource Plan for East Anglia	Tertiary treatment	Indirect potable reuse
		Waterwise	Tertiary treatment	Domestic non-potable uses and river flow augmentation
		Beazer Homes District	Tertiary treatment	Car washes, cooling, fish farming and industrial uses.
		Watercycle , Millennium Dome	Tertiary treatment	Toilet and Urinal flushing and landscape irrigation
29	United State of America	Fulton County, Georgia	Tertiary treatment	Golf course and landscape irrigation
		Orange County Water District (Factory 21), California	Tertiary treatment	Ground water recharge
		Irvin Ranch Water District, California	Tertiary treatment	Irrigation and toilet flushing
		City of St. Petersburg, Florida	Tertiary treatment	Irrigation and industrial uses
30	Yemen	Sana's, Ta'aiz, Al-Hudeidah, and Aden.	Tertiary treatment	Irrigation

Several international wastewater reuse experiences have been proven to help communities meet water demands and alleviate supply challenges without significant health risks if there is significant buy-in by the public and if properly implemented.

2.4 Sources of Non-potable Water

Non-potable water is water unfit for human consumption, but may be suitable for a variety of other uses. The sources of non-potable water can generally be classified as rainwater, stormwater, saline water, brackish water, greywater or municipal wastewater.

2.4.1 Rain Water

Rain water is drops of freshwater that fall as precipitation from clouds. Since ancient times, the only sources of natural water that are recognized as safe to drink are rain water and water from deep wells. Rain water must however be carefully handled so that it does not become contaminated. Once it runs along the surface, it has potential to pick up pollutants (e.g. soil, plant parts, insect parts, bacteria, algae, and sometimes radioactive materials that have been washed out of the air). Hence, because of the health risks in consuming contaminated rainwater, it is with reluctance that communities are encouraged to directly consume it. However, with some filtration and the proper infrastructure, rain water can be harvested and used for non-potable uses e.g. irrigation, toilet flushing, laundry, and car washing (Ilemobade, *et al.*, 2009).

2.4.2 Stormwater

Stormwater is a term used to describe the collection of water that originates during precipitation events. It also applies to water that originates from snowmelt or runoff water from paved areas that enter stormwater systems. Stormwater flows directly into rivers, lakes and streams untreated. As such, everything stormwater collects from the land surface, roadways, sidewalks, parking lots, construction sites, business parks, etc., is carried to gutters, storm drains, canals, drainage, and finally ends up in local rivers and streams untreated. Just like rain water, as stormwater flows over land it picks up heavy metals, bacteria, pesticides, suspended solids, nutrients, and floating materials. The best way to improve stormwater quality is to treat the source through Best Management Practices (BMPs) such as street sweeping, stormwater detention ponds, rain gardens, etc. These practised control stormwater runoff quantity and/or quality and effectively reduce the release of pollutants into receiving waters. Stormwater can also be collected, treated, stored and conveyed for non-potable uses.

2.4.3 Saline Water

Saline water is a general term used to describe water with a significant concentration of dissolved salts, predominantly Sodium Chloride (90 percent). Other salts present in saline water are Magnesium, Sulphur, Calcium and Potassium. The dissolved salt concentration is the amount (by weight) of salt in water as expressed in part per million (ppm). If saline water has a concentration of 10,000 ppm of dissolved salts, then one percent of the weight of the water comes from dissolved salts. The parameters for saline water are indicated in Table 2.5.

Table 2.5: Parameters for Saline Water Classification

Nature	Classification	Salt Contents (ppm)
Freshwater	Freshwater	< 1000
Brackish	Slightly saline water	1,000-3,000
	Moderately saline water	3,000-10,000
Saline	Highly saline water	10,000-35,000

On average, seawater contains about 35,000 ppm of salt. With this level of salinity, seawater is not potable. In 2002, there were about 12,500 desalination plants around the world in 120 countries. They produced some 14 million m^3/day of freshwater, which is less than 1 percent of total world consumption. The most important users of desalinated water are in the Middle East (mainly Saudi Arabia, Kuwait, the United Arab Emirates, Qatar and Bahrain), which use about 70 percent of worldwide capacity; and in North Africa (mainly Libya and Algeria), which use about 6 percent of worldwide capacity (USGS, 2008). Among industrialized countries, the United States of America is one of the most significant users of desalinated with 15 percent of the water used in the year 2000 being saline water. The volume and percentage used for industrial processes, power generation and mining in various states is indicated in Table 2.6.

Table 2.6: Saline Water Use in the United State of America

State	Volume (Million gallon per day)	Percentage
California	14300	20.5
Florida	13400	19.2
Maryland	7270	10.4
New York	5610	8.0
Texas	5400	7.8
Virginia	4080	5.8

State	Volume (Million gallon per day)	Percentage
Massachusetts	4050	5.8
Connecticut	3860	5.5
New Jersey	3800	5.4
Other states	8000	11.5

(Source: USGS, 2008)

Other countries like Japan, Hong Kong and China make use of seawater for domestic uses, mainly for toilet flushing in high-rise and office buildings (Li *et al.*, 2004; Tang, *et al.*, 2006).

2.4.4 Brackish Water

Brackish water is water that has more salinity than fresh water but not as much as seawater. It may result from mixing of seawater with freshwater e.g. in estuaries, or it may occur in a brackish fossil aquifer. Technically, brackish waters contain between 0.5 and 30 grams of salt per liter. Thus, brackish waters cover a range of salinity regimes and are not considered a precisely defined condition.

An estuary, a common location for brackish waters, is the part of a river where it meets the sea. Typically, estuarine waters are slow and sluggish, and often salty and fertile. As a result, they are not always aesthetically attractive to look at as the clear waters of a mountain stream, but are tremendously productive. One characteristic of estuarine water habitats in general, is that while productivity (the amount of aquatic organisms) is high, diversity (the number of species) can be quite low compared with rivers or the sea (Ilemobade *et al.,* 2009). This apparent contradiction is because relatively few fish and invertebrates can tolerate the fluctuations in salinity. On the other hand, those animals that can live there do so in enormous numbers.

For brackish waters to be usable, it needs to be treated (desalinated). Without treatment, brackish waters can cause scaling and corrosion problems in industrial applications. In agricultural applications, it could lead to poor yield and increase in soil salinity.

2.4.5 Greywater

Greywater is non-industrial wastewater generated from domestic processes such as dish washing, laundry and bathing. It comprises wastewater generated from a household except for the toilets (it becomes blackwater if toilet water is included). Greywater comprises 50-60 percent of residential wastewater. In Sydney, it was estimated that an average household of

3.2 people produces 400 litres of greywater each day (Ilemobade *et al.*, 2009). Contribution of each component of greywater is indicated in Table 2.7. In South Africa, it was estimated that water consumption for households with a standpipe in the yard is between 30 and 80 l/c/d, whereas mean consumption ranges from 9 to 50 l/c/d when water has to be carried from an external source (250 m to 3 km from the source) (Alcock, 2002).

Table 2.7: Average greywater produced per household in Australia (Source: Ilemobade *et al.*, 2009)

Greywater source	**Total Greywater**	
	Volume (l/day)	**Total (%)**
Hand basin	28	7
Bath/ shower	193	48
Kitchen	44	11
Laundry	135	34
Total	400	100

Greywater is easier to treat and reuse than blackwater due to its generally lower levels of contamination. However, untreated greywater is still considered a potential health and pollution hazard. While all greywater contains micro-organisms, the health hazards associated with greywater from a multiple dwelling source should be considered different from that of a single dwelling greywater source (Almeida *et al.*, 1999). Experiments conducted on greywater constituents (Friedler, 2004) indicated that washing machines significantly contribute 40 percent of sodium, 37 percent of phosphate and 22 percent of COD to the total greywater loads. Dishwasher contributions in phosphorous and boron were also found to be significant. In general, if contributions from washing machines, dish washers and kitchen sinks were excluded from greywater, the organic matter, nutrients and boron were reduced by more than 50 percent (Friedler and Galil, 2003).

If greywater is collected using a separate plumbing system to blackwater, domestic greywater can be recycled directly within the home or institution and used either immediately or processed and stored for future use. Recycled greywater may be used to provide water for car washing, flushing toilets or garden/ lawn irrigation. Greywater may be applied directly with caution from the sink to the garden as it receives some level of treatment from soil and plant roots. When using raw greywater in the garden, the type of soap and washing powder used must be considered. Many soap products contain ingredients that may affect plants and soil negatively such as phosphorus, pH, bleaches and disinfectants.

Greywater contains impurities and micro-organisms that may cause a health risk and therefore, when used for irrigation, subsurface irrigation should be preferably applied at the roots of the plants being irrigated to avoid contact with humans on the soil surface. The bio-accumulation of potentially toxic elements in plants is also an issue of concern as this may have long term health effects on humans. Greywater should be prevented from overflowing into storm water drains, rivers, streams and ground water as it may contaminate these sources of water.

2.4.6 Municipal Wastewater

Wastewater is any water that has been adversely affected in quality by anthropogenic influences. Municipal wastewater comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations.

When untreated municipal wastewater accumulates, the decomposition of the organic matter present in the wastewater will lead to nuisance conditions including the production of malodorous gases. In addition, untreated wastewater contains numerous pathogenic microorganisms that dwell in the human intestinal tract. Wastewater also contains nutrients which can stimulate the growth of aquatic plants (eutrophication) and may contain toxic compounds or compounds that potentially may be mutagenic or carcinogenic. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment, reuse, or disposal into the environment is necessary to protect public health and the environment.

Municipal wastewater flow fluctuates with variations in water usage, which in turn is affected by a multitude of factors including climate, community size, living standards, dependability and quality of water supply, water conservation requirements or practices, the extent of meter services, the degree of industrialization, cost of water and supply pressure. Wide variations in wastewater flow rates may thus be expected to occur within a community as shown in Table 2.8.

Table 2.8: Variation in wastewater flow within a community (Liu and Liptak, 1999)

Community Size (Population)	Variation in wastewater flow (% of the average daily flow)
1000	20 - 400
1000 – 10 000	50 – 300
10 000 – 100 000	Up to 200

Wastewater quality may be defined by its physical, chemical, and biological characteristics. Physical parameters include colour, odour, temperature, and turbidity. Also falling into this category are insoluble matters such as solids, oil and grease. Solids may be further subdivided into suspended and dissolved solids as well as organic (volatile) and inorganic (fixed) fractions.

Chemical parameters associated with the organic content of wastewater include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total oxygen demand (TOD). Inorganic chemical parameters include salinity, hardness, pH, acidity and alkalinity, as well as concentrations of ionized metals such as iron and manganese, and anionic entities such as chlorides, sulphates, sulphides, nitrates and phosphates. Biological parameters include coliforms, faecal coliforms, specific pathogens and viruses. Both constituents and concentrations of each parameter vary with time and local conditions. Table 2.9 shows typical concentration ranges for various constituents in untreated domestic wastewater. The constituents are classified as strong, medium or weak, depending on their contaminant concentrations.

Table 2.9: Typical composition of untreated domestic wastewater.

Contaminants	Unit	Concentration		
		Low strength	Medium strength	High strength
Total solids (TS)	mg/L	390	720	1230
Total dissolved solids (TDS)	mg/L	270	500	860
Fixed	mg/L	160	300	520
Volatile	mg/L	110	200	340
Total suspended solids	mg/L	120	210	400
Fixed	mg/L	25	50	85
Volatile	mg/L	95	160	315
Settleable solids	mg/L	5	10	20
BOD_5, 20^0C	mg/L	110	190	350
TOC	mg/L	80	140	260
COD	mg/L	250	430	800
Nitrogen (total as N)	mg/L	20	40	70
Organic	mg/L	8	15	25
Free ammonia	mg/L	12	25	45

Contaminants	Unit	Concentration		
		Low strength	Medium strength	High strength
Nitrites	mg/L	0	0	0
Nitrates	mg/L	0	0	0
Phosphorous (total as P)	mg/L	4	7	12
Organic	mg/L	1	2	4
Inorganic	mg/L	3	5	8
Chloride	mg/L	30	50	90
Sulphate	mg/L	20	30	50
Oil and grease	mg/L	50	90	100
Volatile Organic Compounds	µg/L	<100	100 – 400	>400
Total coliforms	No/100mL	10^6 - 10^8	10^7 – 10^9	10^7 – 10^{10}
Faecal coliforms	No/100mL	10^3 – 10^5	10^4 – 10^6	10^5 – 10^8

(Source: Metcalf and Eddy, 2004)

The focus of this thesis is municipal wastewater reclamation and reuse systems in urbanized/or peri-urban settings. Municipal wastewater reclamation typically includes one or more wastewater treatment facilities receiving domestic and pre-treated industrial wastewater. It should be noted that the prerequisite for the implementation of a municipal wastewater reclamation and reuse program is that the community under consideration must be sewered. This presents opportunities for many South African communities that are not yet serviced by sewers so that reuse can be included in their sewerage planning (Carden, *et al.,* 2007a, b).

2.5 Reclaimed Water Applications

Before considering reclaimed water applications, it is necessary to define some terms used frequently in the field of water reclamation, recycling and reuse. Although there is no consensus on the terminology, the widely accepted definitions cover the following terms (Metcalf and Eddy 2004; DWAF, 2006):

i. Dual distribution system – two systems of pipes conveying potable water and reclaimed water for different uses.
ii. Non-potable reuse – all reuse applications that do not involve either direct or indirect potable use.
iii. Reclaimed water – treated wastewater effluent suitable for an intended water reuse application.
iv. Recycled water – see reclaimed water.
v. Water reclamation – treatment or processing of wastewater to make it reusable.
vi. Water recycling – See water reclamation.

vii. Water reuse – see water reclamation.

viii. Direct wastewater reuse – the reuse of wastewater without its discharge into a water body.

ix. Indirect water reuse – the reuse of wastewater after its discharge into a water body. Discharge into a water body allows mixing and assimilation.

Reclaimed water has been used to supplement or replace natural water resources in several ways. The intended reuse application is the major factor influencing the level of treatment needed to protect public health and the environment, and the degree of reliability required for the treatment processing and operation (Metcalf and Eddy, 2004). Different end users classifications have been proposed in the past, and a brief overview of these classifications based on the nature of use, reuse application and their main constraints is presented in Table 2.10. In broad terms, the major non-potable reuse activities are irrigation (restricted and unrestricted), industrial use, toilet flushing, general cleaning, surface water replenishment and groundwater recharge. Of the different activities, agricultural irrigation has been identified as the major user in many areas where wastewater is reused. This is mainly because large volumes of water are used in irrigation with relatively lower qualities require in comparison to other uses (Yang and Abbaspour, 2007).

2.5.1 Non-potable water for Reuse in Agriculture and Landscape Irrigation

As stated earlier, agricultural irrigation represents a significant percentage of the total demand for freshwater. As indicated in Figure 2.2, agricultural irrigation annually uses 7 920 Million m^3 (62 percent) of the available 12 871 Million m^3 of South Africa is freshwater resources (DWAF, 2004).In South Africa, the total DWAF registered irrigation schemes (government and private) are 332 (Stephens, 2007).

Table 2.10: Categories of wastewater reuse and main constraints (Asano, 1998; Metcalf and Eddy, 2004).

Wastewater reuse categories	Potential constraints
1. Agricultural irrigation • Crop irrigation • Commercial nurseries 2. Landscape irrigation • Parks • School yards • Freeway medians	• Surface and groundwater pollution if not properly managed • Marketability of crops and public acceptance • Effect of nutrients, particularly salts, on soil and crops • Public health concerns related to pathogens (bacteria, viruses, and parasites)

Wastewater reuse categories	Potential constraints
• Golf courses • Cemeteries • Greenbelts • Residential	
3. Industrial recycling and reuse • Cooling • Boiler feed • Process water • Heavy construction	• Constituents in reclaimed wastewater may cause scaling, corrosion, biological growth and fouling • Public health concerns, particularly aerosol transmission of pathogens in cooling water
4. Ground water recharge • Ground water replenishment • Salt water intrusion control	• Organic chemicals in reclaimed wastewater and their toxicological effects • Total dissolved solids, nitrates, and pathogens in reclaimed wastewater
5. Recreational/environmental uses • Lakes and ponds • Marsh enhancement • Stream flow augmentation • Fisheries • Snowmaking	• Health concerns due to bacteria and viruses in the effluent • Eutrophication in receiving water due to nitrogen and phosphorus • Toxicity to aquatic life
6. Non potable urban uses • Fire protection • Air conditioning • Toilet flushing	• Public health concerns concerning pathogens transmitted by aerosols • Effect on scaling, corrosion, biological growth, and fouling • Potential drinking water and non-potable water cross connection
7. Potable reuse • Blending in water supply reservoir • Pipe to pipe water supply	• Constituents in reclaimed wastewater, especially trace organic chemicals (mutagenic and carcinogenic) and their toxicological effects • Aesthetics and public acceptance • Health concerns about pathogen transmission, particularly viruses

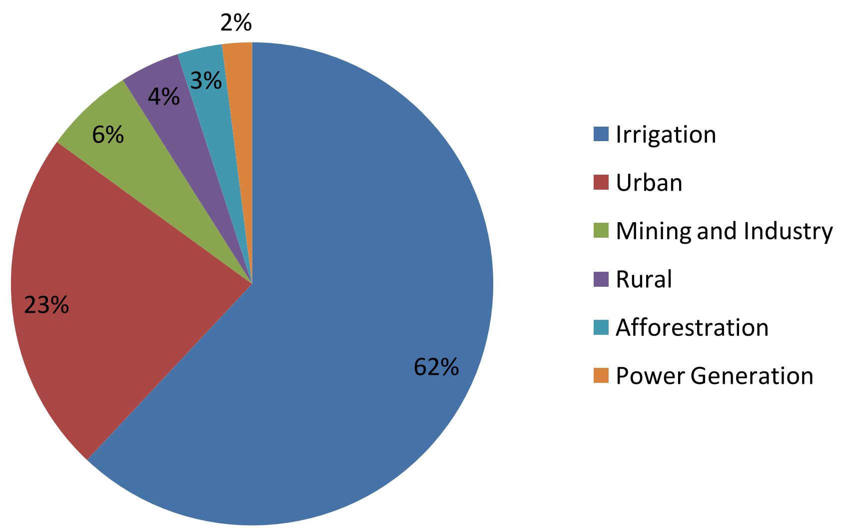


Figure 2.5: Sector water demand in South Africa in 2000 (DWAF, 2004).

Many internationally existing water reuse systems supply reclaimed water for agricultural irrigation as indicated in Table 2.4. Agricultural reuse is often included as a component in water reuse programs for the following reasons:

i. Large volumes of water are required in agricultural irrigation.
ii. To conserve freshwater resources.
iii. Beneficial use of the nutrients (nitrogen and phosphorus) present in wastewater.
iv. To abate the pollution freshwater sources resulting in eutrophication.

Reuse for irrigation is broadly classified into two categories viz restricted irrigation and unrestricted irrigation.

2.5.1.1 Restricted Irrigation

Restricted irrigation is carried out in an area where public access is restricted at any time during or after application of reclaimed water. Water used for restricted irrigation is usually of lesser quality than that of unrestricted irrigation and as such, secondary treatment with disinfection is satisfactory (Table 2.11). Human and animal restriction is enforced so as not to compromise public health.

Table 2.11: Suggested guidelines for wastewater reuse (USEPA, 2004)

Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring	Setback Distance
Urban Reuse	Secondary Filtration Disinfection	pH = 6-9 $\leq$ 10mg/l BOD $\leq$ 2 NTU No detectable faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly Turbidity - Continuous Coliform – daily Chlorine residue - continuous	15 m to potable water supply wells
Restricted Irrigation	Secondary Disinfection	pH = 6-9 $\leq$ 30mg/l BOD $\leq$ 30mg/l TSS $\leq$ 200 faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly TSS - daily Coliform – daily Chlorine residue - continuous	90 m to potable water supply wells
Unrestricted irrigation	Secondary Advance Disinfection	pH = 6-9 $\leq$ 10mg/l BOD $\leq$ 2 NTU No detectable faecal coli/100ml 1 mg/l cl_2 residual (minimum)	pH - weekly BOD - weekly Turbidity - Continuous Coliform – daily Chlorine residue - continuous	15 m to potable water supply wells
Industrial Application	Secondary Advance Disinfection	pH = 6-9 $\leq$ 30mg/l BOD $\leq$ 30mg/l TSS $\leq$ 200 faecal coli/100ml	pH - weekly BOD - weekly TSS - daily Coliform – daily	90 m to potable water supply

Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring	Setback Distance
		1 mg/l cl_2 residual (minimum)	Chlorine residue - continuous	wells
Groundwater Recharge	Site specific and use dependent	Site specific and use dependent	Depend on treatment and use	Site specific

Typical plants irrigated with this quality of water are seed crops, trees, non-recreational parks, food crops not eaten raw, orchards and vineyards, pasture, parks, sports fields and school grounds. For restricted irrigation, WHO recommends that the treated wastewater should contain no more than one human intestinal nematode egg per litre. The use of sprinkler irrigation is allowed in restricted irrigation of forage crops, drip or trickle systems for vineyard or orchard crops while vegetables must be irrigated using subsurface systems.

2.5.1.2 Unrestricted Irrigation

Unrestricted irrigation is carried out in an area where public access is not restricted at any time during or after application of reclaimed water. This is due to the high quality of the reclaimed water used for irrigation. Typical plants irrigated with this quality of water are pasture for milking animals, fodder, sports fields, school grounds, food crops eaten raw, lawns, nurseries, and play parks. To irrigate unrestricted access areas, sprinkler and/or drip irrigation can be used while for turf and landscape applications, pop-up sprinklers and spray heads or drip or trickle can be used.

2.5.2 Non-potable Water Reuse for Industrial Purposes

Industries have been using treated wastewater for cooling, boiler feed and process purposes since the early 1990s. In the United State of America, California, Arizona, Texas, Florida, and Nevada have major industrial facilities using reclaimed water for cooling water and process/ boiler-feed requirements (USEPA, 2004). Utility power plants are ideal facilities for reuse due to their large water requirements for cooling while petroleum refineries, chemical plants, and metal working facilities could use treated wastewater for their process needs. Treated wastewater reuse potential is presented in Table 2.12.

Table 2.12: The Potential for wastewater reuse for non-potable purposes in various sectors (Visvanathan and Asano, 2004)

High Potential	Medium Potential	Low Potential
• Pulp and paper • Cotton textile • Glass and steel • Utility power plants	• Slaughterhouse • Dairy • Canning and food processing • Distillery • Wool textile • Photographic processing • Chemical • Fertilizer • Oil refining • Petroleum • Electroplating • Meat processing	• Tanneries and leather finishing • Pesticide • Rubber • Aluminium • Explosives manufacturing • Paint manufacturing

2.5.2.1 Industrial Cooling Water

Among the three activities performed with treated wastewater in industry, cooling is the largest use of reclaimed water. This is due to advancements in treatment technologies that allow industry to have better control of deposits, corrosion, and biological problems often associated with the use of reclaimed water in concentrated cooling systems.

Two major types of cooling water system that uses reclaimed water are once-through and recirculating evaporative (USEPA, 2004):

In one-through cooling systems, water is pumped from a source through the heat exchange equipment and then discharged. Since there is no evaporation, there is no consumption of the cooling water. The preliminary assessment of feasibility into implementing one-through systems in Southern California Edison showed that the following benefits could be derived from the use of reclaimed water for one-through cooling systems (Ganesh, *et al.*, 2002):

i. elimination of cooling tower fans;
ii. improvement in chillers performance due to lower temperature of reclaimed water;
iii. It eliminates the need for cooling tower chemicals;
iv. it conserves potable water; and
v. multiple applications of water used in the system are possible.

However, the limitation of the proposed system is the possible corrosion of heat exchange pipes.

One example of a one-through system in America is found in the Bethlehem Steel Company in Baltimore, Maryland, which uses 4 380 l/s of treated wastewater effluent from Baltimore's Back River Wastewater Treatment Facility for processes and once-through cooling since the early 1970s. The Rawhide Energy Station utility power plant in Fort Collins, Colorado, has used about 10 753 l/s of reclaimed water for once through cooling of condensers since the 1980s (USEPA, 2004).

On the other hand, recirculating evaporative cooling water systems use water to absorb process heat, and then transfer the heat by evaporation. As the cooling water is recirculated, makeup water is required to replace water lost through evaporation. Water must also be periodically removed from the cooling water system to prevent a build-up of dissolved solids in the cooling water. There are two common types of evaporative cooling systems that use reclaimed water. They are cooling towers and spray ponds (USEPA, 2004):

A cooling tower is a heat exchanger. It transfers heat from circulating water to the atmosphere. It accomplishes this by providing intimate mixing of water and air, which results in cooling primarily by evaporating approximately one percent of the flow for each 10 ºF (6^{o}C) drop in temperature. Because water is evaporated, the dissolved solids and minerals will remain in the recirculated water. These solids must be removed or treated to prevent accumulation in the cooling equipment as well as the cooling tower. This removal is done by discharging a portion of the cooling water known as blow-down. A typical example of reclaimed water use in a cooling tower is found in Curtis Stanton Energy Facility in Orlando, Florida, which receives reclaimed water from Orange County wastewater facility.

Spray ponds are small lakes of water where cooling water is directed to nozzles that spray upward to mix with air. Spraying of this nature usually causes evaporation with little reduction in temperature. Spray ponds are often used by facilities such as utility power plants, where minimal cooling is needed and where the pond can also be incorporated into either decorative fountains or the air conditioning system. Reclaimed water applications in spray ponds is demonstrated in the City of Ft. Collins, Colorado which supplies reclaimed water to the Platte River Power Authority for cooling its 250 megawatt (MW) Rawhide Energy Station.

2.5.2.2 Boiler Feed Water

Boiler feed water is water used to supply a boiler to generate steam or hot water. It is imperative that water required for boiler feed purposes be of very high quality and thus requires a lot of treatment. Quality requirements for boiler make-up water depend on the pressure at which the boiler is operated. Generally, the higher the pressure, the higher the quality of water required. Before reclaimed water could be used as boiler feed water it must be treated to reduce the hardness of the boiler feed water to the barest minimum. Problems associated with low quality water in boiler feed are scale, sludge formation, corrosion, biological growth, priming and foaming. Both freshwater and reclaimed water contain constituents that can cause these problems although their concentrations in reclaimed water are generally high. With the use of advanced wastewater treatment technology, East Bay Municipality Utility District in California provides reclaimed water to the Chevron Refinery for use as boiler feed water.

2.5.2.3 Industrial Process Water

The quality of water required for industrial processes varies from industry to industry. For instance, relatively low quality water is required in the tanning industry while the electronics industry requires very high quality water as process water. However, pulp and paper, textile and metal fabricating industries use neither low nor high quality process water. A full-scale demonstration plant, operated at Toppan Electronics, in San Diego, California, has shown that reclaimed water can be used for the production of circuit boards (Gagliardo *et al.*, 2002). Industrial process water quality requirements for a variety of industries are presented in Table 2.13.

Table 2.13: Industrial Process Water Quality Requirements (USEPA, 2004)

Parameter*	Pulp and Paper			Chemical	Petro-chemical and coal	Textiles		Cement
	Mechanical pulping	Chemical unbleached	Pulp & Paper bleached			Sizing suspension	Scouring, bleach & dye	
Cu					0.05	0.01		
Fe	0.3	1.0	0.1	0.1	1.0	0.3	0.1	2.5
Mn	0.1	0.5	0.05	0.1		0.05	0.01	0.5
Ca		20	20	68	75			
Mg		12	12	19	30			
Cl	1,000	200	200	500	300			250
HCO_3				128				
NO_3				5				
SO_4				100				250
SiO_2		50	50	50				35
Hardness		100	100	250	350	25	25	

Parameter*	Pulp and Paper			Chemical	Petro-chemical and coal	Textiles		Cement
	Mechanical pulping	Chemical unbleached	Pulp & Paper bleached			Sizing suspension	Scouring, bleach & dye	
Alkalinity				125				400
TDS				1,000	1,000	100	100	600
TSS		10	10	5	10	5	5	500
Color	30	30	10	20		5	5	
pH	6-10	6-10	6-10	6.2-8.3	6-9			6.5-8.5
CCE								1

* All values in mg/L except colour and pH

Reclaimed water reuse in the pulp and paper industry is highly dependent on the cost and grade of paper. The higher the quality of paper, the higher the quality of process water required. The impurities found in water can cause the paper produced to change colour with age. Major considerations associated with the use of reclaimed water in the pulp and paper industry include (Camp Dresser and McKee, 1982):

i. Biological growth may cause clogging of equipment and odours and may affect the texture and uniformity of the paper. Chlorination (3mg/l residual) has been found adequate to control micro-organisms;
ii. Corrosion and scaling of equipment may result from the presence of silica, aluminium, and hardness; and
iii. Discoloration of paper may occur due to iron, manganese, or micro-organisms. Suspended solids may decrease brightness of paper.

To successfully use reclaimed wastewater in the pulp and paper industry, tertiary treatment is generally required.

Waters used in textile manufacturing must be non-staining with low turbidity, colour, iron, and manganese. Hardness may cause curds to deposit on the textiles and may cause problems in some of the processes that use soap. Nitrates and nitrites may cause problems in dyeing.

2.5.3 Non-potable Water Reuse for Urban Activities

Reclaimed water can be used in urban areas for the following non-potable purposes (USEPA, 2004):

i. Irrigation of public parks and recreation centres, athletics fields, school yards and playing fields, golf courses, highway medians and shoulders, and landscaped areas surrounding public buildings and facilities;

ii. Irrigation of landscaped areas surrounding single-family, multi-family residences, commercial areas, office buildings and industrial developments;
iii. Commercial uses such as vehicle washing facilities, laundry facilities, window washing, and mixing water for pesticides;
iv. Ornamental landscape uses and decorative water features, such as fountains, reflecting pools, and waterfalls;
v. Dust control, block making and laying and concrete production for construction works;
vi. Fire protection through reclaimed water fire hydrants; and
vii. Toilet and urinal flushing.

In addition to the above mentioned, reuse systems can supply reclaimed water to a combination of industrial, and commercial properties through dual distribution systems as currently being practiced in the City of Cape Town (BVi/CoCT, 2007).

In wastewater reuse systems, the reclaimed water is delivered to consumers through a parallel network of distribution mains separate from the community's potable water distribution system. The reclaimed water distribution system becomes a third water utility, in addition to wastewater and potable water. Reclaimed water systems are operated, maintained, and managed in a manner similar to the potable water system. Wastewater reuse systems have been extensively used in countries like Australia (Rouse Hill, Sydney Olympic Park, Aurora Estate, Bluestone Green Estate, Manor Lakes Estate, Melbourne, Pimpama Coomera, Gold Coast, Mawson Lakes, New Haven, and Adelaide) (Radcliffe, 2004), America (St. Petersburg, Florida; City of Pomona, California; City of Altamonte Springs, Florida; The Irvine Ranch Water District, California; City of Avalon and California) (USEPA, 2004).

2.5.4 Non-potable Water Reuse for Artificial Groundwater Recharge

Artificial recharge is a process where water is introduced into the sub-surface by anthropogenic means. This procedure can be utilized for the disposal of wastewater or storage and recycling. Artificial Groundwater Recharge (AGR) has for a long time provided means to mitigate depletion of groundwater levels, to protect coastal aquifers from saltwater intrusion, reduce subsidence, hydraulic control of contaminant plumes, reduce abstractions from rivers and to store surface water for future use. Artificial groundwater storage has some advantages over surface water reservoirs which might be more costly, high in evaporation loss and have a high environmental impact. Also, soil percolation and aquifer storage act as treatment steps with various filtration, adsorption and degradation processes occurring in the different subsurface horizons while evaporation as well as taste and odour problems due to algae growth in surface storage are avoided.

The utilization of reclaimed water for AGR is of growing importance and offers additional advantages. Wastewater is an alternative water source available throughout the year, depends on population, industry and climatic changes, hence recharge is not limited to periods of surplus surface water. This concept has been in practice in many countries like Australia (Charlesworth *et al., 2002*), Israel (Kanarek and Michail, 1996), Palestine (El Sheik and Hamdan, 2002) and South Africa (Murray *et al.*, 2007).

The concept of AGR offers potential for various uses such as irrigation, industrial process water and augmentation of urban water supplies. The latter is regarded as indirect potable use.

While there are obvious advantages associated with AGR, some drawbacks include (USEPA, 2004; Murray, *et al.*, 2007):

i. extensive land areas may be needed for spreading basins;
ii. costs for treatment, water quality monitoring, and operation of injection/infiltration facilities may be prohibitive;
iii. recharge may increase the danger of aquifer contamination due to inadequate or inconsistent natural treatment;
iv. not all recharged water may be recoverable due to movement beyond the extraction well capture zone or mixing with poor-quality groundwater;
v. clogging occurs at the point of recharge which decreases the rate of recharge;
vi. uncertainty in aquifer hydraulics;
vii. controlled recovery by different users. The concept of whoever stores the water has the right to recover it is generally acceptable throughout the world. It would be highly problematic if there was uncontrolled usage of the stored water;
viii. hydrogeology uncertainties, such as transmissivity, faulting, and aquifer geometry, may reduce the effectiveness of the recharge project in meeting water supply demand;
ix. inadequate institutional arrangements or groundwater laws may not protect water rights and may present liabilities and other legal problems; and

x. environmental concerns relating to fluctuating groundwater. Artificial recharge could result in groundwater levels being raised above and below the norm, and this can have negative environmental consequences such as affecting groundwater level dependent ecosystems, increased aquifer vulnerability to contamination and sinkhole formation in dolomitic aquifers.

The degree to which these factors might affect the implementation of a groundwater recharge system depends on the management and severity of the site specific barriers against wastewater reclamation and reuse.

There are two main techniques for artificially recharging wastewater – surface distribution (spreading) or injection. Surface spreading techniques require a detention area (basin, pit, pond, canal or weir) situated over a permeable unsaturated zone. The detention area is filled with the recharge liquid, which infiltrates through the unsaturated zone to the saturated zone. Injection techniques comprise a well or bore that can introduce recharge liquid into an aquifer or a permeable region of the vadose zone. If conducted by infiltration and percolation through soil and subsoil, the recharge processes, e.g. through the so-called Soil Aquifer Treatment (SAT), offer an additional barrier, particularly for microbial contaminants which are of most concern in any water reuse application. The mixture of reclaimed wastewater with natural groundwater prior to any intended use also positively influences the public acceptance of a reuse scheme.

2.6 Misuse of Wastewater

A major issue with the reuse of wastewater, especially in irrigation applications, is that it is often used for applications that would otherwise not have been irrigated. Thus the availability of cheap wastewater stimulates new water consumption. This problem was experienced in Florida, US during the age of wastewater reuse expansion when many utilities are implementing wastewater reuse programmes and their customer bases grew rapidly. Many reclaimed water customers used more reclaimed water than was necessary for optimum plant growth (Ferraro & York, 2001). Also, the results of the research conducted by the Southwest Florida Water Management District indicate that, in many instances, the use of reclaimed water may only offset about 25 percent of potable water use. That is, if a homeowner was using X gallons of water each month to water his lawn, upon changing to use reclaimed water, he/she may have used about 4X gallons of reclaimed water (SWFWMD, 2002).

Overuse of wastewater can be detriment to human health and the environment by increasing loads on the irrigated soil. In order to avoid misuse and inefficient uses of the reclaimed wastewater, Section 3.3 provides a preliminary precaution by screening of potential markets while section 7.3.6 provides detail precautions to be taken to avoid misuse of wastewater in South Africa.

2.7 Summary

Continuous extraction of water has resulted in depletion of available water sources in the world. In addition, wastewater discharge into natural watercourses has caused surface and groundwater pollution, leaving water unsafe for potable use without major and costly treatment. Technological advancements currently make it possible to treat any source of non-potable water for a variety of non-potable reuses. Most nations in both developed and developing countries are already moving towards wastewater reuse systems to alleviate the problem of water scarcity and pollution. Non-potable waters for different activities depend on concentration and characteristics of pollutants, best available treatment technologies, operation and maintenance costs and availability of raw source. This chapter presented an overview of local and international water reclamation and reuse practices by elucidating on different sources of reclaimed water and their applications.

CHAPTER 3
PLANNING OF WASTEWATER REUSE PROJECTS

3.1 Introduction

Planning of wastewater reuse projects involves a multidisciplinary approach that incorporates the triple bottom line aspects of sustainability i.e. technical and economic, social and environmental. Three major steps (Figure 3.1) should ideally guide the planning of wastewater reuse project i.e. preliminary investigation, screening of potential markets and detailed assessment of selected markets for reuse (USEPA, 2004). Each step builds on previous steps until the assessment is complete. USEPA (2004) therefore recommends the following flow process in assessing wastewater reuse projects:

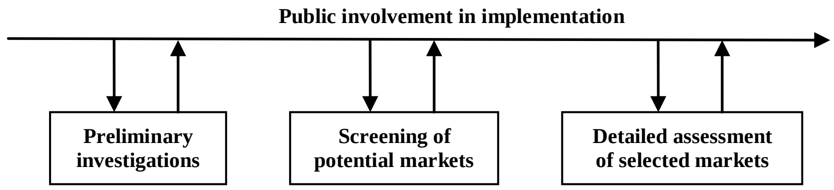


Figure 3.1: Process of wastewater reuse projects assessment (USEPA, 2004)

3.2 Preliminary Investigation

Preliminary investigations prepare the foundation upon which other investigations are made. It incorporates a wide scope by exploring all possible options in the early planning stage. This is to establish a practical context for thorough assessment of all viable alternatives before concluding on the line of action to be taken. At this stage, questions to be asked include (USEPA, 2004):

i. what is the detailed background information of the area under consideration?
i. how sustainable is the present situation of freshwater supply in the area?
ii. what are the present and projected tariffs of freshwater in the area?
iii. who are the potential consumers (local markets) for reclaimed water?
iv. what sources of funding are available to support the reuse project?
v. how would water reuse form an integral part of water resources management in the area?
vi. what are the potential environmental impacts of water reuse in the area?

vii. what public health considerations are associated with reuse, and how can these considerations be addressed?
viii. what type of reuse activities are likely to attract the public's interest and support?
ix. what are the existing or proposed laws and regulations that would affect reuse in the area?
x. what local, provincial or national agencies must review and approve implementation of reuse program?
xi. what are the legal liabilities of a reclaimed water user?

3.2.1 Background Information of the Area

Study area data collection and analysis is fundamental in the feasibility study of any water reuse project. Some necessary data to be collected include (AQUAREC, 2006):

i. basic data and characteristics of the area;
ii. climate;
iii. water balance of the area;
iv. the current water supply situation;
v. water cost and quality requirement; and
vi. the current sanitation situation;

In order to obtain this information, it is important to contact main stakeholders such as DWAF, Municipalities, industries, water and wastewater agencies, Farmers' Associations, Water Users Associations, etc. It may also be necessary to obtain maps showing location of water and wastewater facilities, location of the different water sources, the different land use zones, location of the possible users of reclaimed water and population distribution, different geological zones and so on. This may easily be obtained using aerial photographs and a Geographic Information System (GIS).

3.2.1.1 Basic Data and Characteristics of the Area

Physical characteristics of an area such as landforms, soils, vegetation and topography determine the location of features such as water management areas, urban and\or agricultural settlements, wastewater discharge points etc. These characteristics also influence the location of the different components of the proposed water reuse system i.e. pumping stations, treatment facilities or pipe distribution lines.

3.2.1.2 Climate

Climate encompasses the numerous meteorological factors within a given region over long periods of time e.g. temperatures, humidity, rainfall, atmospheric particle count. The climate of a location is affected by its latitude, terrain, altitude, persistent ice or snow cover, as well as nearby oceans and their currents. Climates can be classified using parameters such as temperature and rainfall to define specific climate types. These parameters will definitely determine water resources and future water needs.

In South Africa, climate variability was observed using 50 years of climate records and the result indicated increasing drought (Mukheibir and Sparks 2004). Climate projection in South Africa shows that the Western part of the country will become drier. Analysis of the rainfall trends for this area indicated a high variability of the rainfall data from year to year, with periods of good rainfall followed by periods of drought (Mukheibir, 2005). Temperature in the country is expected to increase everywhere, with the highest increases (2^{o}-$3^{o}C$) inland and the least ($1.5^{o}C$) in coastal region by 2050. In addition to the increase in temperature, changes are also expected in evaporation, relative and specific humidity as well as soil moisture (Midgley *et al.*, 2005).

In relation to precipitation, South Africa has low volumes of rainfall (average of 500 mm per annum) that is well below world average (800 mm). Rainfall is highly variable and spatially distributed across the country. Hewitson, *et al.*, 2005 predicted a wetter season in the east due to slight increase in precipitation and drier season in the western part of the country.

3.2.1.3 Water Balance of the Area

The current and future yield of surface and groundwater resources in the study area should be analysed to determine the present and future changes in the availability and use of the resources. Two important terms to be considered when accomplishing a water balance assessment are *water stress* and *water scarcity*. Water stress refers to the annual ratio of water withdrawn to the total available within a catchment and expressed in percentage. The higher the ratio/percentage, the more stressed the catchment is. Water scarcity measures water availability per inhabitant per year and expressed in cubic meters per person per year. The higher this value is, the less the water scarcity within the catchment. Table 3.1 shows the commonly used descriptors of water stress and water scarcity as related to measurable criteria (Ilemobade and Taigbenu, 2008).

South Africa is classified as a country with chronic water scarcity (Table 3.2). To address this water scarcity problem, the South African government past efforts have been geared towards the development of new water sources. This option is no longer feasible and government has embarked on a program to reduce water consumption using mechanisms such as water pricing.

Table 3.1: Degrees of water stress and water scarcity (Ilemobade and Taigbenu, 2008)

Water Stress (%)		Water Scarcity (m^3/person/annum)	
Low	< 10	None	> 2000
Moderate	10 to 20	Occasional	1000 – 1700
Medium	20 to 40	Periodic	1700 – 1000
High	40 to 60	Chronic	1000 – 500
Catastrophic	> 60	Absolute	< 500

Table 3.2: Categories of water scarcity associated with varying levels of water supply per person per year (Ashton, 2002)

	Water scarcity index 1: number of people per flow unit (million m^3)	**Water scarcity index 2: volume of water available per person (m^3 person year)**
Beyond the "water barrier": continual, wide-scale water supply problems, becoming catastrophic during droughts.	> 2000	< 500
Chronic water scarcity: continual water supply problems, worse during annual dry seasons, frequent severe droughts *(South Africa falls in this category)*	1000 –2000	500 – 1000
Water stressed: frequent seasonal water supply and quality problems, accentuated by occasional droughts.	600 – 1000	1000 – 1666
Moderate problems: occasional water supply and quality problems, with some adverse effects during severe droughts.	100 – 600	1666 – 10 000
Well-watered: very infrequent water supply and quality problems, except during extreme drought conditions.	< 100	> 10 000

Different tools are available to evaluate the Water Balance of an area. For instance, Decision Support Systems (DSS) using GIS and ArcView3.2 tools for water modelling can be used. Details of water balance in South Africa are well documented in DWAF (2004).

3.2.1.4 The Current Water Supply Situation

The water supply system and population density of an area determines the location of the wastewaters facilities. Currently, most urban and peri-urban cities of South Africa are connected to water supply systems. Different issues to be considered under this section are (AQUAREC, 2006):

i. sources and qualities of the different water supplies;
ii. description and characteristics of the water supply and sanitation facilities;
iii. the proportion of the population served by each facility;
iv. water consumption trend by the different sectors (i.e. industry, agriculture, urban and domestic uses);
v. management of groundwater and associated problems;
vi. current and future costs of tap water, funding of new water projects and water prices. Institutions responsible for setting water prices; and
vii. other relevant aspects such as water losses, etc.

In South Africa, according to the National Water Act (DWAF, 1998), the government is the public trustee of the nation's water resources. Under previous water legislation (Water Act 1956), pricing of water did not generally take into account the real cost of managing water nor the cost of water supply and the scarcity value of water. Using water beyond the free basic water required to meet basic human needs, the principle behind the current water pricing policy in South Africa is that payment for water should be at a level that reflects its scarcity (Van Heerden, *et al.*, 2006). Currently 25l/c/d of water is assumed to meet a basic human need and is provided as free basic water. The pricing policy is structured into three tiers:

i. First tier: raw water tariffs administered by DWAF for the sale of water to water boards;
ii. Second tier: water board sets the wholesale price of water to bulk water users; and
iii. Third tier: Municipalities determine the price of water to charge end-users such as households and industries.

Water consumption is directly linked to water price. A study carried out in California (Asano, 1998) proved that there is a strong elasticity (elasticity is define as percentage change in water demand to increase in price) in this sector and an increase of 50 percent in the water price produced a decrease in the range of 23-75 percent in water consumption. In Similar manner, average water tariffs in South Africa and the semi-elasticity for water demand has been reported by van Heerden *et al.*, 2006 and summarised in Table 3.3.

Table 3.3: Average water tariffs in South Africa and semi-elasticity for water demand (Van Heerden, *et al.*, 2006)

Industry	Water tariff (R/ m^3)	% change in use due to an increase of R1	Elasticity	Semi elasticity
Irrigated field	0.05	2000.0	–0.25	–500.0
Dry field	0.05	2000.0	–0.15	–300.0
Irrigated horticulture	0.05	2000.0	–0.25	–500.0
Dry horticulture	0.05	2000.0	–0.15	–300.0
Livestock	0.05	2000.0	–0.15	–300.0
Forestry	0.025	4000.0	–0.40	–1600.0
Other Agric	0.05	2000.0	–0.15	–300.0
Coal	2.12	47.2	–0.32	–15.3
Gold	2.12	47.2	–0.32	–15.3
Crude, petroleum & gas	2.12	47.2	–0.48	–22.6
Other mining	2.12	47.2	–0.32	–15.3
Food	4.00	25.0	–0.39	–9.8
Textiles	4.00	25.0	–0.33	–8.3
Footwear	4.00	25.0	–0.33	–8.3
Chemicals & rubber	2.12	47.2	–0.15	–7.2
Petroleum refineries	2.12	47.2	–0.48	–22.6
Other non-metal minerals	2.79	35.8	–0.32	–11.6
Iron & steel	2.79	35.8	–0.27	–9.8
Non-ferrous metal	2.79	35.8	–0.27	–9.8
Other metal products	2.79	35.8	–0.27	–9.8
Other machinery	4.00	25.0	–0.25	–9.5
Electricity machinery	4.00	25.0	–0.38	–9.5
Radio	4.00	25.0	–0.38	–9.5
Transport equipments	4.00	25.0	–0.38	–9.5
Wood, paper & pulp	2.12	47.2	–0.59	–27.8
Other manufacturing	4.00	25.0	–0.38	–9.5
Electricity	2.12	47.2	–0.80	–37.7
Water	2.12	47.2	–0.60	–28.3
Construction	4.00	25.0	–0.38	–9.5
Trade	4.00	25.0	–0.19	–4.8
Hotels	6.11	16.4	–0.19	–3.1
Transport services	6.11	16.4	–0.19	–3.1
Community services	6.11	16.4	–0.19	–3.1
Financial institutions	6.11	16.4	–0.19	–3.1
Real estate	6.11	16.4	–0.19	–3.1
Business activities	6.11	16.4	–0.19	–3.1
General government	6.11	16.4	–0.19	–3.1
Health services	6.11	16.4	–0.19	–3.1
Other service activities	6.11	16.4	–0.19	–3.1

3.2.1.5 The Current Sanitation Situation

One of the basic conditions for reuse project is that the area must be sewered. The sewage network system determines the location of the wastewaters to be treated for reuse. Under this sub-section, the different types of information to be compiled and analyzed are (AQUAREC, 2006):

i. Location and number wastewater treatment plants;
ii. Types of wastewater treatment and treatment costs;
iii. Percentage of population connected to sewerage;
iv. Institutions responsible for various components of the sanitation system;
v. Wastewater tariffs;
vi. Quantity and quality of the treated effluents;
vii. Wastewater legislation; and
viii. Forecasts of new WWTWs or proposed extensions.

3.3 Screening of Potential Markets

An important task at the reuse project planning stage is to conduct a preliminary market assessment to identify potential reclaimed water users. This involves identifying the location of large and medium water users in order to establish discussions. On the basis of information gathered in the preliminary investigations (Section 3.2), there may be possibilities of implementing a reuse project for one or more applications in an area. For example, if a large agricultural or industry is located next to a wastewater treatment plant, there is a strong potential for reuse. Users such as these have a high demand for water and the costs to convey reclaimed water would be low. The cost-effectiveness of providing reclaimed water to a given consumer is highly dependent on the consumer's potential demand (volume required), quality requirements and the location of the consumer in relation to the source of reclaimed water. It should also be noted that a concentration of smaller consumers (e.g. domestic users) might represent a service area that would be as cost-effective to serve as a single large user.

Once these anchor customers are identified, it is often beneficial to search for smaller customers located along the proposed route of the main distribution pipeline. It is necessary at this stage to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how the use of reclaimed water might affect the user's operations or discharge requirements. This information can be obtained through a questionnaire. An example of questionnaire is shown in Table 3.4.

Table 3.4: Typical survey form to ascertain interests in water reuse (AWWA, 2009)

Surveyor: ____________________________
Date: ________________________________
Time: ________________________________

Business ____
Contact Name ____
Physical Address ____
Mailing Address ____
City ___________________________ State _______________________ Zip ____________

- Do you own or lease this property?
  - Own: ___________
  - Lease: ___________

Phone Number _______________________ Fax Number ____________________________
Email ____

- Are you familiar with reclaimed water, what it is, how it is used, and its benefits? ___Yes ____ No
  (If yes, explain what it is.) ____
  ____
- Please estimate your daily potable water consumption:
  (gallon per day) ________________________
- Please estimate your daily non-potable water consumption:
  (gallon per day) ________________________
- What is/are your current source(s) of water (city, well, pond, others)? _______________________
- Is the demand at your facilities continuous or batch process? ______________________________
- Is the demand at your facility seasonal? ________ Yes _________No
  - If so, when is the peak season? ____
  - About how long does the peak season last? _____________________________________
  - When is the low season? ____
  - About how long does the low season last? ______________________________________
- If reclaimed water was made available at your facility, would you use it? ________ Yes _____ No
  If no, why not? ____
  ____
- If reclaimed water was made available at your facility, how much water could you utilize on a daily basis?
  ____
- What are the potential uses of reclaimed water at your facility (irrigation, cooling tower, process rinse water)? ____
- If notified by *Example City* that reclaimed water will be made available at your facility, how much lead time would you need to implement a reclaimed water system? _________________________________
- What quality of reclaimed water would be required for your intended use? (e.g., pH, suspended solids, dissolved solids, nitrogen) ____
- What concern might inhibit your facilities usage of reclaimed water? ________________________
  ____
- What would be a reasonable cost for reclaimed water (check one):
  - Identical to potable water rate ___________
  - 75% of potable water rate ______________
  - 50% of potable water rate ______________
  - 25% of potable water rate ______________
- Would you be interested in receiving more information on reclaimed water? ___________________
  Comments ____
  ____

This early planning stage is an ideal time to begin developing or reinforcing strong working relationships among wastewater managers, water supply agencies, and potential reclaimed water users. These working relationships will help to develop solutions that best meet a particular community's needs.

Obviously, potential users will be concerned about the quality of reclaimed water and reliability of its delivery. They will also want to understand state and local regulations that apply to the use of reclaimed water. Potential customers will also want to know about constraints to using reclaimed water. They may have questions about connection costs or additional wastewater treatment costs that might affect their ability to use the product. All concerns of potential customers are thoroughly evaluated during detail assessment.

3.4 Detailed Assessment of Selected Markets for reuse

Following the screening of the potential markets, detailed assessment of the selected market must be done. This is a fact finding stage where technical, economic, social, environmental and legal/institutional issues are sorted out. A detailed assessment should lead to a thorough assessment of the technical, economic and financial feasibility of reuse project. Comparison among alternative reuse programs should be made as well as comparison between the potential reuse projects and alternative water supplies, both existing and the proposed. In this phase, economic comparisons, technical feasibility, and environmental assessment activities leading to a detail plan for reuse might be accomplished.

3.4.1 Technical and Environmental Assessment of Reuse

One of the key considerations in any reuse project is the technical viability of the project. This factor is a fulcrum in the decision making regarding the implementation of any reuse project and should identify some of the following possibility and constraints (USEPA, 2004; AQUAREC, 2006):

i. understanding the treatment requirements for producing safe and reliable reclaimed water that is suitable for its intended applications;
ii. resources requirements (land, civil works, installation of pipelines, storage tanks, energy, human resources, etc.);
iii. identification of the knowledge, skills, and abilities necessary to operate and maintain the proposed system;

- ***Treatment Requirements to meet Reuse Quality***

One of the major critical issues for consideration in a water reuse project is to ensure that public health is not compromised through the use of reclaimed water. This is achieved by safe delivery and proper use of the treated reclaimed water. Protection of public health is achieved by (USEPA, 2004):

i. reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water;
ii. controlling chemical constituents in reclaimed water; and/ or
iii. limiting public exposure (contact, inhalation, ingestion) to reclaimed water.

Potential health risk will vary depending on the reclaimed water applications and the level of human exposure. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided that worker safety is not compromised. Determining the necessary treatment for the intended reuse application requires an understanding of the following:

i. constituents of concern in wastewater;
ii. level of treatment and processes applicable for reducing the constituents to levels that achieve the desired reclaimed water quality;
iii. reliability of and risks attached to the different levels of treatment; and
iv. the reticulation infrastructure which will be used to convey, treat and/or store wastewater.

- ***Constituents of Reclaimed Water***

Reclaimed wastewaters contain two general types of hazards for humans. The first is microbial contaminants, largely present in faecal waste and which have potential to cause outbreaks of viral, bacterial and parasitic diseases. Untreated municipal wastewater contains varying levels of pathogens including bacteria, viruses, protozoa and helminths. The second risk comes from various chemicals, including pharmaceutical products that end up in wastewater. This may cause a range of ill effects should people be exposed to them for prolonged periods of time. Environmental contaminants, industrial chemicals, domestic chemicals and pharmaceuticals can also affect treated effluent composition. Both sets of hazards require sound risk management systems for effective control (Radcliffe, 2004).

The important constituents of concern in municipal wastewater, subject to treatment, are classified as conventional, non-conventional, and emerging. Typical constituents included under each category are described in Table 3.5.

Table 3.5: Classification of typical constituents found in wastewater (Metcalf and Eddy, 2004)

Classification	Constituents
Conventional	Total suspended solids Colloidal solids Biochemical oxygen demand Total organic carbon Ammonia Nitrate Nitrite Total nitrogen Phosphorus Bacteria Protozoa Viruses
Non-conventional	Refractory Organics Volatile organic compound Surfactants Metals Total dissolved solids
Emerging	Prescription and non-prescription drugs Home care products Veterinary and human antibiotics Industrial and household products Sex and steroidal hormones Other endocrine disrupters

The term "conventional" is used to define constituents that serve as the basis for the design of most conventional treatment plants. "Non-conventional" is used to describe constituents that may be removed or reduced using advanced wastewater treatment processes before the water can be used beneficially. The term "emerging" describes classes of compounds that may not be removed effectively with advanced treatment. Although there is little or no information concerning health or environmental effects, some of the compounds that have been identified in reclaimed water are known to have both acute and chronic health effects, depending on their concentrations and exposure pathways (Metcalf and Eddy, 2004).

- ***Levels of Treatment Required for different Applications***

Depending on the composition of the wastewater to be treated and on the required reclaimed water quality, the treatments and systems will differ. In Table 3.6, different treatment trains are proposed depending on the reclaimed water application (Lazarova, 2001). Usually, intensive treatments are more expensive, require advanced technologies and require less space compared to extensive ones.

Table 3.6: Recommended treatment schemes as a function of wastewater reuse applications (Lazarova, 2001)

Reuse Application Type	Extensive Treatment (E)	Intensive Treatment (I)
1. Irrigation of restricted crops	E.1. Stabilization pond in series or aerated lagoons; wetland; infiltration – percolation	I.1. Secondary treatment by activated sludge or trickling filter with or without disinfection
2. Irrigation of unrestricted crops, vegetables eaten raw	E.1. Same as E.1. with polishing steps and storage reservoir	I.2. Same as I.1. with tertiary filtration and disinfection
3. Urban uses for irrigation of parks, sport fields, golf courses	E.3. Same as E.2.	I.3. Same as I.2. with filtration in the case of unrestricted public access
4. Groundwater recharge for agricultural irrigation	E.4. Same as E.2. completed by soil-aquifer treatment	I.4. Same as I.2. with nutrient removal (when necessary)
5. Dual distribution for toilet flushing	E.5. Not applicable	I.5. Same as I.3. with activated carbon (when necessary) or membrane bioreactors and disinfection
6. Indirect and direct potable use	E.5. Not applicable	I.6. Secondary, tertiary and quaternary treatment including activated carbon, membrane filtration (including reverse osmosis) and advanced disinfection

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, is generally defined as any treatment beyond secondary. Generalized wastewater treatment options for various reuses is shown in Figure 3.2

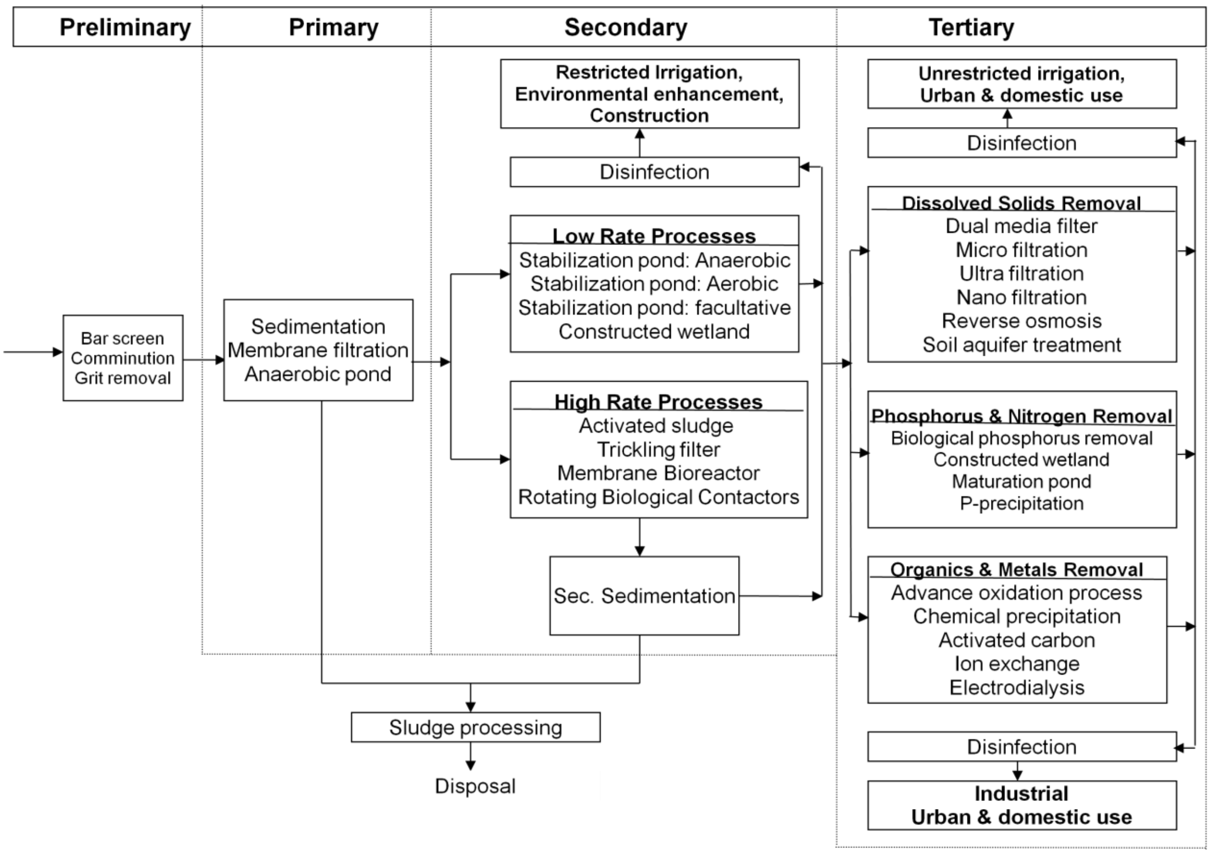


Figure 3.2: Wastewater treatment options for various reuse applications (USEPA, 2004)

- ***Treatment Reliability***

Because of the potential harm that could result from the delivery of improperly treated reclaimed water to the user, a high standard of reliability is required at wastewater treatment plants. Water reuse requires strict compliance with all applicable reclaimed water quality parameters. The need for reclamation facilities to reliably and consistently produce and distribute reclaimed water of adequate quality and quantity is essential and dictates that careful attention be given to reliability features during the design, construction, and operation of the facilities.

In reclaimed water reliability assessment, close monitoring of all elements that make up a water reclamation system is imperative. These elements include power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. Critical units in the water reclamation system include the disinfection unit, power supply and various treatment unit processes. Reliability of water reuse should also consider (USEPA, 2004):

i. operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems;
ii. instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions;
iii. a comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol;
iv. adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or disposal;
v. supplemental storage to ensure that the supply meet users demand ;
vi. a strict industrial pre-treatment program and strong enforcement of sewer use ordinances to prevent illicit sewage of hazardous materials that may interfere with the intended use of the reclaimed water; and
vii. a comprehensive operating protocol that defines the responsibilities and duties of the operations staff to ensure the reliable production and delivery of reclaimed water

Table 3.7 presents the summary of equipment requirements under the EPA guidelines for Class I reliability treatment facilities.

Table 3.7: Summary of Class I reliability requirements (USEPA, 2004)

Unit	Class I requirements
Mechanically cleaned screen	Back-up bar screen shall be provided (May be manually cleaned)
Pump	A back-up pump shall be provided for each set of pumps which performs the same function. Design flow will be maintained with any 1 pump out of service
Comminution facilities	If comminution is provided, an overflow bypass with bar screen shall be provided
Primary sedimentation basins	There shall be sufficient capacity such that a design flow capacity of 50 percent of the total capacity shall be maintained with the largest unit out of service
Filters	There shall be a sufficient number of units of a size such that a design capacity of at least 75 percent of the total flow will be maintained with 1 unit out of service
Aeration Basins	At least two basins of equal volume will be provided
Mechanical Aerator	At least 2 mechanical aerators shall be provided. Design oxygen transfer will be maintained with one unit out of service
Chemical Flash Mixer	At least 2 basins or back-up means of mixing chemicals separately from the basins shall be provided
Final Sedimentation Basins	There shall be a sufficient number of units of a size such that 75 percent of the design capacity will be maintained with the largest unit out of service
Flocculation Basins	At least 2 basins shall be provided
Disinfectant Contact Basins	There shall be sufficient number of units of a size such that the capacity of 50 percent of the total design flow may be treated with the largest unit out of service

Detail description of how treatment plant can be maintained to provide good water quality is provided in Chapter 8.

- ***Risk Analysis***

Risks are closely related to the treated wastewater quality and the reuse application of the water. Risk analysis is used to analyse health implications of an action on humans and the environment. Typically, risk analysis is divided into two parts, namely risk assessment and risk management (Metcalf and Eddy, 2004). Assessment involves the study and analysis of the potential of certain hazards to human health and environment while risk management is the process of reducing risks that are deemed unacceptable (Figure 3.3).

Both human and environmental risk assessments take place in four major steps in sequential order as follows (Metcalf and Eddy, 2004; AQUAREC, 2006):

i. Hazard identification
ii. Dose (concentration) – Exposure (effect) assessment
iii. Risk characterization, and
iv. Risk management

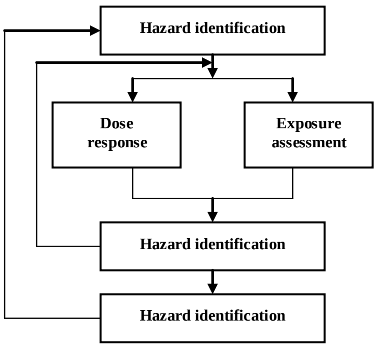


Figure 3.3: Risk assessment process and risk management (Metcalf and Eddy, 2004)

Hazard identification involves weighing the available evidence and determining whether a substance(s) constitute/exhibit a particular adverse health hazard. This is usually carried out by gathering evidence on the potential for the substance(s) to cause adverse health effects in humans or unacceptable environmental impact. Exposure is the process by which an organism comes in contact with the substance(s). Dose response assessment defines a relationship between the amount of toxic constituents to which a human is exposed and the risk that there will be an unhealthy response to that dose. Exposure is the link between hazard and risk. Risk characterization is the last step in risk assessment in which the question of who is affected and what are the likely effects are defined for further investigation. Risk management involves the development of standards, guidelines and management strategies for specific constituents of hazardous influence on human health and environment (Metcalf and Eddy, 2004).

In order to minimise the potential risks associated with water reuse, it is encouraged that a complete monitoring programme together with a guideline of best practices is carried out. The different types of risks associated with water reuse projects are grouped into four main categories (Figure 3.4): environmental, technical, social and economic risks (AQUAREC, 2006). Amongst them, the possible transmission of infectious diseases by pathogenic agents is the most important concern.

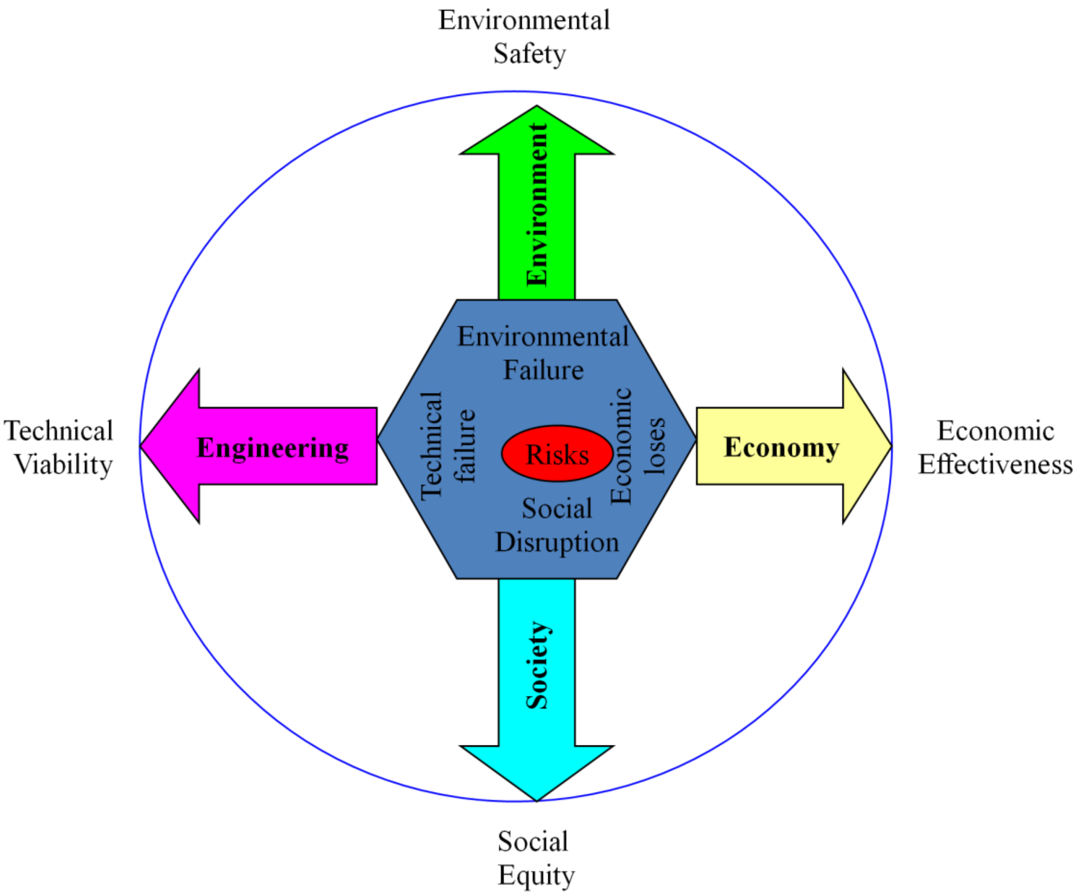


Figure 3.4: Risks and objectives for sustainable wastewater reuse (Ganoulis, 2003)

- ***Reclaimed Water Reticulation***

The design of treated wastewater distribution system is similar to potable water distribution system. Materials of equal quality for construction are recommended. The reliability of the system need not be as stringent as a potable water system. No special measures are required to pump, deliver, and use the water. No modifications are required because reclaimed water is being used, with the exception that equipment and materials must be clearly identified. For service lines in urban settings, different materials may be desirable for more certain identification.

The design of distribution facilities is based on topographical conditions as well as reclaimed water demand requirements. If topography has wide variations, multilevel systems may have to be used. Distribution mains must be sized to provide the peak hourly demands at a pressure adequate for the user being served. Pressure requirements for a dual distribution system vary depending on the type of user being served.

The major concern guiding design, construction, and operation of a reclaimed water distribution system is the prevention of cross-connections. A cross-connection is the point in a distribution system where a potable water system is connected to a non-potable system or a system of questionable water quality. Another major concern is the wrong use of reclaimed water. To protect public health from the onset, a reclaimed water distribution system should be accompanied by health codes, pipes colour codes, procedures for approval (and disconnection) of service, regulations governing design and construction specifications, inspections, and operation and maintenance staffing. Public health protection measures that should be addressed in the planning phase are (USEPA, 2004):

i. establish that public health is the overriding concern;
ii. devise procedures and regulations to prevent cross-connections;
iii. develop a uniform system to mark all non-potable components of the system;
iv. prevent improper or unintended use of non-potable water through a proactive public information program;
v. provide for routine monitoring and surveillance of the non-potable system;
vi. establish and train special staff members to be responsible for operations, maintenance, inspection, and approval of reuse connections;
vii. develop construction and design standards; and
viii. provide for the physical separation of the potable water, reclaimed water, sewer lines and appurtenances.

3.4.2 Economic Assessment of Reuse

Economic assessment is a critical decision tool that is used in assessing if an investment will provide satisfactory returns. It forms a major part of a feasibility study that allows decision makers to make judgement on the implementation of reuse projects by evaluating the benefits of a project from its investments over a determined planning horizon. It includes the monetary (i.e. capital, operation and maintenance, labour and energy costs) and non-monetary value (i.e. environmental benefits) of reclaimed water. The analysis incorporates financial, environmental, social costs and benefits. In a water reclamation project, economic assessment is carried out by clearly identifying the project objective, alternative solution, service area, market assessment, environmental impact, treatment and distribution facilities required (Biagtan, 2008).

Some methodologies have been used to analyze the economic feasibility of implementing reuse projects. In most assessments, economic analyses have been based on a cost-benefit approach where only internal costs (capital investment, operation and maintenance costs, financial costs and taxes) are taken into consideration without due consideration to other external factors that affect directly or indirectly the implementation of a reuse project. Economic analysis has been defined as a tool that enables a water reuse project to be justified in monetary terms, provided that total profits are greater than total costs. A methodology to assess the economic feasibility of a water reuse project taking into account not just the internal impact, but also the external impact (environmental and social, etc) and the opportunity cost derived from the project was proposed by Segui, 2005 and Hernández *et al.*, 2006. While some of these factors identified can be calculated directly, in monetary terms, others like biophysical and social aspects demand the definition of units of measurement.

Under economic analysis, the decision criterion used is known as Potential Pareto Superiority. This criterion identifies a project as superior if those who gain from the project could compensate those who lose from it so that none would be worse off with the project. In the wise, an economic assessment befits the objectives of the public sector and the public at large in decision making. For recycled water projects by public agencies, the benefits and costs comparison used in economic assessment is illustrated in Figure 3.5. By including benefits and costs beyond cash flow, economic analysis results may favour reclaimed water projects (Biagtan, 2008).

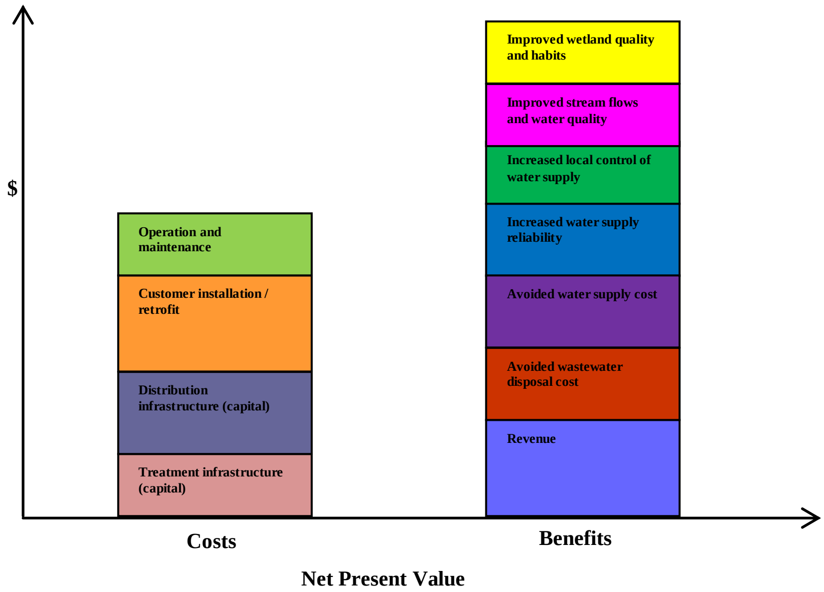


Figure 3.5: Costs and benefits in an economic analysis (Biagtan, 2008)

The cost effectiveness of water reuse projects is directly related to the volume of reclaimed water used; the more water utilized, the more cost-effective the project. In this sense, irrigation generally provides the highest potential for water reuse. Depending on the need for the resource, there is a minimum flow to consider for a water reuse project in order for it to be seen as cost-effective. This level, although difficult to specify, AQUAREC (2006) suggested that it could be in the range of a flow corresponding to 10,000 - 20,000 inhabitants-equivalents, or the same as the water needed to irrigate a golf course or a crop extension of 3,500,000 m^2. The different water reuse options should be compared to the non-reuse existing alternative. Besides the treatment costs, other aspects such as the decrease in the wastewater discharge into the environmental or the increase in the crop yield due to irrigation with treated wastewater (or decrease in the needed fertiliser amount) should be considered.

- ***Methods of Economic Assessment***

Two methods of assessment are most popular in evaluating public projects. They are Benefit-Cost Analysis and Cost-Effectiveness Analysis. Benefit-Cost Analysis is commonly used in formal economic assessment, where alternatives vary widely in financial and environmental costs and social benefits. Cost-Effectiveness Analysis on the other hand is used when it is impractical to consider the monetary value of the benefits provided by the alternatives under consideration. For instance, application of this method of analysis is found when each alternative's benefits are the same, but Rand values cannot be determined. Cost-effectiveness analysis is less comprehensive and used less often than the Benefit-Cost Analysis (Biagtan, 2008).

Benefit-Cost Analysis has evolved to become the generally accepted means to evaluate projects proposed by public agencies. This analytical method is known to improve efficiency for society, as it maximizes the total net benefits available to society. It also provides an avenue for evaluating the social equity of a project since this analytical method satisfies public policy direction to improve the welfare of society by maximizing net social benefits. When calculating the total net benefit, it is worth including net internal benefit, net benefits from externalities and opportunity cost (Hernandez, *et al.*, 2006). This is usually expressed as follows:

$$MaxB_T = B_I + B_E - OC \qquad 3.1$$

Where B_T = total net benefit

B_I = net internal benefit

B_E = net external benefit and

O_C = opportunity cost.

The net internal benefit is obtained from the difference between internal income and internal costs. Internal income is obtained by multiplying the selling price of reclaimed water and the volume supplied. Internal costs are made up of the sum of investment costs (physical infrastructure), operating costs (labour, energy and chemical products), financial costs and taxes. By calculating a project's potential costs and income, it is possible to appropriately assess its feasibility.

If there is no current market for reclaimed water, it is difficult to obtain a price. In order to overcome this problem, the cost per m^3 should apparently be equal to the minimum selling price. In this way, covering costs is guaranteed (Hernandez, *et al.*, 2006). The standard criterion for deciding whether a project can be justified on economic principles is net present value (NPV) which is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits. Discounting benefits and costs transform gains and losses occurring in different time periods to a common unit of measurement. While projects with positive NPV increase social resources and are generally preferred, negative NPV projects should generally be avoided (Massoud and EL-Fadel, 2002).

The minimum selling price is that which makes the NPV equal zero. After having established the qualitative objective for reclaimed water, the next step is to find the most suitable technology to achieve it. Clearly, when there are several technological alternatives, the one that offers the lowest cost per m^3 will be chosen. The following equations can be employed to calculate NPV (Segui, 2005; Hernandez *et al.*, 2006):

$$NPV = \sum_{n=1}^{n} \frac{NB_n}{(1+i)^n} - I_o \qquad 3.2$$

$$NB_n = (AVWR \times SPWR) - (IC_n + OMC_n + T_n + FC_n) \qquad 3.3$$

Where *NPV* = the current net value

I_0 = initial investment

NB = annual net benefit

i = discount rate

n = year

IC = investment cost

OMC = operating and maintenance costs

T = taxes (tax payments derived from tax benefits obtained for the activity)

FC = financial costs

AVWR = annual volume of water reclaimed and

SPWR = minimum selling price of water reclaimed.

This methodology provides the cost per m^3 but is not enough to determine the feasibility of a project over its design life. In order to achieve this, the total net benefit (B_T) must be calculated, according to the equation shown previously. Therefore, total net benefit is given by:

$$B_T = \sum_{n=1}^{n} (AVWR \times SPWR) - (IC_n + OMC_n + T_n + FC_n) \qquad 3.4$$

From equation 3.4, a monetary value can be obtained from the calculation. However, there are a series of external influences for which no explicit market exists. In such cases, economic valuation methods are used, which are based on hypothetical scenarios or patterns observed in related markets. External benefit of the project is calculated using the value of positive and negative externalities as shown in equation 3.5.

$$B_E = \sum_{n=1}^{n} (PE_n - NE_n) \qquad 3.5$$

Where B_E = net external benefit

P_E = positive externalities

N_E = negative externalities.

Externalities as a whole are made up of a positive and a negative impact derived from the project (Table 3.8).

Table 3.8: Identification and valuation of externalities (AQUAREC, 2006; Hernandez, *et al.*, 2006)

Group	Externality Identification	Units
Water Infrastructures	• The avoidance of constructing facilities to capture and store freshwater • The avoidance water purification costs • The avoidance of constructing pipes and water distribution costs	Rands Rands Rands
Reuse of Pollutants	• Reuse of Nitrogen in agriculture • Reuse of Phosphorous in agriculture • Reuse of sludge in agriculture and gardening	Kg of N Kg of P Kg
Uses of Resources	• The increases in quantity of water available due to reuse • Guaranteed supply during times of shortage	m^3 % Confidence
Public Health	• Biological risks associated to wastewater reuse	People exposed
Environment	• Chemical risks associated with wastewater reuse • Change in the level of rivers • over\under exploitation of water-bearing resources • Water pollution • Wetland and river habitat recovery • Increase in pollution due to unpleasant smells and noises • Devaluation of adjacent land	People exposed m^3 Aquifer level, m Kg Waste eliminated Users People exposed Rands
Education	Social awareness required to sustain\develop an understanding of reuse	Number of people

Another important factor to be considered in economic analysis is the opportunity cost. This is defined as the value of goods in terms of a lost alternative use of those goods. Despite the fact that in the case of water treatment and reuse projects the land that the plant occupies is not normally of great value, it is still worth contemplating the possibility of an alternative use with certain profitability. This value is often difficult to estimate, however, a reasonable amount could be obtained using the *contingent valuation* method. Contingent valuation is a survey based economic technique for the valuation of non-market resources. While these resources provide service to people, certain aspects of them do not have a market price as they are not directly sold. By substituting the previous equations (equations 3.3 to 3.5) into equation 3.1, the following expression emerges:

$$MaxB_T = \sum_{n=1}^{n} [(AVWR_n \times SPRW_n) - (IC_n + OMC_n + T_n + FC_n) + (PE_n - NE_n) - OC_n] \quad 3.6$$

It is important in this type of analysis to note that, while having suitable methodology is worthwhile, so also is the quantity and quality of the data used. The combination of both elements is what gives validity to the feasibility study.

Good engineering proposals without economic justification are often uneconomical. The most suitable approach for comparing wastewater treatment train alternatives is the Life Cycle Cost (LCC). Life Cycle Cost Analysis is an economic assessment technique that determines the total cost of owning and operating a facility over a useful period of time. It is often known as the cost of a facility from cradle to grave. LCC is the summation of cost estimates from inception to disposal as determined by an analytical study and estimate of total costs experienced in annual time increments during the project life with consideration for the time value of money. The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives to achieve the lowest long-term cost of ownership (Barringer & Associates, Inc., 2003). LCC results are presented in net present value (NPV) format by considering the capital cost of a project, operation and maintenance, energy cost, replacement, the salvage value and the time value of money as expressed in equation 3.7.

$$LCC = \sum_{i=1}^{p} CC_i + 1.15(LanC_i) + LbRC_{pwi} + O\&M_{pwi} + E_{pwi} + R_{pwi} \quad 3.7$$

Where LCC = Life Cycle Cost of the treatment train

CC_i = Capital Cost of i^{th} unit process

$LanC_i$ = Cost of land for i^{th} unit process

LbC_{pwi} = Present worth of labour cost for i^{th} unit process

$O\&M_{pwi}$ = Present worth of operation and maintenance cost of i^{th} unit process

E_{pwi} = Present worth of energy cost of i^{th} unit process

R_{pwi} = Present worth of replacement cost of i^{th} unit process

p = Number of unit processes making treatment train

A flow chart summarising the economic analysis of reuse project is shown in Figure 3.6.

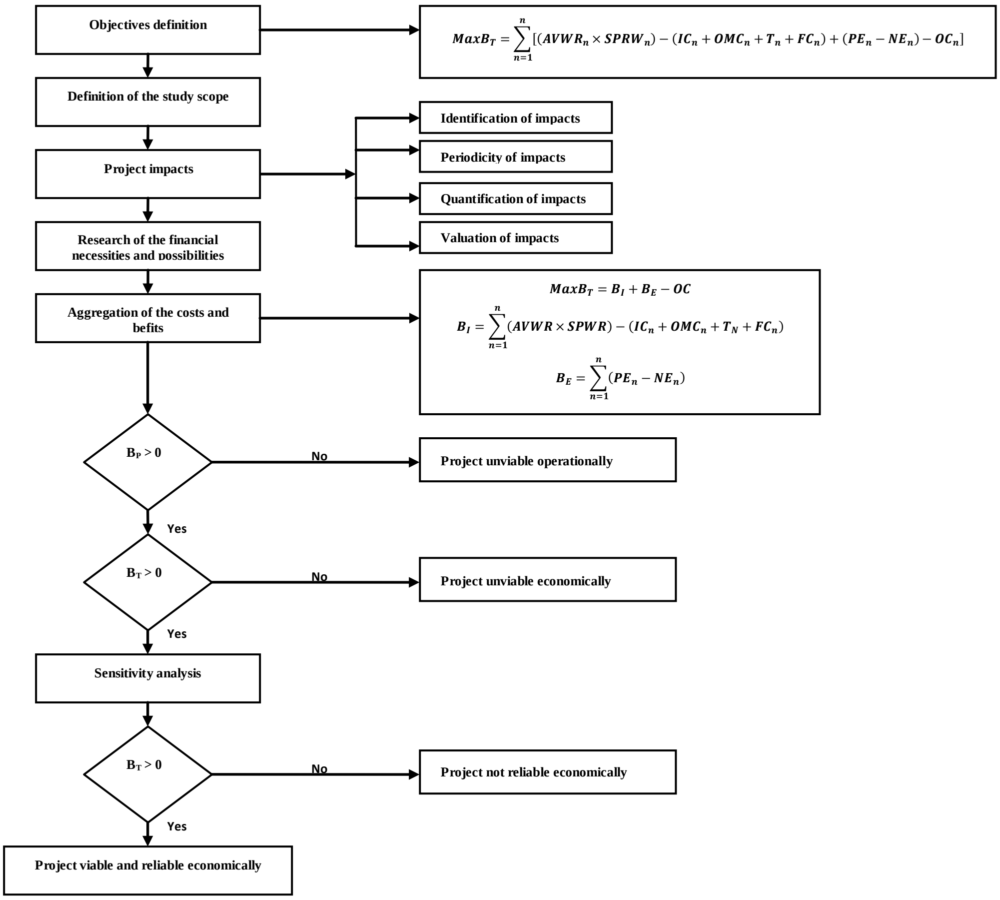


Figure 3.6: Stages in the economic analysis of reuse wastewater projects (Segui, 2005)

3.4.3 Financial Analysis of Reuse

The financial analysis is aimed at determining if a project can be financed or not by assessing if revenues will cover operation and debt service costs. Financial analysis compares cash flow expenditures and revenues of an investment. If expected revenues exceed expenditures over the time interval of the assessment, the project is said to be financially viable otherwise, not viable.

The financial analysis of a reclaimed water project is based on the monetary costs for the installation, operation and maintenance of its treatment and distribution infrastructure and of the revenues collected from customers along with the timing of these costs and revenues. Financial feasibility determines whether sufficient financial resources can be generated to construct and operate the required reclamation facilities. The result is most often unfavourable for reclaimed water projects as shown in Figure 3.7 (Biagtan, 2008). However, in practice, the cost of treating wastewater to safe disposal quality (in most cases, secondary treatment) is already embedded in the sanitary bill of the municipality, hence it is reasonable to only charge the reclaimed water users the cost of additional treatment (tertiary treatment) required to meet consumer's quality requirement. If this is done, then the financial feasibility of the project changes drastically and may become favourable over its design life as explained in Section 6.5. To satisfy the capital requirements for implementation of a reuse program, the majority of the construction and related capital costs are often financed through long-term water and wastewater revenue bonds, which spread the cost over a long period. Supplemental funds may be provided by grants, developer contributions, etc., to offset the annual revenue requirement (USEPA, 2004).

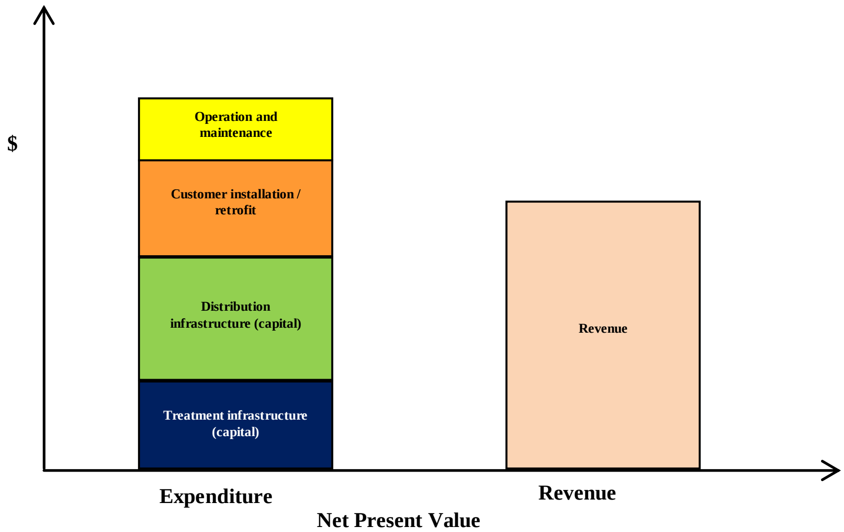


Figure 3.7: Financial analysis illustration (Biagtan, 2008)

Financial analysis was not included in the developed DSS because of various factors that are considered in budgetary allocation of funds to finance a project of this nature which are beyond the scope of this research.

3.4.4 Social and Institutional Assessment of a Reuse Project

Assessment of public acceptance of wastewater reuse and institutional capacity is a critical factor in the success of any reuse project. In contrary to the past practices where public are informed about water projects after decision had been taken, many water agencies are now engaging stakeholders in the planning and implementation of new water management practices such as rainwater harvesting, recycled water, water saving devices, etc. Public engagement is aimed at incorporating public values with science, technology and legal aspects to create pragmatic solutions that are tailored towards meeting specific needs (USEPA, 2004).

In the area of water reuse, the aim of public involvement programs is to identify public concerns at the early stage of planning and provide information in a clear and unambiguous way. Effective public involvement starts from planning and span through the entire project life. Public participation begins with having a clear understanding of the water reuse options available to the community. Once an understanding of possible alternatives is developed, a list of stakeholders, including possible users, can be identified and early public contacts may begin.

In general, effective public participation programs involves two-way communication processes whereby the reuse planners/service providers educate public on reuse and ask for input as the reuse program is developed. Depending on the project, public involvement can involve establishing contact with a number of specific users, or can be expanded to include the formation of a formal advisory committee. Potential recycled water users often have legitimate concerns hence, public education efforts are geared towards providing information on technical capability, institutional capacity, public health and safety, economy and environmental issues. Many citizens may have a pre-conceived notion about reclaimed water and its benefits. It is important to identify each stakeholder’s issues and to address questions and concerns in a clear and satisfactory way.

In discussing public participation for wastewater facilities and reuse planning the following publics may be identified: general public, potential users, environmental groups, special interest groups, home owners associations, regulators and/or regulating agencies, educational institutions, political leaders, and business/academic/community leaders (USEPA, 2004). In communities where reuse has not been introduced in any form, the focus may begin with small and specific audiences. For instance in the city of Cape Town, municipality identified large non-potable water users such as golf course owners, industries and schools (both public and private) where recycled wastewater is supply for non-potable uses. This small, informed constituency can provide the community with a lead-in to reclaimed water options in the future. In this case, large specific users spread reuse benefits informally, and, in the future, the same community may choose to introduce an urban system, offering reclaimed water for irrigation and other non-potable uses. Also, where water reuse is common, there is a need to establish a line of communication to and from potential reuse consumers so that they can have a clear understanding of the program and provide input.

According to USEPA (2004), the most important step in encouraging the public acceptance is to establish and communicate the expected project benefits. If the project is intended to extend water resources, then how much water will be made available through reclamation must be effectively communicated to the potential consumers with the economic benefits of reuse over potable water. When reclamation is considered for environmental reasons, such as to reduce or eliminate surface water discharge, then the selected reuse alternative must also be competitive with other disposal options. Above all, the public must be aware of and understand all of the benefits.

Figure 3.8 provides a flow chart of a public participation program for water reuse system planning.

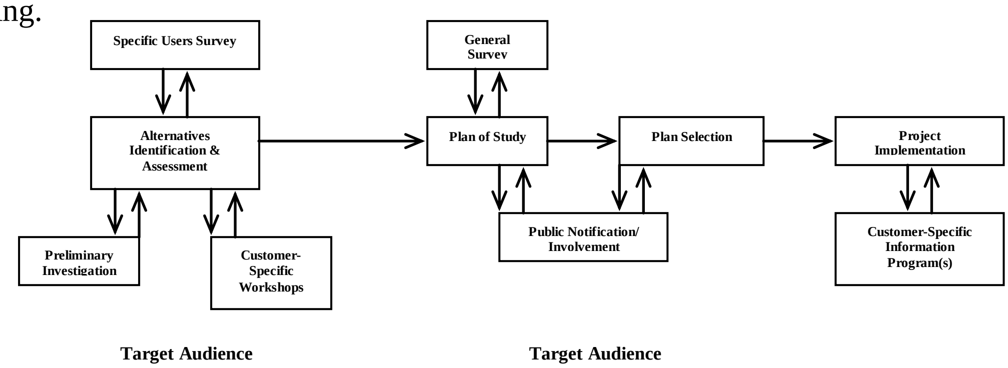


Figure 3.8: Public Participation Program for Water Reuse System Planning (USEPA, 2004)

Public confidence can further be built on institutional capacity to provide safe recycled water that will not compromise public health and safety. This is usually achieved through well developed regulatory framework. There are many reuse guidelines that specify the minimum and maximum allowable concentration of the listed parameters in literature. Of interest are:

i. The World Health Organization (WHO, 1989) recommended microbiological guidelines for wastewater use in agriculture, restricted to specific application
ii. The suggested guidelines of the U.S. Environmental Protection Agency for different water reuse applications (USEPA, 2004)
iii. The legislation of the Title 22 of the California Code of Regulations (1978).

Different countries have developed different regulatory frameworks for wastewater treatment and disposal. The major factor in choosing a regulatory framework is economics, specifically the cost of treatment and monitoring and the need to protect public health and the environment. Most developed countries have established conservatively low risk guidelines based on a high technology/high-cost approach. A summary of selected guidelines for reclaimed water use in a variety of U.S. states and other countries and regions is presented in Table 3.9 (USEPA, 2004).

Table 3.9: Summary of wastewater recycling guidelines and mandatory standards in United States and other countries (USEPA, 2004)

County/ Region	Feacal Coliforms (cfu/100ml)	Total Coliforms (cfu/100ml)	Helminth eggs	BOD$_5$ (ppm)	Turb. (NTU)	TSS (ppm)	DO (% of sat)	pH	Chlorine residual (ppm)
Australia	<1	<2/50	-	>20	<2	-	-	-	-
Arizona	<1	-	-	-	1	-	-	4.5-9	-
California	-	2.2	-	-	2	-	-	-	-
Cyprus	50	-	-	10	-	10	-	-	-
France	<1000	-	<1	-	-	-	-	-	-
Florida	25of any sample for 75 %	-	-	20	-	5	-	-	1
Germany	100	500	-	20	1-2	30	80-120	6-9	-
Japan	10	10	-	10	5	-	-	6-9	-
Israel	-	2.2 (50 %) 12 (80 %)	-	15	-	15	0.5	-	0.5
Italy	-	-	-	-	-	-	-	-	-
Kuwait (Crops not eaten raw)	-	100 (1000)	-	10 (10)	-	10 (10)	-	-	1 (1)
Oman 11A (11B)	<200 (<1000)	-	-	15 (20)	-	15 (30)	-	6-9	-
South Africa	0	-	-	-	-	-	-	-	-
Spain	-	2.2	-	10	2	3	-	6.5-8.4	1
Texas	75	-	-	5	3	-	-	-	-
Tunisia	-	-	<1	30	-	30	7	6.5-8.5	-
UAE	-	<100	-	<10	-	<10	-	-	-
UK	100	500	-	-	2	-	80-120	6-9	-
US EPA	14 for any sample, 0 for 90 %	-	-	10	2	-	-	6-9	1
WHO (lawn irrigation)	200 (1000)	-	-	-	-	-	-	-	-

International guidelines generally follow two basic approaches, i.e. guidelines for *no potential risk* (NR) and *attributable risk* (AR) based on the circumstances in the particular area or population. These guidelines would include specification of crops to be irrigated, treatment requirements, effluent quality standards as well as epidemiology status of user

population. In developed countries, guidelines tend to follow a conservative high technology/high cost/low risk (NR) approach, especially towards health sensitive crops, while in developing countries, guidelines follow a more practical and affordable approach of controlling infection risk with low cost control measures such as irrigation techniques, consumer exposure control and health and hygiene awareness education – measure which are within the economic means of the particular country or community (Ilemobade *et al.*, 2009).
In South Africa, there are some guidelines on water reuse, specifically The South African guide for the permissible utilisation and disposal of treated effluent (DNHPD, 1978) and The South African water quality guidelines (DWAF, 1996). The DWAF (1996) guidelines recommend the different water quality parameters required for various industrial, agricultural (irrigation, livestock watering, aquaculture) and aquatic eco-system applications irrespective of the water source, while the DNHPD (1978) guideline, is specific to the permissible use and disposal of treated effluent.

The DNHPD (1978) guideline is very similar to the US-EPA/USAID guidelines which classify water for health related recycling according to conventional treatment system methods. Since different approaches used in developing guidelines in different countries is aimed at protecting human health and the environment from both microbiological and chemical risks, it is necessary that guidelines for water reuse in South Africa should incorporate these criteria to be effective. South African guideline should have specification for all reuse purposes, treatment requirements and effluent standards that will protect human health and the environment. The USEPA (2004) guideline provides a strict format of application and in many respect can be considered to be high technology, NR approaches towards achieving low risk. In order not to compromise immune system of reclaimed water users in South Africa, USEPA guideline provide the framework upon which the DSS developed in this work was based.

3.5 Summary

Planning of wastewater reuse projects involves a multidisciplinary approach that incorporates technical, economic, environmental and social factors. The starting point of reuse planning is to group activities into preliminary investigations, screening of potential markets and detailed assessment of the selected markets. Each stage of the planning builds on previous stages until enough information is available to embark on reuse plan and to begin negotiating the details of reuse with selected users. Technically, water reclamation facilities must provide the required treatment to meet appropriate water quality standards specified in various countries' regulatory frameworks for the intended use. Reclaimed water quality is a function of specific use (urban, industrial, agricultural etc.) and the treatment methods adopted. Most developed countries have established conservatively low risk guidelines often resulting in high technology/high-cost approaches. In reclaimed water facilities assessment, close monitoring of all elements involved in operating a water reclamation system is imperative so that public health and safety will not be compromised. These elements include power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. The critical units in water reclamation system include the disinfection unit, power supply and various treatment unit processes.

During a feasibility study, a comparison is made between the costs and benefits of freshwater versus reclaimed water while the detailed assessment will also look in more detail at the environmental and social (including public perceptions and institutional capacity) aspects of reuse. A project is identified as superior if those who gain from the project can compensate those who lose from it so that none will be worse off with the project. This chapter presented a detailed literature survey of technical, economic and social considerations in the planning of water reclamation projects.

CHAPTER 4

TECHNICAL, ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF REUSE

4.1 Introduction

The Department of Water Affairs and Environment (DWAF, 2004) has set a number of objectives against which strategies of water institutions or consumers (to influence water demand and use) should be measured. These are economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability (Ilemobade, *et al*., 2009). These objectives form the foundation upon which the framework of the developed DSS of this research work is built. This chapter therefore, presents the framework adopted in the development of the DSS.

Traditional decision-making tools tend to focus on quantifiable factors (especially cost), leaving out equally important, yet mostly non-quantifiable factors that may have a significant influence on the project. The analysis of quantifiable and non-quantifiable factors will assist in casting a wider net to identify important issues that may significantly influence or impact a project. When reuse is being considered as part of water management strategy, some of the issues that require thorough investigation before a final decision is taken are:

i. potential for reuse;
ii. selection of an optimum treatment scheme for a specific reuse application; and
iii. social perceptions to determine public opinion on reuses and the available institutional capacity to support the implementation of reuse.

The above listed issues are laborious to perform without an assessment tool that will provide an overview of the task ahead. These criteria form the fulcrum upon which the decision support system of this work is developed as shown in Table 4.1.

Table 4.1: Links between the DWEA criteria and the DSS

DWEA Criteria	Decision Support System
i. Potential for reuse	**<u>Economic/Technical Assessment</u>** i. Treated effluent potential estimation
ii. Selection of optimum treatment scheme for a specific reuse application and distribution infrastructure	i. Quality of wastewater source ii. Treatment train general costing information iii. Potential uses and maximum allowable water quality parameters iv. unit process detailed information v. qualitative evaluation criteria vi. treatment unit selection vii. distribution infrastructure viii. results of evaluation
iii. Social perceptions to determine public opinion on reuses and the available institutional capacity to support the implementation of reuse	**<u>Perception Survey</u>** i. treated effluent potential users perception • download and print questionnaire • evaluate the questionnaire • view the evaluation results ii. treated effluent service providers perception • download and print questionnaire • evaluate the questionnaire • view the evaluation results

The next sections provide a framework for the assessment of the technical, environmental and economic parameters used in developing the decision support system.

A schematic flow chart of the framework is shown in Fig. 4.1. The framework provides a robust structure for assessing the feasibility of reuse and is designed to provide decision-makers with both quantitative and qualitative criteria that cut across technical, economic and environmental attributes of sustainability while the social attributes are discussed in Chapter 5. In this way, a more balanced view is created rather than one that relies on only quantifiable factors (Ilemobade *et al.*, 2009).

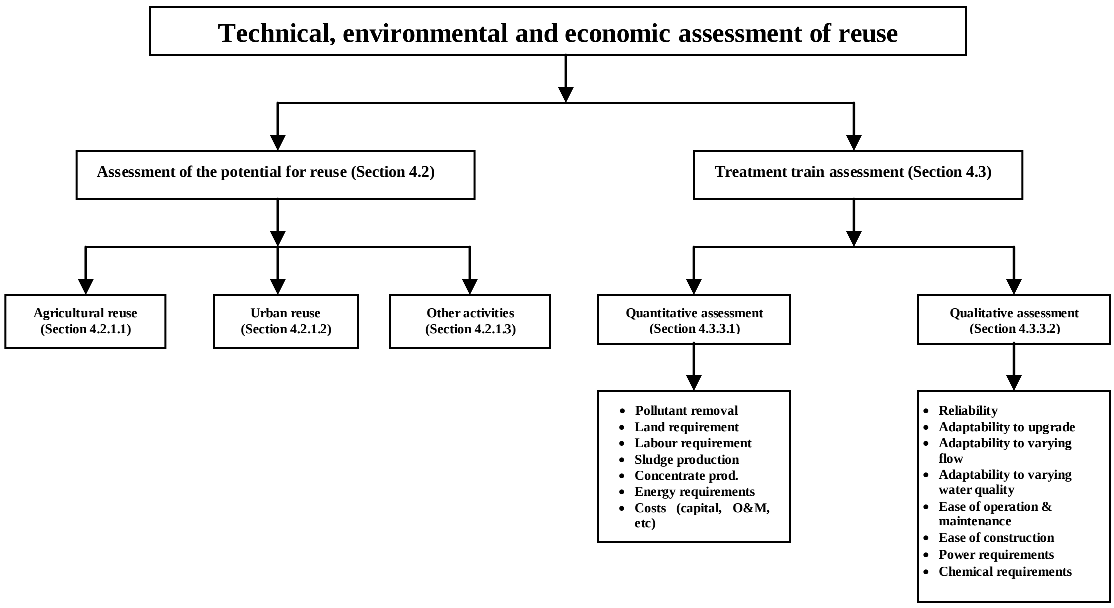


Figure 4.1: Schematic flow chart of the technical, environmental and economic assessment

4.2 Assessment of the Potential for Reuse

The amount of wastewater generated and treated will determine the potential for wastewater reuse. In principle, reclaimed wastewater can be used after appropriate treatment for potable purposes. However, in practice in most cases, the applications are restricted to non-potable uses with the exception of direct reuse in countries such as Windhoek-Namibia and Singapore.

The use of treated wastewater varies from place to place depending on water availability and the quality of treated wastewater. In general, the main uses include public and private irrigation, recreational irrigation (golf courses, playgrounds and sport fields), agricultural irrigation (restricted and unrestricted), commercial, toilet flushing, cleaning of vehicles, buildings and streets, fire protection, construction works including concreting and dust control, industrial processes, groundwater recharge, subsidence control and environmental enhancement (i.e. maintaining urban streams, wet lands, fountains and ponds) (Okun, 2002; Yang and Abbaspour, 2007). All these activities are interrelated in the sense that they obtain their needed water from the available freshwater or potable source within the catchment and dispose their wastewater into the environment after treatment to an acceptable quality. Quantitatively estimating the amount of non-potable water requirements in these sectors can be difficult where volumetric information is not readily available – mostly the case in many developing countries. Where no volumetric information is available, non-potable water demand in each sector can be estimated based on various equations which are described in the next sections. This section is aimed at explaining the systematic framework used in the computation of wastewater reuse potential of various sectors incorporated into the decision support tool (DSS) developed in this project. It is intended that this module will assist water managers in estimating the non-potable water need of each water use sector where no volumetric information exist.

Some publications on potential estimates for wastewater reuse were carried out for specific regions or countries without detailed explanation of the methods employed to achieve the estimates (Angelakis and Diamadopoulos, 1995; Tselentis and Alexopoulou, 1996; Barbagallo *et al.*, 2000 and Angelakis *et al*. 2003). A network flow optimization model was used by Zhang (2004) to develop a comprehensive urban water reuse model to determine sector water demands with the objective of minimizing overall cost of reclaimed water supply subject to technological, societal and environmental constraints. Hoschstrat *et al.* (2005) presented a model for the estimation of water reuse potential in Europe with the assumption that the reclaimed effluent from a wastewater treatment plant is equal to the amount reused to cover a particular fraction of the sector portable water. Chu *et al.* (2004) and Yang and Abbaspour (2007) simply subtract the volume of non-potable water demand from the total volume of water demand in various sectors.

4.2.1 Components of Wastewater Reuse

4.2.1.1 Agricultural Reuse

The supplier of reclaimed water must be able to quantify agricultural demands with their seasonal variation, as well as any fluctuation in the reclaimed water supply. This is to provide assurance that the demand for irrigation water can be met. Unfortunately, many agricultural users are unable to provide sufficient detail about irrigation demands for design purposes. This is because the user's seasonal or annual water use is seldom measured and recorded, even on land surfaces where water has been used for irrigation for a number of years. In some countries, expert guidance is usually available through state colleges and universities and the local soil conservation service office (USEPA, 2004).

Agriculture in South Africa is a very important activity that contributes significantly to the economic growth of the nation and plays a major role in poverty reduction in rural areas. This sector has been identified as the foremost freshwater user at 7 920 Million m^3 (62 %) out of the available 12 871 Million m^3 for the country (DWAF, 2004). The total area under irrigation for commercial and smallholder agriculture is estimated to be 1 290 132 ha with potential expansion of 283 350 ha. Several irrigation scheduling models and methods used in South Africa are available in Stevens (2007).

To assess the feasibility of reuse in the absence of actual water use data, evapotranspiration, percolation, runoff and net irrigation must be estimated, often through approximate equations. The approximate equations used to develop the DSS in this research are modified versions of the equations presented by Chu *et al.* (2004) and Yang and Abbaspour (2007) (equation 4.1).

$$D_1 = V_A - A_V E_V \qquad 4.1$$

Where, D_1 = Treated wastewater requirement for agricultural irrigation (millions m^3)

V_A = agricultural water demand (millions m^3)

A_V = edible vegetable area (million ha)

E_V = vegetable unit area irrigation requirements (m^3/ha)

This equation was modified to allow direct computation of non-potable water needs for each activity rather than simple subtract of the volume of non-potable water demand from the total volume of water demand in various sectors which can often be difficult to obtain if there are no historical water use data. The equation used in estimating demand in the agricultural sector is as follows:

$$Q_A = 0.001 A_a V_a \qquad 4.2$$

Where, Q_A = non-potable water use for agricultural irrigation (m^3)

A_a = area for the agricultural Irrigation (m^2)

V_a = crop water requirements (mm)

The data base of the developed DSS contains 78 different crops and 5 grasses with average crop water requirements computed using SAPWAT3 version 1.0 (van Herdeerden *et al.,* 2009). SAPWAT3 is an enhanced version of SAPWAT program, developed in South Africa and extensively used by irrigation planners and agriculturalists in making decisions. This program makes use of information published in FAO irrigation and drainage report No. 56 titled *Crop evapotranspiration: Guidelines for computing crop water requirements* in calculating evapotranspiration (FAO, 2002). It also includes FAO CLIMWAT weather data base that comprises 3262 weather stations from 144 countries, including South Africa, and contains long-term monthly average data for calculating Penman-Monteith ET_o values as well as rainfall. FAO CLIMWAT weather data output is available as monthly averages. However, SAPWAT3 climate weather calculations are based on daily values derived by statistically fitting a curve to the monthly ET_o (van Herdeerden *et al.*, 2009). SAPWAT3 version 1.0 is available at Water Research Commission, Pretoria. Figure 4.2(a) and 4.2(b) depict the SAPWAT3 interface determining crop irrigation requirements for long grower maize species.

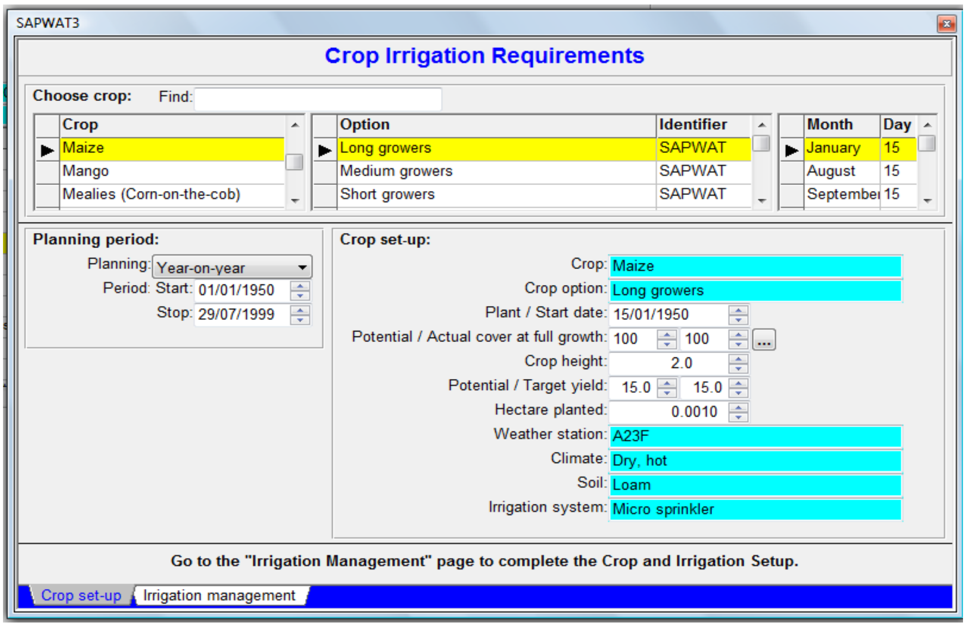


Figure 4.2 (a): Crop set-up page for estimating irrigation requirements

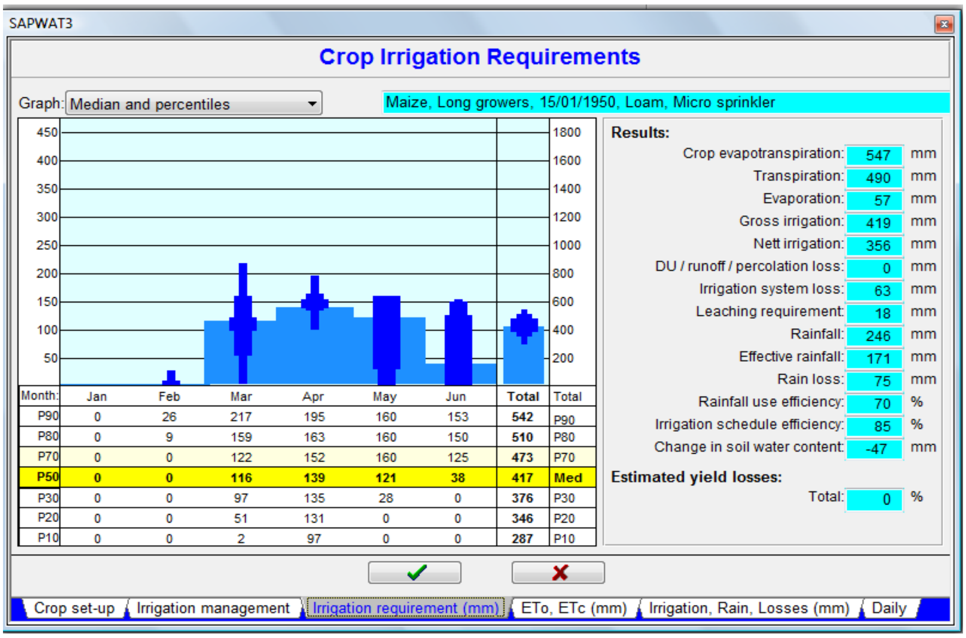


Figure 4.2 (b): Results of irrigation requirements for long grower maize

4.2.1.2 Urban Reuse

Reclaimed water demand in an urban system can be grouped into indoor and outdoor demand. The main indoor application of reclaimed water is toilet flushing and the demand for this activity is highly dependent on the population to be served and the type of sanitary appliances. Outdoor applications on the other hand involve landscape irrigation and recreational water use in ornament and water fountains.

i. Landscape Irrigation and Recreation Requirements

Landscaping has been embraced globally as a means of beautifying the environment and incorporating some of nature (by planting of green gardens and flower belts to maintain the beauty) into developed catchments. To this end a large volume of freshwater are used annually to irrigate landscapes, golf courses, playgrounds, and sports fields in both public and private establishments within South Africa. Irrigation water demand can be estimated from an inventory of the total irrigable area to be served by the reclaimed water system and the crop irrigation requirements. Irrigation requirements are determined by such factors as local soil characteristics, climatic conditions, and type of landscaping. Equation used in computing landscape irrigation is similar to equation 4.2.

ii. Domestic Requirement

Lazarova *et al.* (2003) reports that toilet flushing accounts for approximately 30 percent of in-door water usage and above 60 percent in commercial buildings. This indicates that a large volume of potable water could be saved with the use of non-potable water for toilet flushing and other water features such as self-contained recirculating water features, waterfalls and artificial streams, in ground and above ground ponds, as well as garden accessories (e.g. grindstone birdbaths, animals and figurines with water recirculation). Equation used by Chu *et al.* (2004) and Yang and Abbaspour (2007) in estimating domestic water requirements is as follows:

$$D_5 = k_1 V_d \qquad 4.3$$

Where, k_1 = proportion of toilet water use to domestic water use (%)

V_1 = domestic water demand (million m^3)

In the DSS, domestic non-potable water use is computed using the following predictive equation:

$$Q_D = \frac{365}{1000}(N_t V_t T_t P_t + W_F) \qquad 4.4$$

Where, Q_D = Domestic non-potable water use (m^3)

N_t = total number of toilets in the area

V_t = volume of toilet cistern (L)

T_t = number of toilet flushes per person per day

P_t = total number of people using one toilet

W_F = volume of water required in other water features (L).

iii. Mining and Industry

Industrial reuse represents a significant potential market for reclaimed water in South Africa especially in urban and industrialized areas like Cape Town, Port Elizabeth, East London, Pietermaritzburg, Bloemfontein, Pietersburg, Durban, Pretoria and Johannesburg. Although industrial uses accounted for only about 6 percent of the total water use in South Africa in

2004, it is as high as 23 percent of total water demand in the middle Vaal water management area (DWAF, 2004).

Equation used by Chu *et al.* (2004) and Yang and Abbaspour (2007) in estimating industry water demand is as follows:

$$D_2 = \mathrm{C_e E_e K_e} \qquad 4.5$$

In the DSS, the equation used is as follows:

$$Q_1 = \mathrm{C_e E_e K_e N_e} \qquad 4.6$$

Where, $Q_I = D_2$ = industrial non-potable water use (m^3)

C_e = the generating capacity of power plants (kWh)

E_e = the water consumption of unit generating capacity of thermal power plants (m^3/kWh)

K_e = the ratio of circulating cooling water to total water withdrawal of thermal power plants.

N_e = number of thermal plants.

4.2.1.3 Other Activities

Developing an accurate mathematical model that could be used to predict the volume of water required in other non-potable water uses such as construction works, street flushing, fire protection, groundwater recharge, etc can be problematic. However, an approximate value can be obtained using historical records of water consumption for these activities.

$$Q_o = \sum_{i=1}^{n} Q_i \qquad 4.7$$

The overall objective function of wastewater estimation is therefore to sum each of the user estimates applicable to a particular case:

$$Q_{TNP} = \sum Q_A + Q_I + Q_R + Q_D + Q_O \qquad 4.8$$

Subject to:

$$Q_{TNP} \leq \sum_{h=1}^{n} WWTP_h \qquad 4.9$$

Where Q_{TNP} = the total non-potable water demand in an area

$WWTP_h$ = the amount of treated effluent in all available wastewater treatment works

4.3 Treatment Train Assessment

The number of treatment processes used to treat wastewater has steadily grown over the years. This is particularly true for advanced treatment technologies, thus making the selection of the most suitable sequence of processes (treatment train) for any reuse application more complex (Joksimovic, 2006). Hence, one major challenge faced by decision makers in water reuse planning is the selection of an optimum treatment scheme from the numerous options that exist as well as handling the multiple objectives that treatment systems must satisfy.

4.3.1 Information on Treatment Train Processes

As the first step in treatment train assessment, all realistic unit processes used in wastewater treatment in the South African context are classified according to their position in the treatment train with special attention to their efficiency in pollutants removal to meet the water quality requirements for various reuse applications. A clear distinction is made between primary, secondary and advanced treatment processes, which include both conventional and innovative options as shown in Table 4.2

Table 4.2: Unit process operations included in the model

Treatment Stage	Unit Processes
Preliminary	Bar screen Coarse Screen Grit Chamber
Primary	Stabilization pond: Anaerobic Equalization Basin Sedimentation w/o coagulant Sedimentation w coagulant
Secondary	Stabilization pond: Aerobic Stabilization pond: Facultative Activated sludge Trickling filter Rotary biological contractors

Treatment Stage	Unit Processes
	Membrane bioreactor Secondary sedimentation
Advance	Biological phosphorous removal P – precipitation Chemical precipitation Denitrification Constructed wetland Maturation pond Dual media filter Micro filtration Ultra filtration Nano filtration Reverse osmosis Soil aquifer treatment Activated carbon Ion exchange Advance oxidation process Electrodialysis
Disinfection	Chlorine gas Chlorine dioxide Ozone UV radiation

Preliminary treatment removes coarse solids and floatable objects from wastewater. In conventional treatment, this process increases the efficiencies of downstream treatment processes. This treatment stage does not remove any significant pollutants found in wastewater.

Four unit processes are included in the knowledge base of the DSS under primary treatment. The 4 processes partially remove suspended solids and organic matter from wastewater through the process of sedimentation. The simplest process in this category uses the gravity method to remove pollutants.

Secondary treatment receives partially treated wastewater from primary treatment units. It utilizes a combination of physical, chemical and biological processes to treat wastewater. Under this category, seven unit processes are included. In South Africa, the most commonly used process for secondary treatment is the activated sludge process. The rotating biological contactor is included as an efficient fixed film wastewater treatment technology that is used extensively in municipal and industrial wastewater treatment. Some natural treatment technologies that often require extensive land are also included.

The list of unit processes included as advanced treatment starts with processes that are used to remove nutrients (phosphorus and nitrogen) which in some cases could be regarded as part of secondary treatment but are seldom provided in conventional municipal wastewater treatment plants. This is followed by processes that could be used to polish treated effluent from stabilization ponds. Next is a series of membrane filtration technologies (designed for the removal of micro-pollutants) whose application in water reuse has increased tremendously in recent years due in part to significant reduction in their cost. Maturation ponds used primarily for the removal of pathogens and nutrients through algal activity and photo-oxidation, and constructed wetlands used as a polishing step, are also included as a technology that offers removal of nutrients at low cost and maintenance. Activated Carbons are used to remove negative ions (e.g. ozone, chlorine, fluorides and dissolved organic solutes) from water by absorption, while the ion exchange and electrodialysis are used for reduction of hardness or removal of nitrogen, heavy metals and total dissolved solids. Advanced oxidation technologies were also included. These technologies are used to oxidize complex organic constituents into simpler end products. Finally, the soil aquifer treatment unit included in the database is a sub-surface process which uses the soil matrix to remove a wide range of organic and inorganic constituents.

The final stage included in the treatment processes are disinfection units. Ozone is a disinfecting agent that has been used for perhaps the longest time to address the microbial pollutants in water in addition to chlorine dioxide and chlorine gas. These three methods of disinfection are included in the knowledge base with Ultraviolet disinfection which has advantages over other methods since it does not involve addition of any chemicals.

4.3.2 Synthesis of Wastewater Treatment Trains

The concept of a wastewater treatment train was first introduced by Rossman (1979) in the development of the EXEC/OP model that is aimed at generating a set of design alternatives for municipal wastewater treatment (Joksimovic, 2006). This synthesis is defined as the specification of a system (the choice and arrangement of unit processes and operations) and the design of individual units within that system so that design objectives are fulfilled. In 1989, Rossman also developed a hybrid approach to generate alternatives which include a structured knowledge base containing the following information (Joksimovic, 2006):

i. List of unit processes and information for estimating their performance;

ii. Rules for excluding a unit process based on acceptable configurations and area limitations;
iii. Unit process pre-treatment requirements; and
iv. Procedures for estimating real and pseudo-costs.

Several authors have employed different techniques to synthesis wastewater treatment trains. Some of the techniques include *Bounded implicit enumeration* (e.g. Chang and Liaw, 1985; Liaw and Chang, 1987; Gasso *et al.*, 1992), which is used in the preliminary design of wastewater treatment systems to obtain a least cost design. The technique involves a systematic selection of different treatment unit processes to form treatment trains with minimum cost. *Expert systems* have been used for the selection of optimal schemes in the treatment, disposal and reuse of wastewater (Wee and Krovvidy, 1990; Krovvidy, *et al.*, 1994; Chen and Beck, 1997; Ahmed *et al.*, 2002; Economopoulou and Economopoulos, 2003; Dinesh and Dandy, 2003; Joksimovic *et al.*, 2006; Joksimovic, *et al.*, 2008). An expert system is a computer program that simulates the judgement and behaviour of a human being that has expert knowledge and experience in a particular field. The expert system incorporates a knowledge base containing accumulated experience, an inference engine (thinking machine) which solves the problem and a set of rules used by inference engine when applying the knowledge base to each particular situation that is described to the program.

Analytical Hierarchy Process (AHP) was employed by Addou *et al*. (2004) as well as Bick and Oron (2004) to select wastewater treatment technologies. This technique provided a comprehensive and rational framework for structuring a decision problem to overall goals and for evaluating alternative solutions It first decomposes the problem into a hierarchy of grouped sub-problems that can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time. The AHP converts these assessments into numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way.

Hidalgo *et al.* (2007) used *multi criteria analysis* to develop a decision support system to promote safe urban wastewater reuse. The analysis assigned weights to various indicators like treatment technology, costing factor, land availability, type of soil, type of crops cultivated and their water requirements, meteorological conditions and legislative requirements to score the safe reuse of wastewater effluent. Ellis and Tang (1990) and Tang and Ellis (1994) also used multi criteria analysis (20 criteria) that cut across technical, economic, environmental and socio-cultural factors to form a decision matrix to rank 46 wastewater treatment processes.

Of particular interest are the models developed using expert systems. Most of them are rule-based models that use fuzzy logic based approaches to capture the user's preference for treatment techniques, defined on the basis of the treatment efficiency and the cost of a technique. Rules are represented with if-then constructs, such as *IF compound = X and influent concentration is between A and B AND technology = Y THEN effluent concentration is between C and D* (Joksimovic, 2006). This technique was adopted in the development of all the decision supports for wastewater reuse indicated in Table 4.3.

Table 4.3: Decision support systems for wastewater reuse using expert systems

Name of Decision Support System	Acronym	Reference(s)
Sequence Optimizer for Wastewater Treatment	Sowat	Krovvidy, *et al.*, 1994
Water and Wastewater Treatment Technologies Appropriate for Reuse	WAWTTAR	Finney and Gearheart, 1998
Model for Optimum Selection of Technologies for Wastewater Treatment and Reuse	MOSTWATER	Dinesh and Dandy, 2003
Water Treatment for Reuse with Network Distribution	WTRNet	Joksimovic *et al.*, 2006 AQUAREC, 2006 Joksimovic, 2006 Joksimovic, *et al.*, 2008

Sowat DSS bases its assessment strictly on technical functionality and economic factors while WAWTTAR, MOSTWATER and WTRNet include both quantitative and qualitative assessments of technical, economic, and environmental factors of each unit treatment processes. Other important factors were considered in Ellis and Tang (1990) and Tang and Ellis (1994) but they have proven too ambiguous to use in other locations because of their non-flexibility. However, some important factors like water stress indicators, social perceptions and institutional framework which are crucial in reclaimed water reuse planning are not included in these models. The DSS developed in this research work uses multi-criteria factors in assessing the feasibility of implementing a reclaimed water project in South Africa.

4.3.3 Treatment Train Assessment Criteria

Treatment train assessment criteria used in this research work were adapted from MOSTWATER (Dinesh and Dandy, 2003) and WTRNet (Joksimovic, 2006) where the assessment criteria for each unit process making the treatment trains is classified into technical, environmental and economic types. The technical criteria considered are performance, reliability, adaptability to upgrade, varying flow rate, change in water quality, ease of O&M and construction. The environmental criteria considered are power and chemical requirements, odour generation, impact on groundwater, land area requirements and sludge production, while economic criteria relates to the project life cycle costs (i.e. capital, operating and maintenance, replacement, labour, energy, etc). Of these criteria, the calculated are pollutant removal, costs, land area requirements and energy requirements, while the other criteria/items are considered as qualitative. Table 4.4 present a summary of the above.

Table 4.4: List of treatment train and unit process assessment criteria

Type of Criteria	Sub-Criteria
Quantitative Technical and Economic	Pollutant removal efficiencies Land and labour requirements Sludge production Concentrates production Costs (capital, O&M, replacement, etc)
Qualitative Technical	Reliability Adaptability to upgrade Adaptability to varying flow rate Adaptability to varying water quality Ease of Operation and Maintenance Ease of construction
Qualitative Environmental	Chemical and power Requirement Odour generation Impact on groundwater

4.3.3.1 Treatment Train Quantitative Criteria

i. Pollutant Removal Efficiencies

The ability of treatment process units to meet the quality requirement of reclaimed water is a major factor of consideration in treatment train selection. The parameters used in assessing reclaimed water vary from country to country and region to region depending on the guideline in use.

The number of contaminants considered in wastewater reclamation and reuse worldwide is indeed growing, with continually emerging new contaminants of concern in various water sources. Although the bulk of the materials reviewed dealt with conventional wastewater treatment, some explicitly considered reuse.

The most common approach used by earlier researchers in specifying the capacity of a unit process to remove pollutants from wastewater has been to express it in terms of percentage removal. This simplification adopted by earlier researchers was deemed appropriate for screening of treatment trains in feasibility study and was also adopted in this research work and expressed as follows:

$$C_{eff} = C_{inf}(1 - R_i)$$
$$R_i \in \{R_{min}, R_{ave}, R_{max}\} \qquad 4.10$$

Where C_{eff} = effluent concentration

C_{inf} = influent concentration

R_i = removal efficiency

ii. Costs

The costs associated with wastewater treatment trains are capital and operation and maintenance (O&M) costs. The capital costs involved in constructing wastewater treatment facilities cover the costs of building and installing unit process equipment, land costs, and also ancillary costs associated with the provision of standby units, emergency power, instrumentation and alarms, process piping, site development, administration buildings, etc. On the other hand, O&M costs include staff salaries, and expenses related to power consumption, chemicals consumption and repair and maintenance of equipment. The lifecycle cost, computed by combining amortized capital costs with annual O&M costs is used as an estimate of the overall costs of treatment alternatives.

The methodologies for cost estimation of wastewater treatment processes are numerous, but not easily comparable or globally appropriate due to the assumptions used in their development, which are also not always specified. In this research, the cost information for unit processes was obtained from literature (Joksimovic, 2006; Ahmed *et al*, 2002; ESCWA, 2003). Equations for estimating both the capital and O&M costs of various components in treatment trains developed are in the given forms of expression in equation 4.11 - 4.16. (Details are available in Appendix A)

$$CC = C_1 Q^{C_2} \qquad 4.11$$

$$Q \in \{Q_{ave}, Q_{pday}, Q_{dwf}\}$$

$$CC = C_1 A \qquad 4.12$$

$$CC = C_1 V_{anu} \qquad 4.13$$

$$OMC = C_1 V_{anu} \qquad 4.14$$

$$OMC = C_1 CC \qquad 4.15$$

$$OMC = C_1 A \qquad 4.16$$

Where C_1, C_2 = capital cost coefficient, C_2 ranges from 0.6 – 0.8

CC = unit process capital cost

OMC = unit process operation and maintenance cost

V_{anu} = annually processed volume

A = unit process area

Q_{ave} = average flow

Q_{pday} = peak daily flow

Q_{dwf} = dry weather flow

Individual unit process costs of O&M, sludge and concentrate production, treatment and disposal, labour and energy consumption are added to determine their respective total cost of treatment train. General costs associated with construction work of treatment plant are as Table 4.5.

Table 4.5: Common treatment facility costs (Joksimovic, 2006).

Cost Description	Amount
Piping	8 %
Controls and instrumentation	8 %
Site electrical	9 %
Site development	8 %
Site works	6 %
Engineering	12%
Contingency	15%

iii. Land Requirements

It is well known in practice that different unit processes utilize different mechanisms to remove different pollutants and at the same time occupy different land spaces. For instance, fast treatment unit processes like activated sludge, trickling filters, rotating biological contactors, etc require less space compared to the rate biological treatment processes like aerobic, anaerobic and other stabilization ponds.

Depending on the type of treatment unit process and their mode of operation, three different expressions are included in the knowledge base for the calculation of land requirements for unit processes, as shown in equation 4.17 to 4.19. Land costs are calculated separately for each unit process and subsequently added to the total cost of treatment train using a fixed cost/m^2 of land acquisition specified by the user.

$$LaR = C_1 Q_i^2 + C_2 Q_i + C_3 \qquad 4.17$$

$$Q \in \{Q_{ave}, Q_{pday}, Q_{dwf}\}$$

$$LaR = \frac{Q_i}{SOR} \qquad 4.18$$

$$LaR = C_1 Q_i^{C_2} \qquad 4.19$$

Where LaR = process land requirement

SOR = surface overflow rate

In order to account for the land occupied by site facilities such as roads, fencing and administrative buildings, an additional 15 percent of the total area required for unit processes is added to the land requirements and the new expression becomes.

$$LaR_{TT} = 1.15 \sum_{i=1}^{N} LaR_i \qquad 4.20$$

Where LaR_{TT} = Treatment train land requirement

N = No. of unit processes in the treatment train

LaR_i = land requirement for unit processes i

iv. Labour Requirements

Labour requirements in operating wastewater treatment facilities vary with technology and the level of automation. High skilled labour is required to operate and maintain advanced automated wastewater treatment facilities than manually operated systems. A difficulty in estimating labour requirements for individual unit processes arises from the fact that operating staff hours are typically distributed to activities dealing with several processes, as well as administration, which makes the development of expressions for individual unit processes more difficult. The default values used in this work are based on literature values of existing wastewater treatment works.

v. Sludge and Concentrate Production

Sludge and concentrate production in wastewater treatment varies with technology and unit processes. Sludge is the solid content of wastewater often removed at the secondary treatment stage. It can be treated, disposed or reused in many ways. Concentrate is the byproduct of wastewater treatment by membrane processes. Concentrate can be disposed of in a number of ways including blending with other wastewater flows in smaller facilities. For larger facilities, ocean discharge is the most commonly used and least costly option, which is not available for inland facilities that require more expensive and environmentally sensitive options such as transmission through long pipelines, evaporation, deep well disposal or spray irrigation. The choice of ultimate sludge and concentrate disposal is driven to a large extent by local conditions and regulations, and could potentially have significant implications in treatment train selection.

Depending on the unit process under consideration, equations used in calculating sludge and concentrate are:

$$SlP = C_1 BOD_{rem} \tag{4.21}$$

$$SlP = C_1 SS_{rem} \tag{4.22}$$

$$SlP = C_1 P_{rem} \tag{4.23}$$

$$CnC = C_1 V_{anu} \tag{4.24}$$

Where *SlP* = sludge production

CnC = concentrate production

BOD_{rem} = biochemical oxygen demand removed

SS_{rem} = suspended solids removed

P_{rem} = phosphorous removed

V_{anu} = annually processed volume

C_1 = sludge or concentrate production coefficient

vi. Energy Consumption

All the fast rate wastewater treatment processes are powered by electrical energy. The energy consumption varies depending on the electrical equipment used. The expression used in computing energy consumption of the unit processes is given as follows:

$$EnC = C_1 V_{anu} \tag{4.25}$$

vii. Life Cycle Costs

The lifecycle cost of treatment trains is then calculated by adding initial and discounted recurrent costs, future replacement cost of civil and electromechanical works (EM), sludge and concentrate disposal costs and O&M costs over the life of the project (equations 4.27). The annualized treatment cost (AC_{TT}) is calculated by multiplying the lifecycle cost of treatment train with The Capital Recovery Factor (*CRF*) which is based on the discount rate (*r*) and the planning period (*n*). The unit cost of treatment (UC_{TT}) is computed using Equation 4.28.

$$LC_{TT} = CC_{TT} + \sum_{i=1}^{N} \frac{(RC_i}{(1+r)^n} + \frac{OMC_{TT} + SIC_{TT} + ConC_{TT}}{\frac{r}{1-(1+r)^n}} \tag{4.26}$$

$$AC_{TT} = \frac{r}{1-(1+r)^n} \times LC_{TT} \tag{4.27}$$

$$UC_{TT} = \frac{AC_{TT}}{V_{anu}} \tag{4.28}$$

Where

LC_{TT} = treatment train lifecycle cost

CC_{TT} = treatment train capital cost

$PW\,(RC_i^n)$ = present (discounted) cost of replacing a component of unit process in a year

UC_{TT} = treatment train unit cost

OMC_{TT} = treatment train O&M cost

AC_{TT} = treatment train annualized cost

SiC_{TT} = annual cost of sludge treatment and disposal

$ConC_{TT}$ = annual cost of concentrates treatment

The details of the cost functions used for each unit process are provided in Appendix A.

4.3.3.2 Treatment Unit Qualitative Criteria

i. Reliability

Metcalf and Eddy (2004) define wastewater treatment plant reliability as the percent of time that the effluent concentration meets specified permit requirements. This factor is of paramount importance in wastewater reuse because inadequate treatment can have serious health implications. On existing wastewater treatment works, statistics can be used to assess the reliability of different unit processes based on performance data. However, during planning, this information is not available and qualitative indicators are quite commonly used. This approach is used in this work.

ii. Adaptability to upgrade

Due to urban, industrial and population growth, infrastructure planning is often done in phases. In potable water systems, the quality of water supply to the consumers is constant. However, in reclaimed water systems this may change in both quality and quantity with time as new customers are added. Treatment trains used in water reclamation may have to be modified by adding additional treatment steps or by combining existing with other technologies to match the developmental changes experienced. For some packaged unit processes, this may be relatively easy, but processes that need large tanks and accordingly sized equipment to operate may require extensive investment to meet future demand. Adaptability to upgrade is used in this work to reflect the ease with which treatment trains could be upgraded or combined with other processes.

iii. Adaptability to varying flow rate and quality

The adaptability to varying flow rate and quality of the inflow refers to the resilience of the treatment system to the changes in operating conditions. Although all unit processes are designed for certain influent conditions, some are more adaptable to changing conditions in terms of flow and quality of inflow. This is the case even with preliminary treatment processes where, for example, a grit chamber might not cope with changes in operating conditions as well as a bar screen, due to its limited storage capacity and detention time. These factors are accounted for by using separate qualitative marks assigned to each unit process in the assessment of treatment trains.

iv. Ease of operation and maintenance

The difference in efforts required to operate and maintain different treatment processes can be quite large. Natural treatment processes such as lagoons, for example, require only periodic maintenance while biological treatment and membrane processes require extensive monitoring and control. The ease with which each unit process can be operated is reflected in qualitative marks assigned to them.

v. Ease of construction

Construction of treatment processes can require specialized knowledge and skills as well as certain type of site conditions. On the other hand, packaged treatment processes are typically constructed off-site and put in place with no extensive construction activities. This criterion is used in this work for each unit process.

vi. Chemical requirements

Certain treatment processes require the addition of coagulant and other chemicals to achieve high levels of contaminant removal. Other processes that use filtration as the primary pollutant removal mechanism require periodic cleaning with chemicals, while chemicals are used as the primary pollutant removal in processes such as chlorination. On the other end of the spectrum, mechanical and natural treatment processes require very little chemicals in their operation. The level of use of chemicals for treatment in different processes is indicated with a qualitative mark.

vii. Odour generation

Different processes that may achieve the same pollutant removal efficiencies can emit different levels of air pollution. Although odour control equipment can be used to virtually eliminate this concern, it requires additional costs and operational complexity, which is not required if certain processes are used. To reflect these differences between processes on odour generation, a qualitative mark is used.

viii. Impact on groundwater

Although the potential for groundwater pollution is very low for the majority of municipal wastewater treatment processes, some processes such as Soil Aquifer Treatment (SAT) have the potential to seriously degrade groundwater. To account of this, a qualitative mark is assigned to each unit process.

The treatment train score for each qualitative criterion described above is computed using the weighted average technique, which necessitates that each unit process be given individual scores on all criteria considered. Quantitative items (***Nil, Low, Medium or High)*** which respectively represent scores (0, 1, 2 and 3) are used.

The classification of the qualitative assessment criteria shown in Table 4.3 is divided into technical and environmental. In the analysis, technical criteria are positive while environmental criteria are negative. For instance, in positive (technical) criteria, a score of HIGH indicates that the unit process is, for example, highly reliable based on operating experience or adaptable to varying conditions. On the other hand, a score of HIGH assigned to negative (environmental) criteria indicates that a unit process, for example, consumes large quantity of chemicals, generates a lot of odours, or has a high potential for groundwater pollution.

The process of determining the qualitative treatment criteria scores is as follows:

i. Calculate the average criteria score (equation 4.29)
ii. Normalise the score according to the criteria type i.e. positive (technical) and negative (environmental) (equations 4.30 and 4.31)
iii. Calculate the overall treatment train score (equation 5.32)

$$AEC_i^{TT} = \frac{\sum_{j=1}^{N} EC_{ij}^{up}}{N} \qquad 4.29$$

$$EC_i^{TT} = \frac{1}{3} AEC_i^{TT} \qquad 4.30$$

$$NEC_i^{TT} = 1 - \frac{1}{3} AEC_i^{TT} \qquad 4.31$$

$$QS_i^{TT} = \frac{\sum_{i=1}^{M} W_i . NEC_i^{TT}}{\sum W_i} \qquad 4.32$$

Where

AEC_i^{TT} = Treatment train average score for criteria i

EC_{ij}^{up} = Unit process j score for criteria i

NEC_i^{TT} = Normalized treatment train score for criteria i

QS_{TT} = Overall treatment train qualitative criteria score

N = Number of unit processes in the treatment train

W_i = Weight of criteria (user assigned)

M = Number of qualitative assessment criteria

Detail information on treatment train assessment are shown in Appendix A and B.

4.3.3.3 Classification of Treated Effluent End Users

The end users category contained in the knowledge base of the decision support system is shown in Table 4.6 Information stored as default in the knowledge base specifies the maximum contaminant concentrations for each end user type. The pollutants considered in this research are Turbidity (Turb), Total Suspended Solids (TSS), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Faecal Coliforms (FC) and Total Coliforms (TC). Considerations were not given to heavy metals concentration because of the stringent Department of Water Affairs and Forestry (DWAF) regulations on the disposal of complex industrial wastewater into urban sewage systems. It is mandatory under law (DWAF, 1998) that all wastewater emanating from industries with toxic chemicals be treated on-site to specified pollutant limits before discharge to municipal sewers. Compliance with this law is enforced through regular monitoring and sanction.

Table 4.6: Classification of reclaimed water end users

Reuse Type	Description of Reuse
Domestic	Toilet flushing, garden/ lawn irrigation, home air conditioning systems, car washing and cleaning
Landscape and Recreational Irrigation (Urban)	Open access landscape areas like school fields, parks, golf courses, sport fields, etc
Industrial	Industrial cooling, boiler feed and process water except for food industries
Construction	Blocks and concrete making and laying, dust suppression, composting site, etc.
Agricultural Irrigation (unrestricted)	Irrigation of raw consumed food crops, fruit trees sprinkler irrigation, greenhouse crop irrigation, etc.
Agricultural Irrigation (restricted)	Irrigation of pasture for milking or meat animals, fodder, cereals, fibres, seed crops and other areas where public access is prohibited.

Since South African guidelines for wastewater reuse promote the concept of "No potential risk" without specifying the maximum allowable concentration of pollutants, the stringent conditions suggested in USEPA (2004) guidelines are used to develop the maximum contaminant concentrations for each end use as shown in Table 4.7.

Table 4.7: Potential uses and maximum allowable water quality parameters

End Uses	Maximum Allowable Pollutant Concentration							
	Turb	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Domestic	1	5	5	10	5	0.2	0	0
Irrigation	5	10	10	30	10	2	0	0
Industrial	5	10	20	10	5	0.2	200	1000
Other Activities	10	10	20	70	10	0.2	200	1000

4.3.3.4 Methodology for Generating Treatment Trains

The combination of unit processes shown in Table 4.2 to form a treatment train is not a very simple design process. This means that a selection has to be made among various treatment unit processes to form standard treatment trains for reuse purposes.

Rules taken into consideration when developing a knowledge base for assembling treatment trains are (Joksimovic, 2006; Kubik and Hlavinek, 2005):

i. rules that dictate possible starting points (unit processes) depending on the influent water quality,

ii. rules that prohibit the formation of unacceptable process configurations that violate sound engineering practice, and
iii. rules to check if the required pre-treatment or the maximum allowable quality requirement for unit processes are met.

A typical example of the first rule is that *'if raw wastewater is used as the source, it has to receive preliminary treatment prior to application of any additional treatment, unless lagoon systems are used'*. The second type of rule could be that *'Membrane bioreactor can only be used for effluents from one of the primary treatment processes, excluding anaerobic ponds'*. In the third type rule, *'the quality of treated effluent should meet the quality requirements for reuse activity'*.

The general structure of the rules can be summarized with the following expression: ***IF (unit process A / unit process (es) from category X) IS (present / absent) THEN (unit process (es) B / unit process (es) from category Y) (can / must / cannot) be present.***

The first sets of treatment train rules, dealing with possible starting unit processes, are addressed simply by specifying the quality of wastewater to be treated to meet any reuse purpose as the starting point.

4.4 Treated Wastewater Reticulation Infrastructure

Since the design of treated wastewater distribution system is similar to potable water distribution system, any available software (e.g. Water Cad, EPANet etc.) could be used to optimally size the distribution system element based on the predetermined branched layout and demand at each node. The following information obtained from this analysis serve as an input to the DSS:

i. size of the pipe;
ii. length of the pipe and
iii. size of the pump.

4.5 Summary

This chapter explain the framework used in developing the technical, economic and environmental assessment module of the DSS. It explains the major components of the DSS and the governing parameters of assessment that based on the multi-criteria approach method. The framework provides a robust structure for evaluating reuse feasibility and is designed to provide decision-makers with a valuable tool that uses both quantitative and qualitative criteria that cut across technical, economic and environmental attributes of sustainability. The social aspect of the DSS is explained in Chapter 5.

CHAPTER 5
SOCIAL AND INSTITUTIONAL ASSESSMENT OF WASTEWATER REUSE

5.1 Introduction

The success of any reuse project largely depends on public perception. Positive community perceptions towards recycled water use have been identified as a key component of water reuse project success. Some proposed reuse schemes in America failed in the absence of community acceptance (Okun, 2002; Po *et al.,* 2004). It is widely recognised that the following factors highly influence public perceptions regarding the use of recycled water: perceived health risk, political issues, and the degree of human contact with recycled water (Kantanoleon *et al.,* 2007; Hurlimann & McKay 2007; Friedler *et al.,* 2006; Robinson *et al.,* 2005; Po *et al.,* 2004; Hartley, 2003 and Marks *et al.,* 2003). Despite the fact that few perception surveys on water reuse are found in the literature, the large majority were conducted in the USA, Australia, Western Europe and the Middle East. For the purpose of developing strategy and policy, perception studies are required in each national and sometimes sub-national context because of large variations in culture, climate, water availability, economy, etc. (Friedler *et al.,* 2006). Such variability makes the transferability of specific findings and conclusions from one country to another somewhat problematic.

The results of some public perception in the surveys on various uses of reclaimed water are summarized in Table 5.1. Public acceptance of irrigation of non-edible crops (90–99%) and toilet flushing (77–97%) is generally high. As expected, the majority of respondents are strongly opposed to drinking reclaimed water (direct potable reuse). The outcome of most of the surveys could be subjected to wide interpretation but may be useful in assessing public attitude for the purposes of developing information programs and promoting better understanding of issues regarding water reuse.

Direct contact with reclaimed water, as opposed to ingestion, is more broadly accepted. About 15 to 25 percent of those surveyed in Table 5.1 were opposed to swimming in reclaimed water and 7 to 21 percent were opposed to irrigating vegetables, pasture and vines with reclaimed water. There is minimal objection to the use of reclaimed water for the irrigation of golf courses and landscapes, industrial processes and cooling/air conditioning.

Table 5.1: Percentage of respondents opposed to various uses of reclaimed water in a general survey (Radcliffe, 2004)

	ARCWIS (2002)+ N=665 %	**Lohman, Milliken (1985)* N=403 %**	**Milliken, Lohman (1983)* N= 399 %**	**Bruvold (1981)* N=140%**	**Olson *et al.* (1979)* N=244%**	**Kasperon *et al.*(1974)* N=400 %**	**Stone & Kable (1974)* N=1000 %**	**Bruvold (1972)* N=972 %**
Drinking	74	67	63	58	54	44	46	56
Cooking at home	-	55	55	-	52	42	38	55
Bathing at home	52	38	40	-	37	-	22	37
Washing clothes	30	30	24	-	19	15	-	23
Toilet flushing	4	4	3	-	7	-	5	23
Swimming	-	-	-	-	25	15	20	24
Irrigated dairy pastures	-	-	-	-	15	-	-	14
Irrigated vegetable crops	-	9	7	21	15	16	-	14
Irrigated vines	-	-	-	-	15	-	-	13
Orchard irrigation	-	-	-	-	10	-	-	10
Irrigation of alfalfa hay	-	-	-	-	8	-	9	8
Home garden irrigation	4	3	1	5	6	-	6	3
Irrigated park	-	-	-	4	5	-	-	3
Golf course irrigation	2	-	-	4	3	2	5	2

*these studies were conducted in United State of America; + was conducted in Australia

As discussed above, the public acceptance of water reuse varies with the water reuse application. The greater the degree of contact with reclaimed water, the more unfavourable it is to the public. However, the specific needs of a community could make reuse objectives vary from community to community. For example, respondents in one study were found to favour water reuse options that conserved water, enhanced the environment, protected public health, or held down water and wastewater treatment and distribution costs (Water reuse, 2008). Thus, it is important that project objectives reflect community desires.

Protection of public health is generally the greatest public concern with the use of reclaimed water. The possible health risks associated with water reuse are related to the reliability of the water reclamation system and the extent of people's exposure to the reclaimed water. It is expected that adequate precautions must be taken not to compromise public health.

In South Africa for example, Wilson and Pfaff (2008) carried out research in Durban and compared their results with international experience in order to determine if there were fundamental religious or philosophical objections to potable reuse of wastewater. They concluded that fundamental religious objections to direct potable wastewater reuse do not exist both internationally and locally but people are generally not comfortable with the idea of direct potable reuse. Further investigations revealed that there was no empirical research investigating community perceptions towards non-potable water reuse for schemes in South Africa. This chapter focuses on the issue of public support/objection to treated wastewater effluent reuse for non-potable applications via dual water reticulation system in the province of the Western Cape (City of Cape Town) and Limpopo (Seshego, Sisulu and Ext 44 within Capricorn District Municipality; Vhembe District Municipality).

5.2 The Case Study Site Selection and Survey

Cape Town is a typical coastal city in South Africa with acute water shortages. Cape Town Municipality has incorporated a non-potable water reuse scheme via dual reticulation as part of its Water Demand management plans. In the City of Cape Town (henceforth CoCT), some of the Wastewater Treatment Works (WWTWs) supply treated effluent for non-potable uses such as golf course and landscape irrigation, industrial processes, and cooling. According to the 2007 Census (Statistics South Africa, 2008), there were about 3 497 097 people and 902 278 households living in the city. The total coverage area is approximately 2 474 km^2 and its coastline is 371 km long. Western Cape is located in the Berg Water Management Area with an acute water shortage as indicated in Tables 1.1 and 1.2.

For the purpose of establishing a broad view of public perceptions regarding water reuse in South Africa, two inland municipalities (Capricorn and Vhembe in the province of Limpopo) were also identified as probable locations to generate the data needed for the study. Limpopo is a water scarce province in South Africa. According to DWAF (2004), the Limpopo Water Management Area has a total yield of 281 million m^3/a while the total water requirement for economic growth was estimated to be 322 million m^3/a in year 2000. The agricultural sector alone requires as much as 238 million m^3/a (85% of total yield) to sustain production. Capricorn and Vhembe contribute significantly towards South Africa's agricultural production in the areas of field crops (e.g. cereals and oil seeds) and horticultural crops (e.g. potato, vegetables, citrus and deciduous). Wastewater reuse is therefore seen as profitable for many of the agricultural holdings within these two municipalities as it shows promise of reducing the current dependence on the drinking water supply for most activities, and reducing the total bill paid monthly on drinking water. In terms of households, there were 1 243 167 people living in 285 565 households in Capricorn in 2007 while Vhembe housed 1 240 035 people in 287 190 households (Statistics South Africa, 2008). Use of treated wastewater for some households' non-potable water requirements such as toilet flushing, presents itself as promising when considering the arid climate within the municipalities.

5.2.1 The City of Cape Town Survey

A well-structured questionnaire was developed and administered to institutional non-potable water consumers in the CoCT to obtain information on the current water use and perceptions regarding reclaimed water use. Details of the questionnaires are available in appendix D**.** An address list of different consumers of non-potable water was obtained from the CoCT Water Service Department's billing list. The address list contains consumers' names, contact person(s) and telephone number(s). Out of 45 consumers on the list, 30 agreed to participate in the survey by filling out the questionnaire. While the majority of those who declined to participate stated that they were constrained by their condition of service not to release any official information relating to their operations. Others (mostly government-owned schools) required the approval of the Ministry of Education before participating. All respondents were contacted by telephone before a face to face meeting. An introductory letter informed the respondents of the aim of the project and stated that the information provided would be treated with utmost confidentiality. A summary of participating respondents is shown in Table 5.2.

Table 5.2: Questionnaire administered to institutional respondents in the City of Cape Town

Respondents	No of questionnaires administered	No of returned questionnaires
Irrigation:		
Schools / Sports field	19	9
Lawn/ Flowers	4	2
Agriculture	1*	1
Industries:		
Petroleum	1	1
Pulp and paper	2	1
Textile	1	
Construction	2	2
Total	***30***	***16***

* Represents a group of 20 farmers who use treated effluent for irrigation

5.2.2 The Capricorn and Vhembe Municipality Survey

Two questionnaires were developed and administered to potential institutional (i.e., agricultural businesses, commerce, education, parks) and domestic non-potable water consumers in Capricorn and Vhembe in order to obtain information on current water supply and sanitation and general perceptions regarding water reuse. The questionnaires were randomly administered to as many institutions and people who were willing to participate. Similar to the City of Cape Town, the majority of potential consumers in the agricultural sector declined to participate in the survey. In contrast, a large number of respondents from high schools and within households participated. A summary of questionnaires administered are shown in Table 5.3.

Table 5.3: Questionnaire administration in Capricorn and Vhembe

Respondents	No of questionnaires administered	No of returned questionnaires
Institutions		
Agriculture	20	1
Commerce/Industry	20	17
Education/ Sport	50	47
Public	10	7
Total	***100***	***72***
Domestic	150	125
Total	***150***	***125***

The study population for potential domestic respondents were 52 males and 71 females aged 18 to 65 years, with mean age of 25.23 years (SD = 7.23). The majority of respondents were black (99%) and mostly students in higher institutions. With reference to marital status, 60.1% were single, 12.2% were married, 25.2 % were married with children and the remaining 1.62% were divorced or widowed. Most of the participants (69.5%) lived in Reconstruction and Development Program (RDP) houses (low income), 19.8% in stand-alone houses, 4.96% in apartments, 4.13% in traditional houses and 1.65% in shacks/informal settlements. Household numbers varied from 2 to 10 with an average of 6 (SD = 5.18).

5.2.3 Questionnaire Structure

The general structure of the questionnaire administered to respondents in the City of Cape Town, Capricorn and Vhembe (Appendix D) is subdivided into four sections:

- **Section 1:** This section contains introduction, aim of the project and short definition of non-drinking water.

- **Section 2:** This section requests background information on the activities each respondent performs/willing to perform with non-potable water
- **Section 3:** This section extracts information on potable water (e.g. source, distance, availability, cost, etc) and non-potable water such as problems encountered and perceived risk (for CoCT only).
- **Section 4**: This section was used to obtain respondents' perceptions regarding the use of non-potable water.

It should be noted that the potential non-potable water respondents' questionnaire contains an additional section requesting demographic information from respondents such as gender, age, racial group, marital status, academic qualification, type of house and approximate monthly income.

5.2.4 Preliminary Analysis of Respondents' Perceptions

- ***Activities performed/willing to perform with non-potable water***

Figure 5.1 shows the activities performed with non-potable water in the CoCT. The majority of the institutional consumers (80.95%) use non-potable water for irrigation while industrial sectors (manufacturing and refinery) account for 9.5% and the remaining 9.5% use non-potable water for dust suspension in public places.

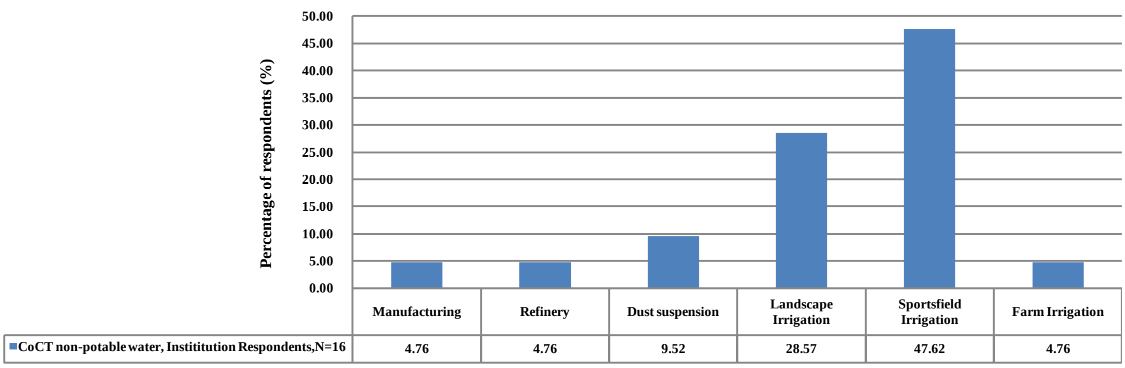


Figure 5.1: Activities performed with non-potable water (N = 16)

Figures 5.2 (a) and (b) show the activities the potential institutional and domestic consumers in Capricorn and Vhembe are willing to perform with non-potable water. The majority of the potential institutional consumers are willing to use non-potable water for landscape irrigation (75%) while the majority of domestic respondents choose minimal human contact water requirements (e.g. laundry and toilet flushing). This is similar to previous studies on public perceptions towards wastewater reuse which revealed that people were generally favourably disposed to using non-potable water for activities that require minimal human contact, thereby reducing health risks (Kantanoleon *et al.*, 2007 and Friedler, *et al.*, 2006).

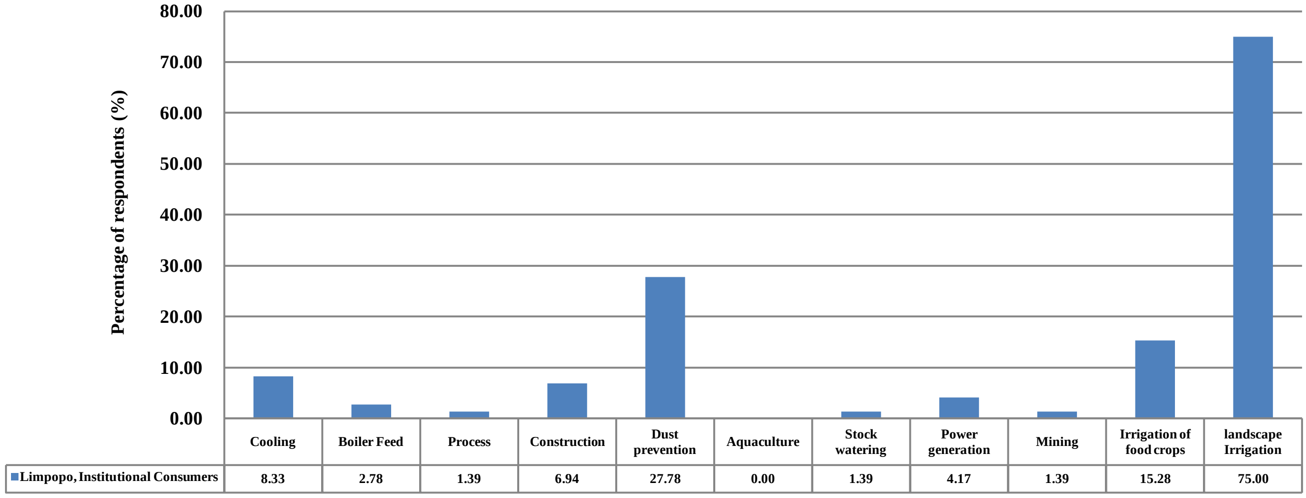


Figure 5.2 (a): Preferred activities for non-potable water (N = 72)

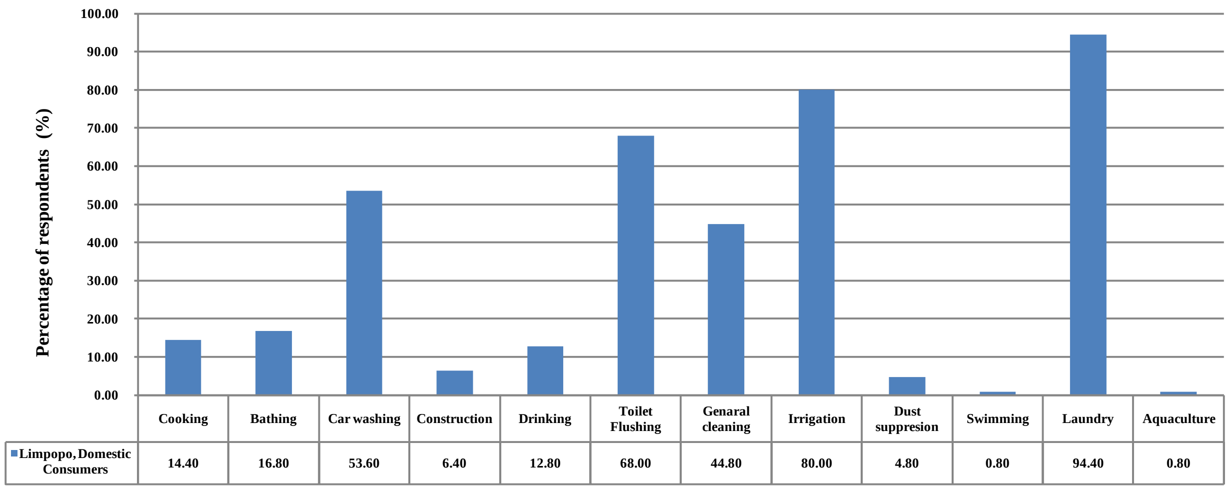


Figure 5.2(b): Preferred activities for non-potable water (N = 125)

- **Distance of consumers from non-potable water source**

Piping infrastructure and pumping are major costs impacting on the economics of water reuse schemes. Distribution costs are in proportion to the proximity of user markets (Mills and Asano, 1998). Figure 5.3 shows the distance of consumers from the treated wastewater source. It can be seen that more than half of the consumers (56%) are located less than 500m from the connection point. Since the costs of pipe connection to the wastewater treatment works are the sole responsibility of consumers, the farther the source from the consumer, the higher the cost. This cost may be a major deterrent for many potential large consumers of non-potable water.

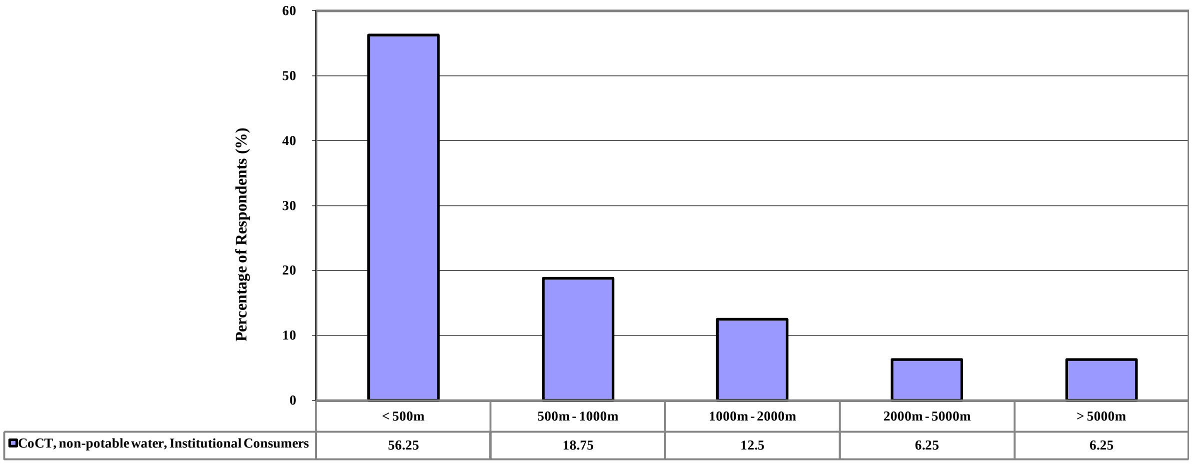


Figure 5.3: Distance of the treated effluent from source (N = 16)

- **Availability of drinking water at all times**

Over 80% of the non-potable water consumers in the CoCT and potential consumers in Capricorn and Vhembe indicated that potable water is available at all times as shown in Figure 5.4. Not having water supply some of the time may contribute to greater acceptance of using treated effluent for certain uses.

Respondents in the CoCT revealed that the desire to or actual use of non-potable water is always high during periods of water restrictions. For more than a century, the city has experienced recurring periods of water restrictions due to drought (DWAF, 2007).

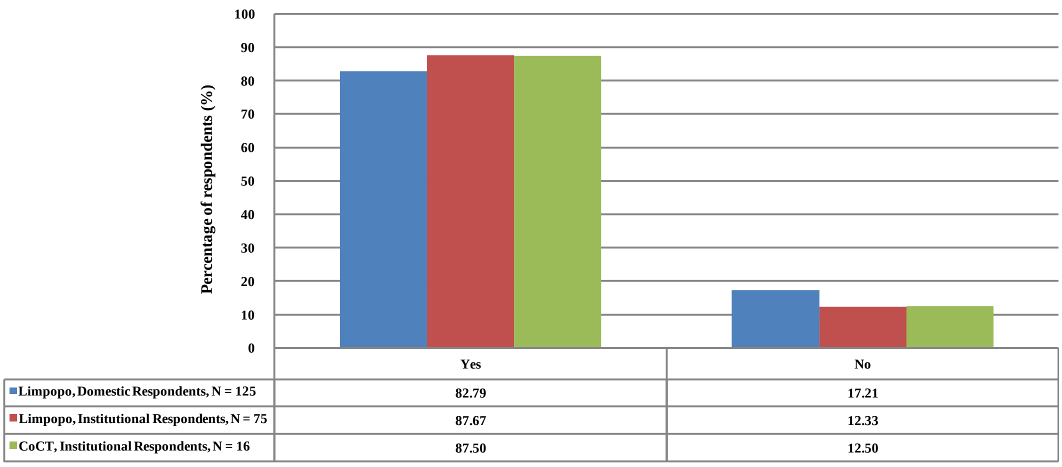
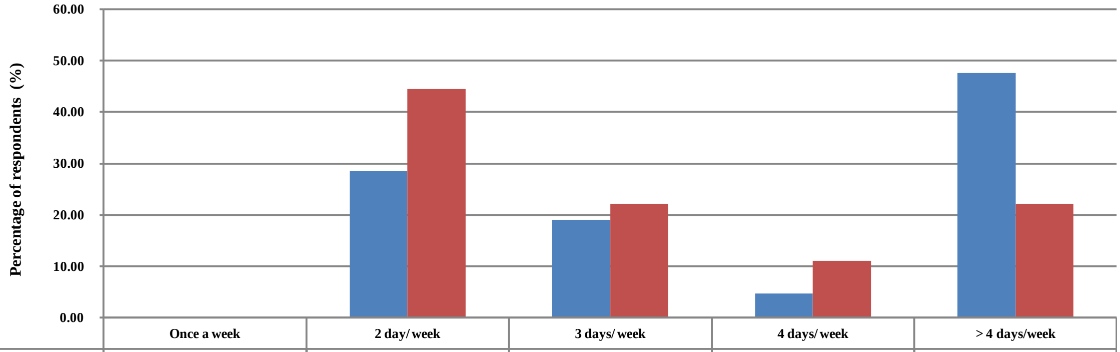


Figure 5.4: Availability of potable water at all times

Respondents in Capricorn and Vhembe who do not have constant water supply indicated how often they received water within a typical week (Figure 5.5). As indicated for institutional respondents facing water restriction in the CoCT, these respondents will likely be open to non-potable reuse for certain activities.

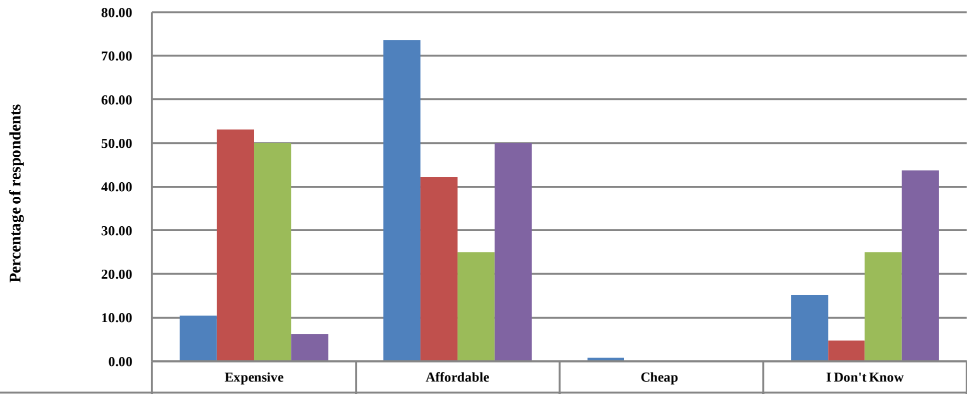


	Once a week	2 day/ week	3 days/ week	4 days/ week	> 4 days/week
Limpopo, Domestic Respondents, N = 125	0.00	28.57	19.05	4.76	47.62
Limpopo, Institutional Respondents, N = 72	0.00	44.44	22.22	11.11	22.22

Figure 5.5: Frequency of water availability

- ***Potable and non-potable water prices (Capricorn and Vhembe respondents)***

Figure 5.6 shows the opinions of respondents on the price of potable and non-potable water in the study communities. In City of Cape Town, 50% of the respondents indicated that the cost of potable water and non-potable water is expensive and affordable respectively. In Capricorn and Vhembe, the majority of domestic respondents indicated that potable water was affordable (73.60%) while 53% of potential institutional non-potable water consumers indicated that the price of potable water was expensive.



	Expensive	Affordable	Cheap	I Don't Know
Limpopo, potable water, Domestic Respondents, N=125	10.40	73.60	0.80	15.20
Limpopo, potable water, Institutional respondents, N=75	53.13	42.19	0.00	4.69
CoCT, potable water, Institutional Respondents, N=16	50.00	25.00	0.00	25.00
CoCT, non-potable water, Institutional Respondents, N=16	6.25	50.00	0.00	43.75

Figure 5.6: Opinion on average potable and non-potable water price

It is a common practice to use pricing mechanisms as a way of allocating scarce resources, and water is no different. As potable water prices in these arid communities increase, non-potable water reuse will likely increase also as long as non-potable water is priced below potable water. At the time of this survey, potable and non-potable water tariff at the CoCT are presented in Table 5.4 and 5.5. With this pricing dynamic persisting in the CoCT, non-potable reuse is certain to become more attractive for many users.

Table 5.4: Tariff for non-potable water in the City of Cape Town

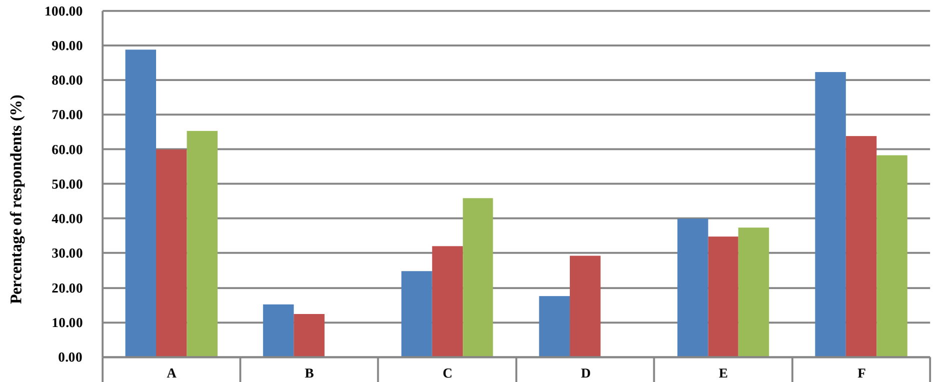
Category	Description	Unit	Amount (Rand)
Industrial/Commercial		per kl	2.35
Municipals, Schools, Sport fields		per kl	2.07
Public Golf Courses	These are courses that have historical links to council and provide services to the public	per kl	0.37
Bulk users	These are users in excess of 5.0ML/day	per kl	0.53
Informal & Private	Administration fee for metering, chlorination, etc.	per kl	0.05

Table 5.5: Tariff for potable water in the City of Cape Town

Category	Unit	2004 Rate (Rand)	2010 Rate (Rand)
Domestic Full			
Step 1 (0-6kl)	per kl	0.00	0.00
Step 2 (7-12kl)		2.56	4.55
Step 3 (13-20kl)		5.46	9.70
Step 4 (21-40kl)		8.08	14.38
Step 5 (41-50kl)		9.98	17.76
Step 6 (>50kl)		13.17	23.43
Domestic Cluster	per kl	5.47	9.70
Commercial	per kl	5.83	10.10
Industrial	per kl	5.83	10.10
Schools/Sports	per kl	5.15	9.70
Government	per kl	5.53	9.81
Municipal	per kl	5.15	9.70

- ***Reasons for using non-potable water***

Figure 5.7 presents the consumers' reasons for using non-potable water in CoCT and if faced with the reality of using non-potable water in Capricorn and Vhembe. It should be noted that some respondents indicated up to three reasons for using non-potable water. The Figure shows that the overwhelming reasons for using or wanting to use non-potable water were to conserve drinking water and to safe on costs of potable water which are likely to continually increasing into the future.



	A	B	C	D	E	F
Limpopo, Domestic Respondents, N = 125	88.80	15.20	24.80	17.60	40.00	82.40
Limpopo, Institutional Respondents, N = 72	59.94	12.50	31.94	29.17	34.72	63.89
CoCT, Institutional Respondents, N=16	65.27	0.00	45.80	0.00	37.36	58.26

Figure 5.7: Reasons for using non-potable water

A – to conserve drinking water

B – to postpone costly investment in water and wastewater treatment facilities

C – to provide backup water during drought

D – to reduce effluent discharge into surface water

E – to improve soil productivity

F – to save money on water bill

- **Incidence of disease outbreak (CoCT respondents)**

For a DWRS to gain public confidence and acceptance, the risk of disease outbreaks must be minimal. In Figure 5.8, 94% of the respondents indicated that there has not been any incident of disease outbreak since they began to use non-potable water for non-potable purposes. This high percentage can be attributed to the fact that, in the CoCT, the application of non-potable water is restricted to outdoor/industrial purposes with low human contact and that necessary precautions stipulated in the treated effluent reuse bylaws have been strictly adhered to. However, 6% of respondents indicated that there have been cases of people who contracted typhoid when non-potable water was mistakenly ingested by farm workers who had poor knowledge of the water source.

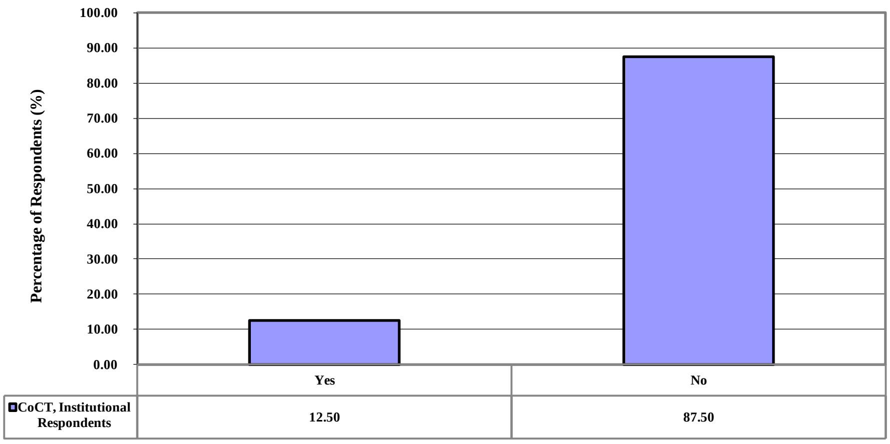


Figure 5.8: Incidence of disease outbreak (N =16)

Non-potable water consumers' perception of the risk of using non-potable water is shown in Figure 5.9. 88% of respondents indicated that they have no fear of any risk in using non-potable water for non-potable purposes. However, this is a very sensitive perception that may quickly change if non-potable water is considered for indoor usage because of the potential increased contact involved.

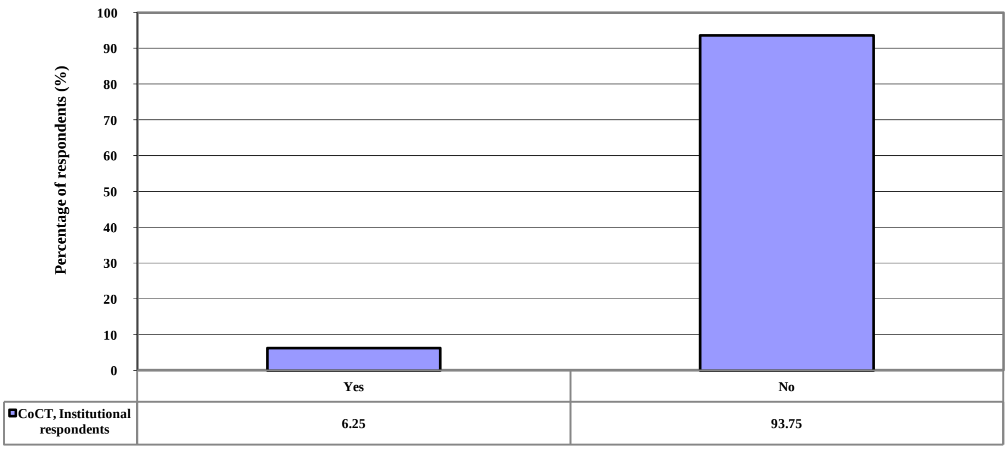
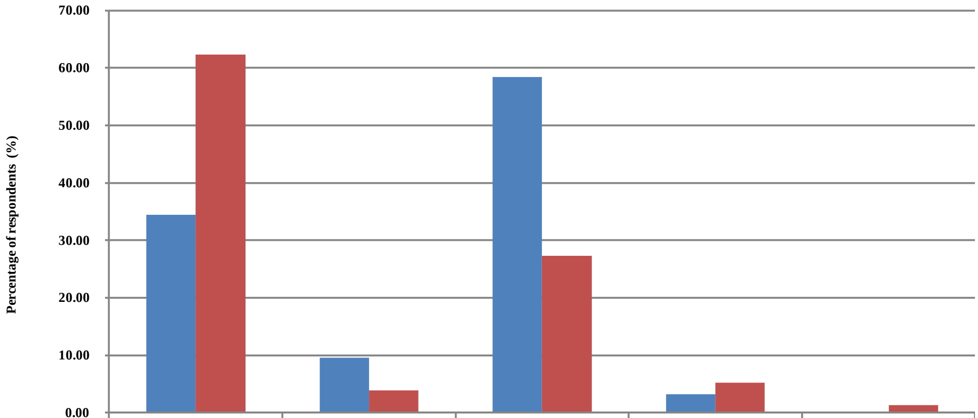


Figure 5.9: Perceived risk in the use of non-potable water (N =16)

- ***Methods of wastewater disposal (Capricorn and Vhembe respondents)***

One of the conditions that must be fulfilled before considering wastewater reuse is that the area must have a sewerage system. Respondents were asked to indicate how they disposed their wastewater. This was to determine if there would be sufficient wastewater for reuse and also to determine if some form of reuse was informally taking place amongst respondents.

Figure 5.10 shows that 58% of domestic respondents and 27% of institutional respondents were already employing wastewater for garden irrigation.

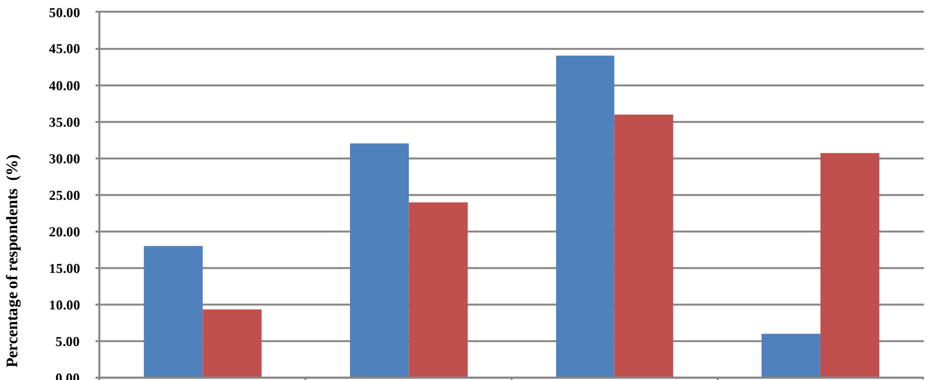


	Sewer	Into the street	Into the Garden	Septic tank	Recycled
Limpopo, Domestic Respondents, N = 125	34.40	9.60	58.40	3.20	0.00
Limpopo, Institutional Respondents, N = 75	62.34	3.90	27.27	5.19	1.30

Figure 5.10: Methods of wastewater disposal

- ***General perceptions towards non-drinking water reuses (Capricorn and Vhembe respondents)***

Respondents were asked to indicate the general term they could use to describe non-drinking water reuse (Figure 5.11). About 50% of domestic respondents and 66% of institutional respondents were positive about non-drinking water reuse.



	Disgusting	Unhealthy & Dangerous	Good & OK	Environmentally friendly
Limpopo, Domestic Respondents, N = 125	18.00	32.00	44.00	6.00
Limpopo, Institutional Respondents, N = 75	9.33	24.00	36.00	30.67

Figure 5.11: General perceptions towards non-drinking water reuse

5.3 Understanding Respondents Perception and Predicting Intention to Accept/Reject Non-drinking Water Reuse

5.3.1 Background

The issue of public acceptance of wastewater reuse systems could lead to success or defeat based on public perceptions. In view of the significant effect public opinion has on water reuse, it is important that perceptions be investigated prior to the implementation of wastewater reuse because understanding people's perceptions and attempting to enhance understanding of reuse amongst potential consumers has become an important decision variable in successful reuse schemes (Po *et al., 2005*). Ultimately, perceptions influence intentions.

Investigations into the different factors that influence public perceptions about reuse has preoccupied many researchers in recent times (e.g. Okun, 2002; Po *et al.,* 2004; Friedler *et al.,* 2006; Hurlimann & Mckay, 2007; Hurlimann, 2007 and kantanoleon *et al.,* 2007). The objective of many of these research efforts has been to develop a better understanding of the relationship between perceptions and the intention to accept/reject reuse. Previous research suggested that public acceptance of reuse is a product of attitude, emotion, control over source of water, subjective norms (influence of people around you), knowledge, associated risk, trust in the implementing authority, quality satisfaction, choice, specific use, source(s) of recycled water, cost, water scarcity and socio-demographic factors (Water reuse, 2008). These perspectives have been investigated differently in various places where water reuse schemes have been implemented or are planned.

This section attempts to employ a psychology methodology, the Theory of Planned Behaviour (TPB) introduced by Ajzen (1995), to investigate the perceptions and the major factors influencing intention to accept/reject wastewater reuse for non-potable water uses. The TPB has been previously used to predict a range of human behaviours including the prediction of customer loyalty in the purchase of commodities (Li and Wang, 2006); factors behind attempts by consumers to disguise their identities through fabrication (Lwin and Williams, 2003); predicting and understanding factors affecting paper recycling (Cheung *et al*. 1999; Boldero, 1995; Taylor and Todd, 1995); water conservation (Harland *et al*., 1999); riparian zone management (Fielding *et al*., 2005); environmental activism (Fielding *et al.,* 2008); electronic waste recycling (Nnorom *et al.,* 2009); solid waste management (Jones *et* *al.*, 2009); knowledge sharing among senior managers (Lin and Lee, 2004) and farmer's conservation behaviour (Beedell and Rehman, 1999).

5.3.2 Application of Ajzen's Theory of Planned Behaviour to Determine Intention to Accept Wastewater Reuse

The TPB attempts to understand and predict behaviour by measuring the underlying determinants of that behaviour. According to the TPB, the most common factor that determines an individual's behaviour is the person's intention to engage in the behaviour. Intentions are in turn predicated on three main belief based measures (also known as constructs): attitudes, subjective norms, and perceived behavioural control (Figure 5.12) (Fielding *et al., 2008;* Beedell and Rehman, 1999). According to the TPB, the brief definitions of these beliefs based measures are given below:

An attitude is the beliefs about the likely outcomes of the behaviour and the assessments of these outcomes (behavioural beliefs). It is a complex mental state involving feelings, values and dispositions to act in a certain ways. It measure overall positive or negative predisposition to behave in a certain way.

Subjective norms is the beliefs about the normative expectations of others and motivation to comply with theses expectations (normative beliefs). It is a general measure of the perceived importance of other people in the life of respondents who would want them to perform (or not perform) the behaviour (i.e. social pressure).

Perceived behavioural control is the beliefs about the presence of other factors that may facilitate or impede performance of the behaviour and the perceived power of these factors (control beliefs). It measures the extent to which an individual has the capacity to perform the behaviour.

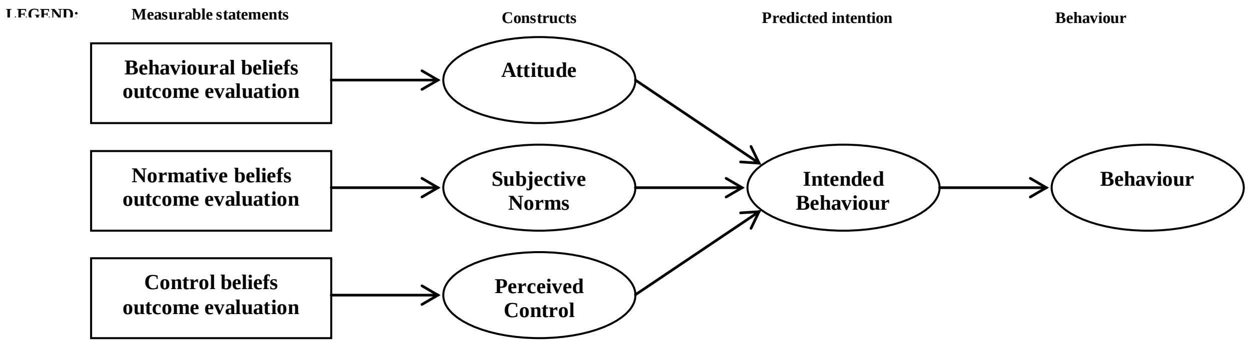


Figure 5.12: Ajzen's Theory of Planned Behaviour (Ajzen, 1985)

In order to identify factors that might have a significant influence on community's acceptance/rejection of recycled water for various uses, Po *et al.* (2004) conducted further research on Ajzen's TPB as depicted in Figure 5.12. Prior to their research, limited research had been conducted explaining the theory to determine perceptions and intended behaviour with respect to wastewater reuse. However, previous research explaining the theory on food (Eiser, *et al*., 2002) suggests the inclusion of the following parameters in the original Ajzen's TPB (1985):

i. perceived risks and benefits
ii. knowledge of reuse
iii. trust in authorities, experts and technology

Based on the suggested inclusions to the TPB earlier proposed (Ajzen, 1985), Po *et al.*, (2005) proposed a revised model with additional factors (e.g. knowledge of the scheme and emotion) as depicted in Figure 5.13.

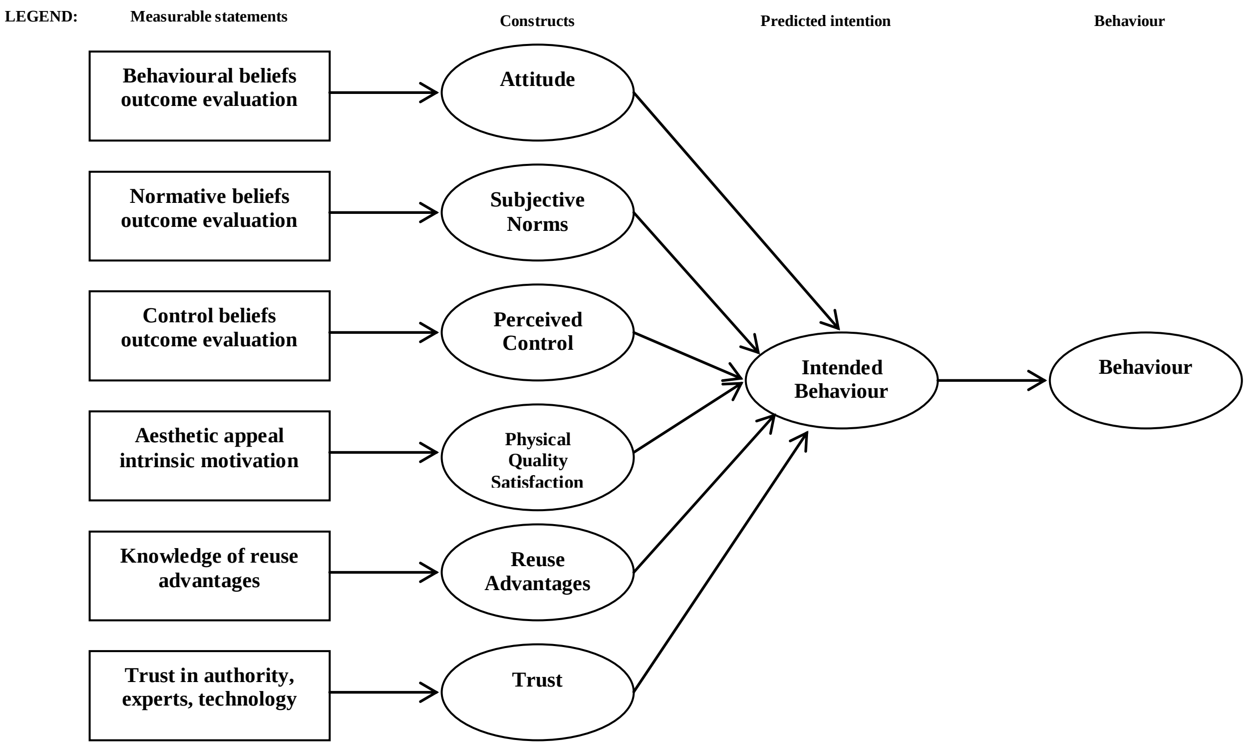


Figure 5.13: The revised Ajzen's Theory of planned behaviour by Po *et al.*, (2005)

The constructs shown in Figure 5.13 are hypothetical variables that have been shown in previous research (Po *et al*., 2005; Ajzen, 1985) as the factors that underpin the intention to reuse wastewater. They cannot be directly observed but must instead be inferred from respondents' responses generated from questions/statements that statistically correlate with constructs.

The following section of this chapter presents the application of the revised Ajzen's TPB to predict intention to accept/reject recycled water for non-potable uses.

It was the intention of this study to provide a module in the decision support system that will analyse in detail the perceptions and therefore predict intention of users towards non-potable reuse. While conducting this research, it became clear that the development of such a tool would be onerous and beyond the scope of this project given the specialist (psychological and statistical) nature and detailed programming demands of such a tool. As a result, a module to psychologically and statistically analyse potential consumer's perceptions and intention is not included in the developed DSS.

However, the sections below report the application of a commercially available psychological and statistical tool (AMOS 6.0^{TM}) whose methodology (the revised Ajzen's TPB used by Po *et al,* 2005) was employed to analyse perceptions of potential beneficiary of non-potable wastewater reuse system in Vhembe and Capricorn (Limpopo province). The applicable result of this analysis was employed in the simplified module of the developed DSS which attempts to determine respondents' perceptions using discrete answers.

The revised TPB model for intention to accept or reject recycled water was tied to a series of hypotheses as discussed below.

Knowledge of reuse advantages: The knowledge of reuse advantages has not been tested in the content of recycled water. However, similar to this is the knowledge of recycled scheme tested by Po *et al*., (2005). In this study, it is of the opinion that if the respondents have good knowledge of reuse advantages, it would enhance the intention to accept recycled water for non-potable uses, hence the following hypothesis:

H1: Respondents knowledge of reuse advantages has a positive effect on intention to accept non-potable water.

Trust on authority: The results of prior researches conducted in Australia (Po *et al., 2005;* Fielding *et al*., 2009) have identified trust in Water Authority as a major determinant of acceptance of recycled water. Also, a study conducted by Lin and Wang (2006) shows that trust has a positive effect on customers' loyalty and consumers' satisfaction. However, studies of perceptions conducted by Eiser *at al.* (2002) on food related risks have found to have weak support for trust leading to satisfaction. These conflicting results in closely related studies make adaptation of findings somehow difficult. Relating to this, the following hypothesis was developed:

H2: Respondents trust in the treated wastewater service provider has a positive effect on intention to accept non-potable water.

Attitude: Attitude towards performing a particular behaviour is the degree to which an individual has a favourable or unfavourable assessment of the behaviour. TPB predicts that the more favourable an individual evaluate a particular behaviour, the more likely he/she will intend to perform that behaviour (Ajzen, 1995). Attitude factors have been tested and shown to be significant in predicting the intention to accept recycled water (Po *et al*., 2005) and organizational behavioural intention to share knowledge (Lin and Lee, 2004; Bock and Kim, 2002). In this study, attitude towards acceptance of recycled water refers to the respondents' positive or negative disposition to accept recycled water. Thus, the following hypothesis was formulated:

H3: Respondents positive attitude towards water reuse will increase the intention to accept non-potable water.

Perceived behavioural control: Perceived behavioural control refers to the presence or absence of requisite resource and opportunities to carry out behaviour. Chang (1998) reported that perception of volitional control or perceived difficulty towards completion of the act will affect an individual's intent as well as successful performance of that behaviour. His findings also show that the perceived behavioural control significantly influenced moral behavioural intention. Limited control over source of water and its applications has not been tested in the context of intention to accept recycled water. It is of the opinion that if respondents have limited control of the source of their water and its application, it will affect the intention to accept recycled water positively. Thus, the following hypothesis was formulated:

H4: Respondents limited control over source of water and its application has positive effect on intention to accept non-potable water.

Subjective norms: The term subjective norms in TPB are closely related to social pressure. It measures how important people in the life of respondents would approve or disapprove of their performing a particular behaviour. Subjective norms have been found to affect knowledge sharing intentions among groups (Ruy *et al*., 2003) and among senior managers (Lin and Lee, 2004). Fielding *et al.* (2009) and Po *et al.* (2005) have also reported that subjective norms significantly affect behavioural intention to accept recycled water. In this study, subjective norms about recycled water refer to how social pressure affects the intention to accept recycled water among respondents. Hence, the following hypothesis was developed.

H5: Greater subjective norm towards water reuse has positive effect on respondents' intention to accept non-potable water.

Aesthetic appearance: The relationship between aesthetic appearance and acceptance of recycled water has not been tested. However, in a comparative literature, Hurlimann and McKay (2007) found out that colour of recycled water was the most important attribute for consumers to accept recycled water for washing clothes. In this study, aesthetically appealing recycled water refers to visibly cleared recycled water. This led to the formulation of the following hypothesis:

H6: Aesthetically appealed recycled water will have positive effect on intention to accept non-potable water.

Table 5.6 summarises the hypotheses explained above. These hypotheses are based on the intention to accept wastewater reuse.

Table 5.6: Intention to accept wastewater reuse hypotheses employed in the revised TPB model

Variables	**Description of hypothesis**
Reuse Advantages (ADV)	H1: Respondents knowledge of reuse advantages has a positive effect on intention to accept non-potable water.
Trust (TRU)	H2: Respondents trust in the treated wastewater service provider has a positive effect on intention to accept non-potable water.
Attitude (ATT)	H3: Respondents positive attitude towards wastewater reuse will increase the intention to accept non-potable water.
Control over source of water (CON)	H4: Limited control over the source of water and its application has a positive effect on the intention to accept non-potable water.
Subjective norm (SNO)	H5: Greater subjective norm value towards wastewater reuse has a positive effect on the respondents' intention to accept non-potable water.
Physical quality satisfaction(PQS)	H6: Aesthetically pleasing water will have positive effect on the intention to accept non-potable water.

Section 5.2.3 describes the structure of the questionnaire used in this study. The section of the questionnaire requesting perception responses list statements aimed at measuring respondents' *positive or negative attitude towards wastewater reuse*, *knowledge of the reuse advantages*, *trust in the service provider*, *subjective norms*, *physical quality satisfaction of the reuse water* and *perceived control over the source of water and its application*. The respondents were required to rate how much they agreed or disagreed with each statement on a 5-point likert scale from 1 (strongly agree) to 5 (strongly disagree).

The Likert scale is a psychometric scale commonly used in questionnaires and is the most widely used scale in survey due to its ordinal nature, flexibility and ease of construction (Hurlimann, *et al.*, 2008). A recent study by Dawes (2008) found out that none of the 5-, 7- or 10-point scales is less desirable from the viewpoint of obtaining data that will be used for regression analysis because kurtosis and skewness were similar for all the three formats. Dawes (2008) research concluded that the three formats are comparable for analytical tools such as confirmatory analysis or structural equation models. However, the result also pointed out that 5- or 7-point scale may produce slightly higher mean scores relative to the highest possible attainable score when compared to those produced from a 10-point scale. The 5-point scale used in this study provides a simple list of scale descriptor for the respondents to read in order to avoid a lengthier clarification that may be required for higher point scales since the method has been justified to produce the same result with higher scales when using structural equation model.

The TPB constructs were measured in accordance with the recommendations of Ajzen (1985). Since the beliefs were measured with multiple statements, it was necessary that the different statements used to assess the same construct should correlate with each other and exhibit high internal consistencies. This was achieved by determining the Cronbach's alpha (α) value amongst multiple items measuring a belief. Cronbach's alpha is commonly used to measure the extent to which multiple items of a construct belong together and vary from 0 to 1.0. It is generally accepted that a Cronbach's alpha value above 0.7 is an indication of good internal consistency between items. (Vicente and Reis, 2008).

The analysis of the correlation between statements and with their construct was performed using a Structural Equation Modelling (SEM) package called AMOS™ 6.0. This package allows multiple relationships to be analyzed simultaneously while maintaining statistical efficiency. AMOS 6.0 uses the maximum likelihood (ML) method to estimate parameters. SEM in its general form consists of a measurement model and a structural equation model. The measurement model specifies how latent variables depend on or are indicated by the observed variables. The structural equation model specifies the relationships between constructs, describe their effects (either negative or positive) and assigns the explained and unexplained variance of the endogenous constructs. The *average variance extracted* measures the amount of variance captured by the constructs in relation to the amount of variance due to measurement error.

A two-step approach recommended by Anderson and Gerbing (1992) was adopted to evaluate whether the hypothesized model fits the data. The first step involved a confirmatory factor analysis to estimate the measurement component of the constructs in the TPB in order to identify items of the same construct with high internal consistency. If the psychometric properties of the structure were deemed accepted, we proceed to the second step. The second step involves the combination of the theoretical and measurement model (Huchting *et al., 2008)*.

5.3.3 Results from the Application of the TPB to City of Cape Town and Vhembe & Capricorn, Limpopo

5.3.3.1 Institutional Non-potable Water users in the City of Cape Town

Table 5.7 shows the Cronbach's alpha value for the measured items. A goodness of fit test could not be performed on the Cape Town data because of the small sample size (N = 16). To obtain an acceptable goodness of fit, Byrne (2001) recommends a minimum sample size of 80. Nevertheless, the reliability test on statements indicated strong internal consistency with the constructs as indicated by the Cronbach's alpha values shown in Table 5.7

Table 5.7: Analysis of statements/questions from institutional respondents in the City of Cape Town

Construct	Statement	Statistics
Reuse advantages	1. Non-drinking water use has reduced pollution to the environment ADV1 2. Non-drinking water use has reduced the depletion of groundwater and surface water resources ADV2 3. The use of non-drinking water can save many South African communities from drought ADV3 4. This institution feels good when it does something positive to reduce environment pollution ADV4	Composite reliability, α = 0.90
Physical quality satisfaction	1. The non- drinking water this institution uses looks absolutely clear PQS1 2. The non-drinking water this institution uses is odourless PQS2 3. This institution is generally satisfied with the non-drinking water service PQS4	Composite reliability, α = 0.85
Attitude	1. This institution feels personally obligated to do whatever it can do to save water ATT1 2. This institution would rather not use non-drinking water ATT2 3. Many institutions affiliated with us support the use of non-drinking water ATT3	Composite reliability, α = 0.77
Perceived control	1. Fruits and vegetables irrigated with non-drinking water (e.g. recycled wastewater) should be labelled in the supermarket CON1 2. Every household should be free to choose their source of water supply (e.g. groundwater, surface water, recycled wastewater, etc.) CON2	Composite reliability, α = 0.90

5.3.3.2 Potential institutional and domestic non-potable water users in Vhembe and Capricorn, Limpopo

For potential institutional respondents, the initial 20 statements in the questionnaire measuring the six TPB constructs were subjected to item-to-total correlation and exploratory factor analysis. The item-to-total correlation is a correlation between a statement score and the sum of the remaining statements that form the scale. The test is performed to check whether any statement is not consistent with the remaining statements. Once the number of correlated statements are determine, exploratory factor analysis is performed to determine their factor loadings. Four of the 20 statements with factor loadings of less than 0.34 were excluded from subsequent analysis. Factor loadings are the correlation coefficients between the statements and the constructs. Factor loadings greater than 0.71 (> 0.71) are typically regarded as excellent and less than 0.32 are regarded as very poor (Yongminga *at al*., 2006).

Details of factor loadings for each statement are shown in Table 5.8. The excluded statements with factor loadings of less than 0.34 were used to measure *the physical quality satisfaction* and *subjective norms* constructs. The non-excluded 16 statements representing the remaining four constructs that explained 81.32% of the variance among the statements were considered reliable for further analysis. For potential institutional respondents, different items used to measure the same construct were grouped together i.e. *attitudes* (6 statements), *reuse advantages* (4 statements), *trust in service provider* (4 statements) and *perceived control over the source of water* (2 statements).

Table 5.8: Factor loadings and internal consistency of statements for potential institutional respondents questionnaire

Construct	Statement	Factor loading	Statistics
Reuse advantages	1. The use of non-drinking water can reduce the amount of wastewater discharged to the environment ADV1	0.80	Composite reliability, α = 0.81
	2. Non-drinking water use can reduce the depletion of groundwater and surface water resources ADV2	0.60	
	3. The use of non-drinking water can save many South African communities from drought ADV3	0.82	
	4. There are considerable savings of fertilizer on farms irrigated with recycled wastewater ADV4	0.53	
Trust in implementing authorities	1. This institution will use non-drinking water if it is not disgusting TRU1	0.69	Composite reliability, α = 0.82
	2. This institution will use non-drinking water if it does not stain or cause corrosion TRU2	0.81	
	3. This institution trusts the municipality to provide non-drinking water that is safe and does not constitute a health risk TRU3	0.83	
	4. This institution will use non-drinking water if the quality can be proven to be satisfactory TRU4	0.57	
Attitude	1. This institution feels personally obligated to do whatever it can do to save water ATT1	0.57	Composite reliability, α = 0.78
	2. Water is a valuable resource that should be recycled ATT2	0.52	
	3. This institution would rather not use non-drinking water ATT3	0.70	
	4. This institution would never use non drinking water even in times of shortages ATT4	0.61	
	5. This institution would only be prepared to use non - drinking water in times of water shortages ATT5	0.58	
	6. The government is partly responsible for water shortages ATT6	0.54	
Perceived control over source of water	1. Every household should be free to choose their source of water supply (e.g. groundwater, surface water, recycled wastewater, etc.) CON1	0.43	Composite reliability, α = 0.90
	2. Fruits and vegetables irrigated with non-drinking water (e.g. recycled wastewater) should be labelled in the supermarket CON2	0.51	

For potential domestic respondents, the initial 20 statements measuring the 6 TPB constructs were subjected to item-to-total correlation and exploratory factor analysis. Three statements measuring *the physical quality satisfaction* construct generated a factor loading of less than 0.34 and was excluded from subsequent analysis. The non-excluded 17 statements that represent 5 constructs explained 87.02% of the variance and were therefore reliable for further analysis. For potential domestic respondents, different statements used to measure the same construct were grouped together i.e. *attitudes* (3 statements), *reuse advantages* (4 statements), *trust in service provider* (4 statements), *subjective norms* (3 statements) and *perceived control over the source of water* (3 statements). Details of factor loadings for each statement for potential domestic respondents are shown in Table 5.9.

Table 5.9: Factor loadings and internal consistency of statements for potential domestic respondents' questionnaire

Construct	Statement	Factor loading	Statistics
Reuse advantages	1. The use of non-drinking water will reduce the amount of wastewater discharged to the environment ADV1 2. Non-drinking water will reduce the depletion of groundwater and surface water resources ADV2 3. The use of non-drinking water can save many South African communities from drought ADV3	0.94 0.81 0.78	Composite reliability, α = 0.82
Trust in implementing authorities	1. I will use non-drinking water if the quality can be proven to be satisfactory TRU1 2. I will use non-drinking water if it is not disgusting or irritating TRU2 3. I will use non-drinking water if it does not stain washing TRU3 4. I trust the municipality to provide non-drinking water that is safe and does not constitute a health risk TRU4	0.70 0.98 0.94 0.96	Composite reliability, α = 0.73
Attitude	1. I feel personally obligated to do whatever I can to save water ATT1 2. Water is a valuable resource that should be recycled ATT2 3. I would have preferred not to use non-drinking water ATT3 4. I would only be prepared to use non-drinking water in times of water shortages ATT4 5. The government is partly responsible for water shortages ATT5	0.51 0.52 0.60 0.47 0.41	Composite reliability, α = 0.68
Control over Source of Water	1. I have the right to adequate drinking water supply CON1 2. I have the right to know if fruits or vegetables are irrigated with recycled wastewater CON2 3. Fruits and vegetables irrigated with non-drinking water (e.g. recycled wastewater) should be labelled in the supermarket CON3	0.39 0.98 0.80	Composite reliability, α = 0.81
Subjective Norms	1. I will use non-drinking water if others are using it SNO1 2. Most people who are close to me support the use of non-drinking water SNO2 3. Non-drinking water use is an option for the poor and the rich SNO3	0.47 0.94 0.38	Composite reliability, α = 0.85

Following the exclusion of statements with factor loadings less than 0.34, good fits were obtained for both domestic and institutional respondents (Table 5.10).

Table 5.10: Goodness of fit for revised model

Fit index	Recommended value (Arbuckle, 2005)	Institutional respondents	Domestic respondents
		Structural model	Structural model
$\frac{x^2}{df}$	$\leq$ 3.00	2.60	2.30
AGFI	$\geq$ 0.80	0.84	0.83
NFI	$\geq$ 0.90	0.91	0.93
GFI	$\geq$ 0.90	0.92	0.91
CFI	$\geq$ 0.90	0.90	0.94
IFI	$\geq$ 0.90	0.90	0.92
TLI	$\geq$ 0.90	0.92	0.90
RMSEA	$\leq$ 0.10	0.08	0.06

Table 5.11 shows the composite reliabilities (i.e. Cronbach's alpha, α) and average variances extracted for the statements administered to institutional respondents. The composite reliabilities for PQS and SNO were below threshold value of 0.70. Therefore, only ADV, TRU, ATT and CON were employed in further analysis.

Table 5.11: Reliabilities and average variances extracted for institutional respondents

Constructs	**No of items**	**Composite reliability (α)**	**Recommended value (Vicente and Reis, 2008)**	**Average variance extracted**
Reuse Advantages (ADV)	4	0.81	> 0.70	0.78
Trust (TRU)	4	0.82		0.80
Attitude (ATT)	6	0.78		0.86
Control over source of water (CON)	2	0.90		0.71
Physical quality satisfaction(PQS)	2	0.31		0.35
Subjective norm (SNO)	2	0.42		0.48
Intention to accept		0.85		0.80

Table 5.12 shows the estimated reliabilities (i.e. Cronbach's alpha, α) and average variances extracted for the statements administered to domestic respondents. The composite reliabilities and variances for ATT and PQS were below the threshold value of 0.70. Therefore, only values above the threshold were employed in further analysis.

Table 5.12: Reliabilities and average variances extracted for domestic respondents

Constructs	**No of items**	**Composite reliability (α)**	**Recommended value (Vicente and Reis, 2008)**	**Average variance extracted**
Reuse Advantages (ADV)	3	0.82	> 0.70	0.85
Trust (TRU)	4	0.73		0.77
Attitude (ATT)	5	0.68		0.84
Control over source of water (CON)	3	0.81		0.71
Physical quality satisfaction(PQS)	2	0.43		0.46
Subjective norm (SNO)	3	0.85		0.75
Intention to accept		0.80		0.88

Figure 5.14 shows a simplified schematic of the standardized path coefficients and t-value (in parentheses) of the hypothesized model. As reported in the literature (Fielding *et al.*, 2009; Po *et al.*, 2005) a strong contribution is represented by values greater than 0.40; moderate contribution has a range of values 0.20 - 0.40 and a weak contribution represents values below 0.20. All the paths specified were statistically significant: *reuse advantages* (path coefficient, $\beta = 0.39$, t-value, $p < 0.01$) and *trust in service provider* ($\beta = 0.21$, $p < 0.01$) were found to have moderate contribution to respondents' intention to accept non-potable water. These variables, therefore, support hypotheses H1 and H2 respectively. *Attitude* ($\beta = 0.60$, $p < 0.01$) and *control* ($\beta = 0.59$, $p < 0.01$) have strong contributions to respondents' intention to accept non-potable water. Thus, hypothesis H3 and H4 were also supported by the constructs.

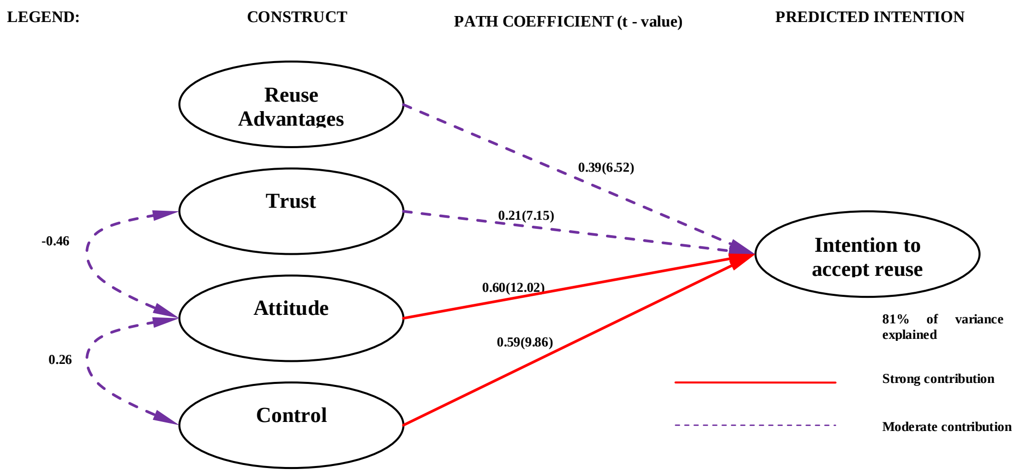


Figure 5.14: Simplified Path coefficient of potential institutional consumers' perception in Capricorn and Vhembe

Figure 5.15 shows the simplified schematic of the standardized path coefficients and t-value (in parentheses) of the hypothesised model. All the paths were statistically significant: *reuse advantages* (β = 0.62, p < 0.01), *trust in authority* (β = 0.44, p < 0.01), *attitude* (β = 0.44, p < 0.01) and *control* (β = 0.55, p < 0.01) were found to have strong contributions to respondents' intention to accept non-potable water. These variables therefore support hypotheses H1, H2, H3 and H4. However, subjective norm (β = 0.33, p < 0.01) has moderate contributions to respondents' intention to accept non-potable water. Thus, H5 was supported moderately.

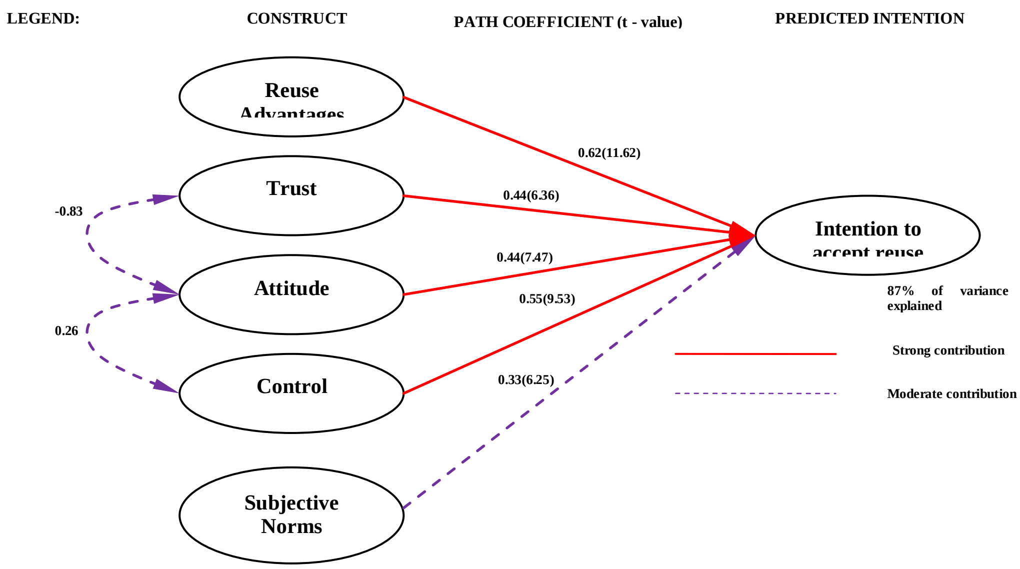


Figure 5.15: Simplified version of the perception analysis for potential domestic consumers in Capricorn and Vhembe

- ***Implication of the results***

i. The constructs that primarily influence intention to accept wastewater reuse amongst institutional consumers are firstly, their *attitude towards wastewater reuse* and secondly, the degree of *control over the source of water and its application* within their institution. Secondary influences (which are not as strong as primary influences) are the institutions' appreciation of the *advantages of reuse on the environment* and *trust in the service provider* to provide a reliable and efficient service. However, *physical quality satisfaction* of the treated wastewater and *subjective norms* has minimal to no influence on potential institutions intention to accept wastewater reuse. The result for *physical quality satisfaction* is logical considering that most institutions carry out additional, treatment of the effluent prior to reuse.

ii. For domestic respondents, the constructs that primarily influence intention to accept wastewater reuse amongst domestic respondents are firstly, their appreciation of the *advantages of reuse on the environment* and secondly, the degree of *control over the source of water and its application*. Respondents *attitude towards wastewater reuse* and *trust in the service provider* to provide a reliable and efficient service also have a strong influence on intention to accept wastewater reuse. The only secondary influence is the subjective norms of the respondents. Similar to what was obtained in institutional respondents, *physical quality satisfaction* has no influence on potential domestic respondents' intention to accept wastewater reuse. This is a strange result as households are expected to be very concern about the physical appearance of the reclaimed water. However, this may probably be due to the expected non-potable reuse of reclaimed water with little human contacts.

Based on the results of 1 and 2 above, the users' perception module in the DSS was developed with different weights assigned to the statements according to their influence on intention to accept wastewater reuse. The approached adopted in the development of the service providers' perception module in the DSS is explained in section 5.4.

5.4 Regulatory Institution and Service Provider's Assessment

Assessment of regulatory institution and service providers' capacity to effectively operate a reuse scheme is essential to successful implementation of reuse programme. A holistic assessment exercise with sustainable results should ideally incorporate the Triple Bottom

Lines (TBLs) attribute of sustainability that cut across technical and economic, social, institutional and regulatory (including legal and legislation) and environmental (including public health and safety) factors.

According to Ilemobade *et al.* (2008), the TBLs approach involves the following:

i. goals to be measured
ii. criteria which determine whether the goals are achieved
iii. assessment questions/statements by which each criteria is measured, and
iv. a range of scores for measuring each criterion.

Any number of goals and criteria can be selected. In developing goals and criteria, the following important rule must be followed (CRD, 2007):

i. independent;
ii. non-duplicative;
iii. measurable; and
iv. exhaustive/comprehensive.

These rules facilitate an objective approach to achieving the stated goals for each system and measuring these goals will reveal the performance of one system compared to another, which is critical in decision making process.

As reported in Ilemobade *et al.* (2008), the 7 key issues employed in the social surveys formed the backbone for the framework, with each key issue generating a list of items to be evaluated (see Appendix D for questionnaires detail). The framework was categorised using the different aspects of the TBL of sustainability. Weights were allocated to each of the key issues based on the weighted average rank allocated by respondents when asked to rank the seven key issues in order of importance when planning a wastewater reuse systems (Table 5.13). These weights determined the level of importance given to the key issues within the framework. From Table 5.13, it is interesting to note that consumers gave higher priorities to key issues which are traditionally high on decision-makers' priorities (i.e. public health and safety, economics, etc.). As such, issues that are very important to consumers such as social acceptance and public education were ranked the least important. It is important to note that several reuse projects (e.g. the Dublin County Clean Water Revival Project, California) have failed in the past due to the lack of social acceptance (Po *et al.*, 2003) and as such, decision-makers must pay adequate attention to social acceptance and public education especially for a reuse project.

Table 5.13: Critical issues to be considered in planning water reuse system in order of priority (Ilemobade *et al., 2008*)

Key issues	Service provider ranking	Decision-makers ranking	Overall ranking	Overall weight
Public health and safety	1	2	1	1.00
Economics	2	3	2	1.16
Technical/Engineering	5	1	3	2.09
Regulation	3	5	4	2.28
Organisational capacity	4	6	5	2.44
Social acceptance	7	4	6	2.84
Public education	6	7	7	2.85

Table 5.14 presents the framework of goals, criteria, assessment questions/statements and scores for assessing technical and economic; social, institutional and regulatory; environmental, public health and safety; and recycled water education, public enlightenment and legislation. The framework was developed primarily from the surveys administered, case study and other source materials (i.e. CRD, 2007; DWAF, 2006; Dimitriadis, 2005; Mukheibir and Sparks, 2005).

The framework in Table 5.14 was simplified into questionnaire in the DSS. The DSS user is expected to print out the template of the questionnaires and administer it to the decision makers/service providers. Responses from the questionnaire administered are feedback into the DSS for analysis. The DSS uses Boolean factor to determine the criteria score in accordance with Loetscher and Keller (2002). The user's input (i.e. ***Yes, I don't know*** or ***No***) is converted into ***1, 2*** or ***3***. The result obtained by summation of all questions/statements is then aggregated to obtain standardized outcome indices for public health and safety, economical efficiency, organizational capacity and trust, and social acceptance.
Arithmetic mean is used to aggregate the standardized value obtained in questions/statements involved in DSS questionnaires using the expression below:

$$a_j = \frac{1}{m}\sum_{i=1}^{m} wx_{ij} \qquad 5.1$$

Where a_j = aggregation result for assessment criteria j (j = 1, 2, 3, 4…n)

x_{ij} = merit of criteria j with regard to statement i (i = 1, 2, 3, 4…m)

w_i = weight of criteria *I i* (i = 1, 2, 3, 4…m)

As a guide, the assessment result based on the aggregated weighted mean of real scores for the perception survey interpretation is shown in Table 5.15.

Table 5.14: Framework for assessing triple bottom lines attribute of sustainability (Ilemobade *et al., 2008*)

Goal	Criteria	Assessment Questions/Statements	Score			Weight	Range of Scores
			1	2	3		
Technical feasibility	Potable water savings	Percentage of potable water savings due to non-potable water use	Significant (> 10 %)	Moderate (5 – 10 %)	Insignificant (< 5 %)	2.09	2.09- 6.27
	Potential supply to current demand	Ratio of potential non-potable supply to current demand for non-potable water supply	Significant (> 2)	Moderate (1 – 2)	Insignificant (< 1)	2.09	
	Distance	Average distance between potential supply and demand	Insignificant (> 0.5 km)	Moderate (0.5 – 1.0 km)	Significant (< 1.0 km)	2.09	
	Non-potable water use/reuse	Potential for human contact with the non-potable water	Insignificant	Moderate	Significant	2.09	
	Treatment technology	Treatment technology is available?	Locally available	Nationally available	Must be imported	2.09	
	Ease to retrofit	Ease to retrofit a dual system?	Significant	Moderate	Insignificant	2.09	
	Supply reliability	Reliability of non-potable water supply	Significant	Moderate	Insignificant	2.09	
	Treatment quality reliability	Treatment technology meets effluent quality requirements under expected operating conditions?	Significant	Moderate	Insignificant	2.09	
	Operation & Maintenance	Level of skill required to operate and maintain the dual system	Low	Moderate	High	2.09	
	Utilise existing infrastructure	Potential to utilise existing infrastructure (e.g. WWTW)	Significant	Moderate	Insignificant	2.09	
	Upgradeability	Extent dual system can be readily expanded to supply future flows?	Significant	Moderate	Insignificant	2.09	
Technical sustainability	Long-term applicability	Period of impact of the system? (short to long term)	Significant (> 10 yrs)	Moderate (3-10 yrs)	Insignificant (< 3 yrs)	2.09	2.09- 6.27
	Flexibility	Technology can be adapted to meet more stringent effluent standards in the future?	Significant	Moderate	Insignificant	2.09	
	Future supply to current demand	Ratio of future non-potable supply to future demand for non-potable water supply	Significant (> 2)	Moderate (1-2)	Insignificant (< 1)	2.09	
Economic feasibility	Cost difference	Difference in the overall cost of supplying potable and non-potable water	Significant	Moderate	Insignificant	1.16	1.16-3.48
	Savings	Extent of cost savings for non-potable use	Significant	Moderate	Insignificant	1.16	

Goal	Criteria	Assessment Questions/Statements	Score			Weight	Range of Scores
			1	2	3		
	Financial help	Financial assistance/incentives for non-potable use	Significant	Moderate	Insignificant	1.16	1.16-3.48
	Job creation	Potential for creation	Significant	Moderate	Insignificant	1.16	
Social feasibility	Disgust	Extent of ‘disgust’ to non-potable water use	Insignificant	Moderate	Significant	2.84	2.84-8.52
	Acceptance	Acceptability of the wastewater reuse system by the community	Significant	Moderate	Insignificant	2.84	
	Aesthetics	Unpleasant sight, noise and/or odour emissions from the system	Insignificant	Moderate	Significant	2.84	
	Trust/confidence in service provider	Consumers’ level of trust and confidence in the potable water service	High	Moderate	Low	2.84	
Institutional feasibility	Local capacity	Availability of institutional capacity to operate the system	Significant	Moderate	Insignificant	2.84	2.84-8.52
	Acceptability	Acceptability of wastewater reuse system by decision makers	Significant	Moderate	Insignificant	2.84	
Regulative availability	Regulation	Municipality Regulations/by-laws available to guide system planning and operation	Significant	Moderate	Insignificant	2.84	
Environmental feasibility	Erosion and scouring	Anticipated increase in erosion and scouring in receiving water course?	Insignificant	Moderate	Significant	1.0	1.0-3.0
	Flow regimes	Anticipated unnatural alterations of flow regime in the receiving water course?	Insignificant	Moderate	Significant	1.0	
	Water quality	Anticipated negative changes in water quality in the receiving water course?	Insignificant	Moderate	Significant	1.0	
	Wetlands	Extent to which wetland will be negatively affected and/or wetland value diminished?	Insignificant	Moderate	Significant	1.0	
	Habitats	Extent to which habitats in the downstream water course will be disrupted?	Insignificant	Moderate	Significant	1.0	
	Downstream availability	Anticipated decrease in downstream water availability for users due to upstream reuse?	Insignificant	Moderate	Significant	1.0	
	Energy efficiency	Application of technology results in	Insignificant	Moderate	Significant	1.0	

Goal	Criteria	Assessment Questions/Statements	Score			Weight	Range of Scores
			1	2	3		
		greenhouse gas emissions?					
Public health and safety	Monitoring and control	Monitoring and control systems in place to minimise public health hazards?	Significant	Acceptable	Insignificant	1.0	1.0-3.0
	Risks	Health risks to O&M staff or consumers?	Low	Acceptable	High	1.0	
	Liability	Insurance cover in case of system failure?	Significant	Acceptable	Insignificant	1.0	
Public education	Education/Awareness	Current level of education/awareness about non-potable water use	High	Acceptable	Low	2.85	2.85-8.55
	Public education	System implementation enables public education opportunities to be maximised	Significant	Acceptable	Insignificant	2.85	

Table 5.15: Interpretation of aggregated weighted mean of real scores (Ilemobade *et al.*, *2008*)

Real Scores	Interpretation
5.9-8.6	Very high potential to be viable
8.6-11.4	High potential to be viable
11.4-14.2	Middle to low potential to be viable
14.2-17.5	Unlikely to be viable

5.5 Summary

Descriptive analysis of the major variables in CoCT shows that non-potable water is used mainly for irrigation of sports fields with little industrial and public applications. All industries that use non-potable water carried out further treatment before usage while no further treatment was carried out in the case of irrigation purposes. The desire to use non-potable water is boosted by proximity to the non-potable water source. However, the consumers tend to appreciate the price of non-potable water that is considered affordable when compared to the price of potable water which is generally viewed as expensive.

Revised Ajzen's TPB was used to predict intention to accept treated wastewater for non-potable uses in Capricorn and Vhembe. The results explained how the TPB constructs (*attitude, subjective norms* and *perceived behavioural control*) and additional factors (*trust, physical quality satisfaction* and *reuse advantages*) affect respondents' intention to use treated wastewater. In general, the findings from the investigated institutional and domestic respondents support hypotheses H1, H2, H3, and H4 which represent *reuse advantages, trust, attitude* and *control* over source of water respectively. H5 which represents *subjective norms* is only supported in the analysis of domestic respondents. The non-significance of *physical quality satisfaction* in predicting intention to accept reuse in domestic and institutional respondents may be attributed to low human contact of the anticipated usage. In the further analysis of the factors that underpin the intention to accept or reject treated wastewater reuse, *physical quality satisfaction* was eliminated. Thus, hypothesis H6 was therefore, not supported and eliminated in the analysis of domestic and institutional respondents. The finding of Jeffrey and Jefferson (2002) that people in the UK often relied on the physical appearance of recycled water to assess water quality and decide whether they could accept or reject it, was not supported in this project's findings. In the final analysis, the hypothesized model successfully accounted for 81% and 87% variance of the intention to accept treated wastewater by potential institutional and domestic users respectively.

According to the path coefficient in Figure 5.14 and 5.15, *attitude* exhibited the strongest (0.60, 0.62) predictor of intention to accept treated wastewater in both institutional and domestic respondents' analysis. This is supported by Po *et al.* (2005) in a similar research conducted in Perth, Australia. Therefore, for any wastewater reuse project to be successful in South Africa, the attitude of the potential beneficiaries must be adequately addressed. Attitudes towards wastewater reuse may be addressed through public awareness campaigns that target issues such as current and/or predicted water shortages and environmental impacts of wastewater discharge into sensitive ecosystems may be employed. These campaigns using newspapers, fliers, billboards, radio and TV programs, newsletters, symposia, workshops, exhibitions, teaching curriculum in schools and stakeholders' meetings have been proven to build broad-based community support for wastewater reuse projects in many communities (e.g. City of Tampa's residential reclaimed water project, Florida) (USEPA, 2004).

Also, *reuse advantages* and *trust* have strong (0.62, 0.39) and moderate (0.44, 0.21) impact in the prediction of intention to accept treated wastewater by domestic and institutional respondents respectively. Hence the more proactive respondents are about *reuse advantages*, the more likely they will accept wastewater reuse. However, *trust* in the implementing authority does not have such a strong effect on the intention to accept wastewater. Po *et al.* (2005) show that *trust* in the Water Corporation of Western Australia to provide safe recycled water was one of the main reasons for people's willingness to use recycled water. The result further strengthens the need for public awareness campaigns to sensitize the beneficiaries about treated wastewater reuse in addition to building confidence in the quality of treated wastewater produced. *Reuse advantages* (e.g. conserving potable water, postponing costly investment in new water supplies and/or wastewater treatment facilities, a backup water source during drought, reducing of effluent discharges into surface waters and improving soil productivity through the nutrients in treated wastewater) and risks of reuse can be effectively communicated to beneficiaries using the public awareness campaigns. Utilizing treated wastewater in government facilities and high density, high-to-medium income dwellings will also boost public *trust* in implementing authorities.

Similar to *attitude, perceived behavioural control* also has a strong impact on prediction of the intention to accept treated wastewater by domestic and institutional respondents. Legislation that strengthens the right to choose could play a vital role in improving *perceived control* among beneficiaries.

CHAPTER 6

A CASE STUDY OF ASSESSING THE FEASIBILITY OF IMPLEMENTING WASTEWATER REUSE AND TESTING OF THE DECISION SUPPORT SYSTEM

6.1 Introduction

As stated in Section 3.2, preliminary investigations prepare the foundation upon which the decision to implement wastewater reuse as part of water conservation and management are based. Data required to justify reuse are: background information of the area, water balance of the area, current water supply situation, potential consumers, reuse activities that are likely to attract public interest and the existing laws and regulation that would affect reuse in the area.

6.1.1 Basic Background Information of Cape Town

6.1.1.1 Location

The CoCT is located in the Western Cape Province on the south-eastern corner of South Africa. The total area is approximately 2 474 km^2 and its coastline is 371 km long.

6.1.1.2 Climate

Cape Town has a mean annual rainfall of 515mm/annum and an average temperature of 16.7^{o}C. The town is a winter rainfall area. The meteorological depressions that typically bring rain to this area during winter move past to the south of the area during summer; resulting in long dry spells. It is during the dry summer that the water demands are highest, due to the higher temperatures and the fact that watering of gardens is the norm in almost all the residential areas. This contrast complicates the management of a bulk water supply system, as sufficient run-off needs to be stored during winter in order to meet the increased water demand in the hot and dry summer months.

6.1.2 Water Balance of CapeTown

Surface water represents 440.5 Mm^3/year, or 97.1% of the total yield. The City currently obtains 70 to 75% of its raw water requirements from DWAF and the remainder from its own sources. Groundwater resources make up 6.64 Mm^3/year yield, representing only 1.46% of the total yield as shown in Table 6.1 (CoCT, 2006).

Table 6.1: Surface and groundwater resources

Source	Classification/ Names of Source	Owned and Operated by	Yield (Mm^3)	CoCT Registered Usage (Mm^3)	% of Total Supply
Surface water	**Major Sources**				
	Theewaterskloof Dam/ Kleinplaas Dam	DWAF	219.00	120.00	48.30%
	Voëlvlei Dam	DWAF	105.00	70.50	23.20%
	Palmiet River	DWAF	22.50	22.50	5.00%
	Wemmershoek Dam	CoCT	54.00	54.00	11.90%
	Steenbras Upper and Steenbras Lower Dam	CoCT	40.00	40.00	8.80%
	Sub Total		***440.50***	***307.00***	***97.10%***
	Minor Sources				
	Lewis Gay Dam, Kleinplaas	CoCT	1.85	1.85	0.40%
	Land en Zeezicht Dam	CoCT	0.50	0.50	0.10%
	Woodhead Hely-Hutchinson De Villiers Dam Victoria Dam Alexandra Dam	CoCT	4.00	4.00	0.88%
	Sub Total		***6.35***	***6.35***	***1.38%***
Groundwater					
	Albion Spring	CoCT	1.64	1.64	1.46%
	Atlantis (44 boreholes)	CoCT	5.00	5.00	
	Sub Total		***6.64***	***6.64***	***1.46%***
	Grand Total		**453.50**	**320**	**100%**

The total bulk water treated for 2004 was 310 Mm^3/ annum (about 850Ml/day), dropping to 282 Mm^3/ annum (about 775Ml/day), for 2005 as a result of the restrictions (20% reduction in water use) triggered by the drought and effective water distribution management measures (see Section 6.1.3) and increasing again in 2006 to 294 Mm^3/ annum (about 806Ml/day), as shown in Figure 6.1. With the current implementation by DWAF of the Berg River Scheme, the existing water resources supplying water to Cape Town will be sufficient at least until 2013 (CoCT, 2006).

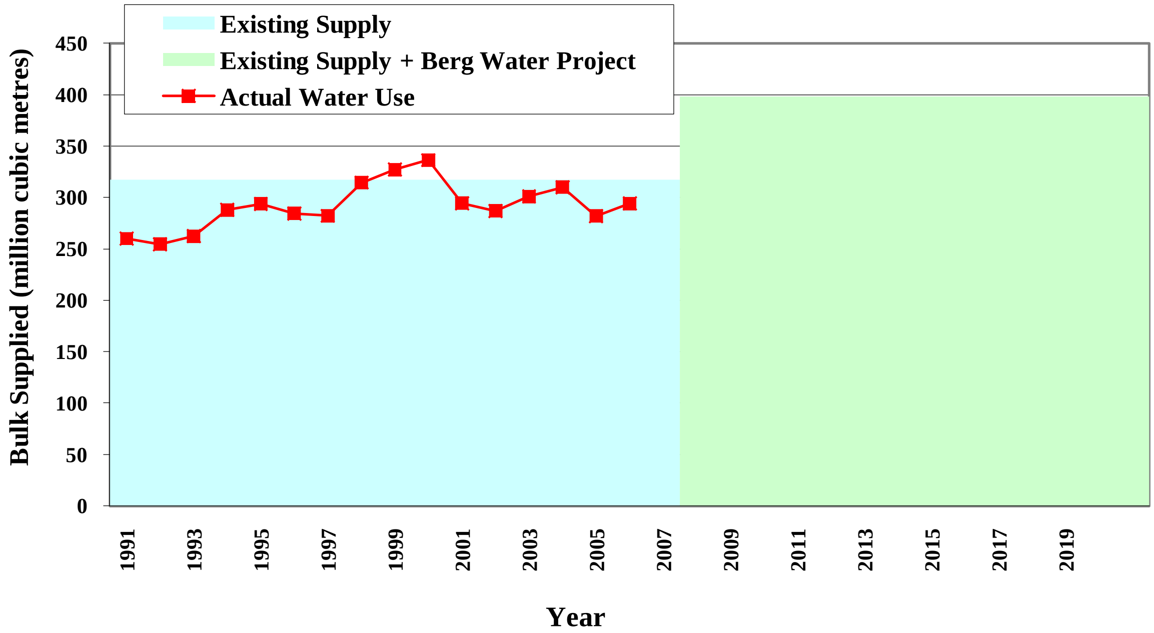


Figure 6.1: Water supply in the City of CapeTown

The available water resources in the CoCT are utilized as shown in Figure 6.2. Losses in bulk water supply are due to leakages and unaccounted for water (UAW).

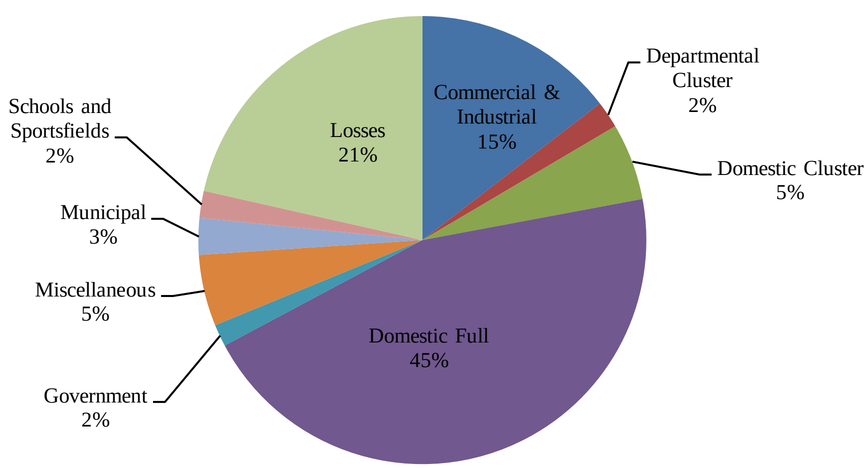


Figure 6.2: Water utilization in the City of CapeTown

6.1.3 Water conservation and demand management (WC/WDM) in the City of CapeTown

Cape Town is a large city of approximately 3.5 million people that is expected to consume increasingly more water, because of population and economic growth. The availability of water resources and adequate bulk water and wastewater infrastructure to meet the growing water demand in the City of Cape Town (CCT) is a limiting constraint to the social and economic prosperity of the city. As early as in 1995 City of Cape Town committed itself to a 10% saving on the historical demand growth of 4 % per annum (CoCT, 2006)..

Water conservation and demand management of CoCT is aimed at protecting water source and the environment by limiting water abstracted from rivers and also reducing the pollution discharged through the wastewater reuse. The research conducted by the CoCT in 2004 on demand analysis concluded that water demand can be reduced by 323Ml/day through WC/WDM (CoCT, 2006). Table 6.2 illustrates where the various opportunities exist within each water sector.

Table 6.2: Components of WD/WCM that will achieve the savings envisaged

Savings Component	**Max. Saving**	**% Savings targeted**	**Targeted Savings (Ml/day)**	**Activities to achieve savings**
Reduction of UAW (leaks only)	93.00	60%	55.80	Comprehensive reticulation management programme
Inefficient water consumption in poor areas	39.20	75%	29.40	Comprehensive management programme in poor communities
Inefficient water consumption of business/industry	77.00	80%	61.60	• behavioural change • retrofitting • leak repair
Inefficient water consumption of domestic	148.70	75%	111.50	• behavioural change • retrofitting • leak repair • effective tariff
Recycling and alternative water resources	87.00	75%	65.30	• effluent recycling • rainwater harvesting
Total	**444.80**		**323.50**	

6.1.3.1 Pressure/leakage reduction

In 2006, the average water pressure in Mfuleni township was reduced from 7 to 4 bar to generate a savings of 36 000 kl (R200 880.00) per month. The night flows were significantly reduced by more than 50%. The project cost was estimated to be R300 000.00 and have a very short payback period of 2 months. Similar project was also implemented in Gugulethu that resulted in a savings of 48 180kl (R268 844.00) per month with a payback period of 1 month.

6.1.3.2 Public information and education programmes

Water consumers in CoCT have been made aware of the need to save water through efficient public enlightenment campaigns. Many shopping malls have been targeted in recent time in addition to the Airwave media. Display stands have been set up at most events held around the City including during Local Government Water and Sanitation Weeks.

The awareness and education campaign ‘Hlonipha Amanzi” organised primarily in informal settlements is aimed at ensuring that water is not wasted through lack of knowledge, once fully serviced plots are provided. This is a pragmatic way of dealing with water wastage before implementing any water project.

6.1.3.3 Treated Wastewater Reuse

Two thirds of the City’s water consumption ends up in more than 22 Wastewater Treatment Works across the City (Fig 6.3) from where final effluent is normally discharged back into the environment. The opportunity for re-using the treated effluent has not yet been fully exploited.

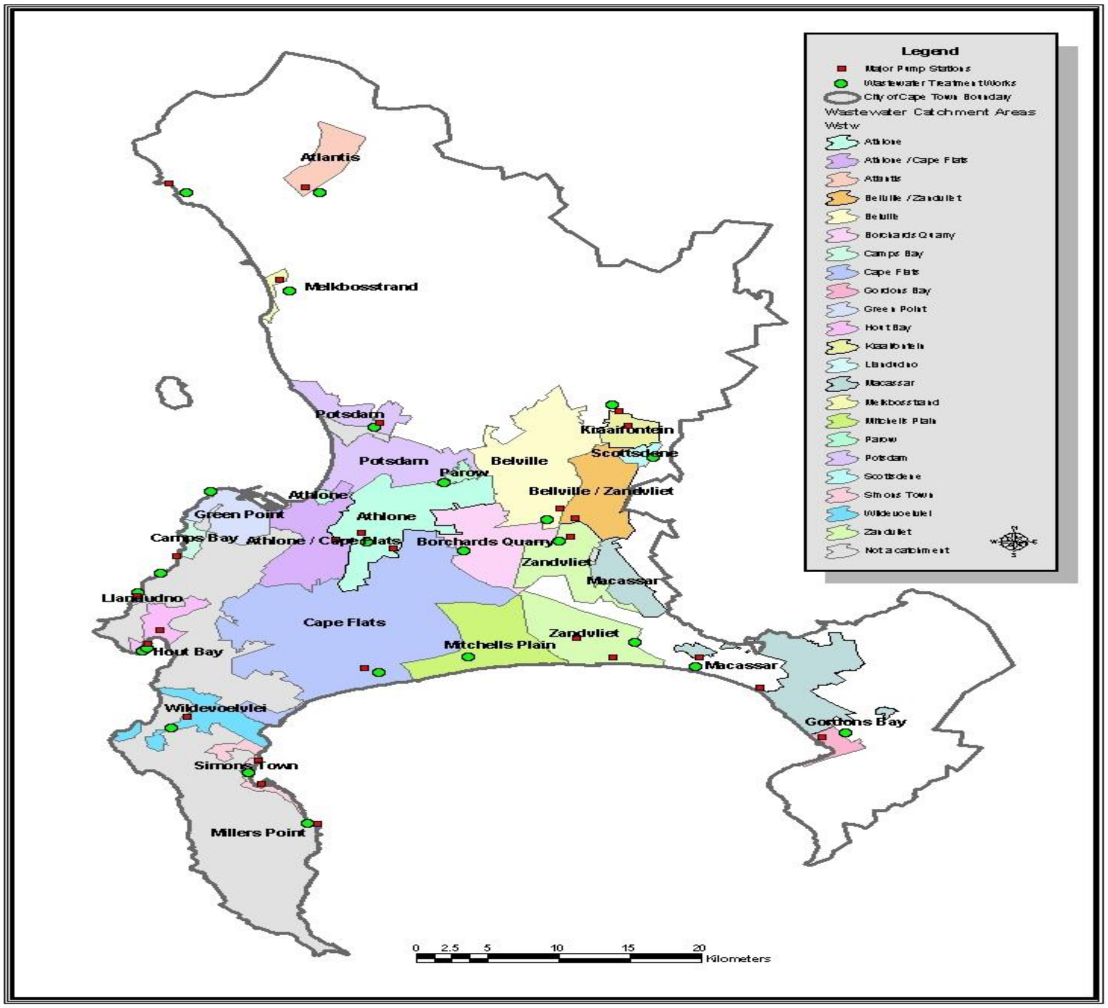


Figure 6.3: Location of Wastewater Treatment Infrastructure in CoCT

Thus far, the majority of Golf Courses in the City are using treated effluent for irrigation purposes, so also some parks, sport fields and schools. A limited number of Industries (e.g. Caltex refineries and Sappi Paper) using treated wastewater are also benefiting from the lower tariff. The total existing average daily summer re-use is estimated at 80.50 Ml per day with further potential reuse of 75Ml/day (Table 6.3).

Table 6.3: Current, potential and total potential treated wastewater reuse in CoCT

Wastewater treatment works	Average volume of wastewater treated (Ml/day)	Peak daily summer reuse (Ml/day)	Potential reuse (Ml/day)	Current and potential reuse (Ml/day)
Athlone	120.00	3.50	11.80	15.30
Bellville	56.00	7.30	12.20	19.50
Borcherds Quarry	30.00	2.00	No further reuse	2.00
Cape Flats	200.00	6.60	9.50	16.10
Dove	10.00	n/a	n/a	n/a
Gordonsbay	3.50	0.70	1.30	2.00
Klipheuwel	0.03	No reuse	n/a	n/a
Kraaifontein	18.80	8.60	0.40	9.00
Liandudn	0.50	No reuse	n/a	n/a
Macassar	35.00	3.50	7.60	11.10
Melkbosstrand	3.10	2.20	n/a	2.20
Miller's Point	0.03	No reuse	No reuse	No reuse
Mitchells Plain	37.50	No reuse	6.10	6.10
Oudekraal	0.03	No reuse	n/a	n/a
Parow	1.50	1.50	0.40	1.90
Philadelphia	0.08	No reuse	n/a	n/a
Potsdam	32.00	32.10	12.50	44.60
Scottsdene	7.50	6.20	2.10	8.30
Simon's Town	5.00	No reuse	n/a	n/a
Wesfleur (Athlantis)	14.00	4.80	1.60	6.40
Wildevoelvlei	14.00	No reuse	4.80	4.80
Zandvliet	55.00	1.50	4.50	6.00
Total	**643.57**	**80.50**	**74.80**	**155.30**

Grobicki and Cohen (1999) proposed an urban water demand model for water reuse potential in South Africa (Fig. 6.4).

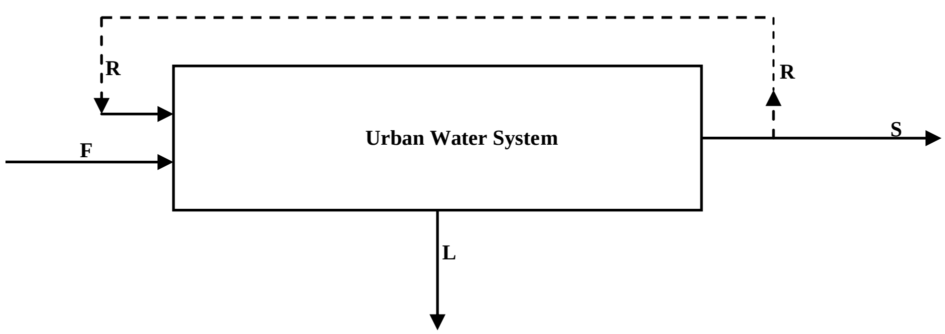


Figure 6.4: A schematic balance of an urban water system incorporating reuse (Grobicki and Cohen, 1999)

Where F = Potable water supply

R = Recycled water supply

L = Losses (e.g. leakages, evaporation, etc)

S = Effluent discharge

A water balance equation for the urban water system represented in Figure 6.4 is given in equation 6.1.

$$F + R = L + S + R \qquad 6.1$$

For the CoCT in 2006, F = 806Ml/d; S = Total wastewater treated – Current reuse = 563.07Ml/d and R = 80.50Ml/d. Therefore, equation 6.1 becomes:

$$806 + 80.5 = L + 563.07 + 80.5 \qquad 6.2$$

$$L = 242.93 \ \sim 27.4\% \ of \ F + R \qquad 6.3$$

If all Current and potential reuse is implemented and losses remain unchanged, then S = 488.30Ml/day and the required potable water supply will be:

$$F + 155.30 = 242.93 + 488.30 + 155.30 \qquad 6.4$$

$$F = 731.23ml/day$$

This implies that daily ***potable water demand can be reduced by approximately 10%*** in the City of CapeTown if all potential reuse is implemented.

6.2 Decision Support System

Decision support systems (DSS) are interactive computer based systems, that help decision makers utilise data and models to solve unstructured problems. Over the last two decades, considerable advances have been achieved in the development of decision support programs as a valuable tool in finding solutions to many engineering and management problems (Ndiritu and Daniel, 2001; Safaa *et al.*, 2002; Ndiritu, 2003; Ilemobade *et al.*, 2005;

Ilemobade and Stephenson, 2006; Kahinda *et al.*,2009). In the field of wastewater treatment engineering, several contributions have been made to arrive at optimum treatment design by the use of computer programs. Many of these programs synthesise treatment trains, evaluate synthesised treatment trains, screen synthesised trains and select optimum treatment trains using different techniques.

6.3 Decision Support System Structure

The name of the DSS developed in this research work is called ***WASWARPLAMO***. ***Waswarplamo*** is an acronym for **Was**te **Wa**ter **R**euse **Pla**nning **Mo**del. It is a software tool developed to assist financiers, engineers, water resources planners and decision makers in improving their planning of successful wastewater reuse projects in South Africa communities. International records of wastewater reuse to date are characterised by both failures and successes testimonies due to several factors - technical, economic, social and institutional. ***Waswarplamo*** is a suit of computer programs that incorporate all these factors in its analysis to assist decision makers to successful implement reuse schemes through improved strategies.

The GUI in this DSS was developed using Java^{TM}. The user-friendly interface was designed as a point and click to provide interactive access to input, output and action screen. The system includes the following modules and sub-modules:

i. *General information*: community name, province and water management area
ii. *Pre-feasibility assessment*: Survey form to ascertain interests in water reuse
iii. *Technical/economic and environment assessment*: treated effluent potential reuse estimation, quality of wastewater source, treatment train general costing information, potential uses and maximum allowable water quality parameters, detailed information of unit processes, treatment unit selection, distribution infrastructure and result of assessments.
iv. *Social and Institutional assessment*: survey of potential consumers and service provider/decision maker.

Each of these consists of many sub-modules which the user is guided through in sequential order to assist in decision making. A schematic flow chart of the DSS is shown in Fig. 6.5. Detail description of the DSS is available in Appendix C.

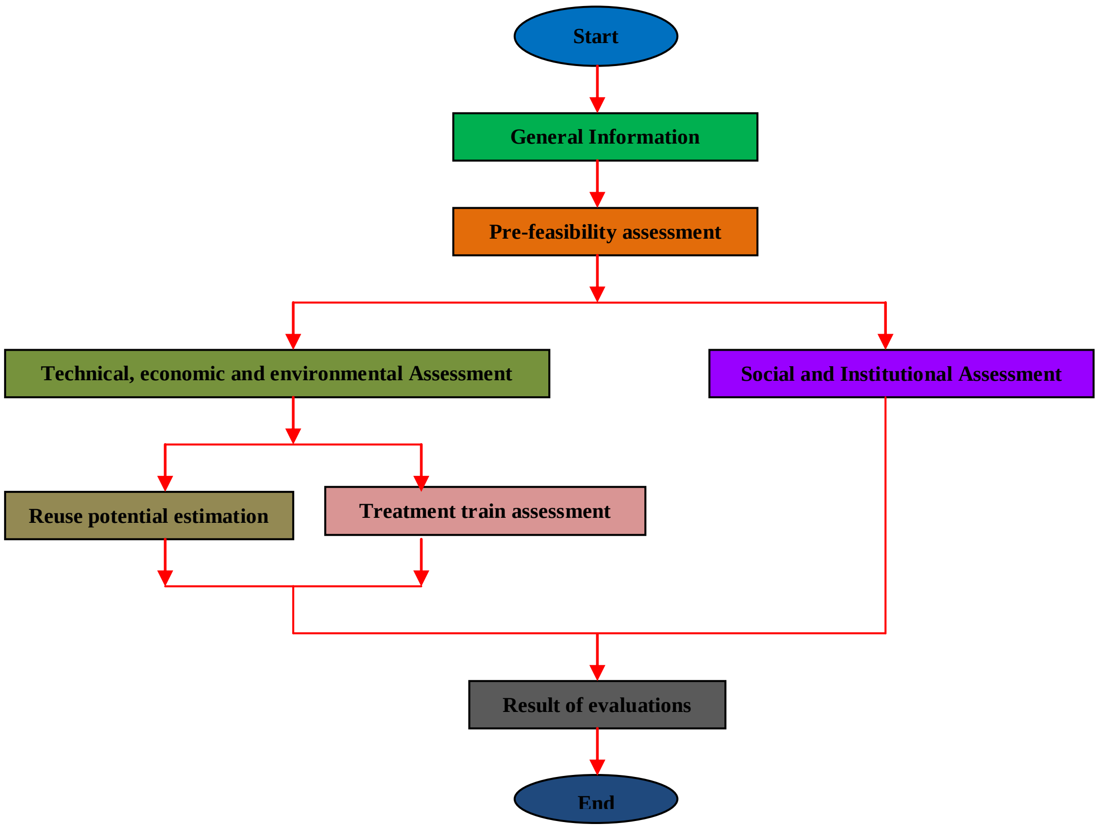


Figure 6.5: Decision support system algorithm

6.4 Testing of the Decision Support System

In order to examine the performance of the developed DSS in achieving the desired purpose, it was applied to Parow Wastewater Treatment Work in Cape Town. This case study examines the technical/economic assessment of the DSS.

6.4.1 Description of the Parow WWTW

Parow is a northern suburb in the city of Cape Town, Western Cape Province, South Africa. It is located about 20 km to the north of the city centre along longitude 33° 54′ 0″ S, latitude 18° 36′ 0″ E. Parow WWTW has a design capacity of 1.2 Ml/d but currently treats 1.0 Ml/d

(85% of design capacity). The treatment trains include extended aeration, activated sludge, maturation pond and chlorine gas for disinfection. All the effluent from the treatment plant is used for irrigation of Parow golf course and football fields for Ajax and Vasco Da Gama football clubs (i.e. location 3, 4, 5 and 6 in Figure 6.6). It can be upgraded to supply treated effluent to irrigate Fairbairn College, Presidential Secondary, Parow North Primary School and Northern Parow Sports Complex (i.e. location 1, 2, 7 and 8 in Figure 6.6). The layout of the Parow WWTW and the locations of treated effluent users with the optimal sizing of the distribution system based on the predetermined layout are shown in Figure 6.6.

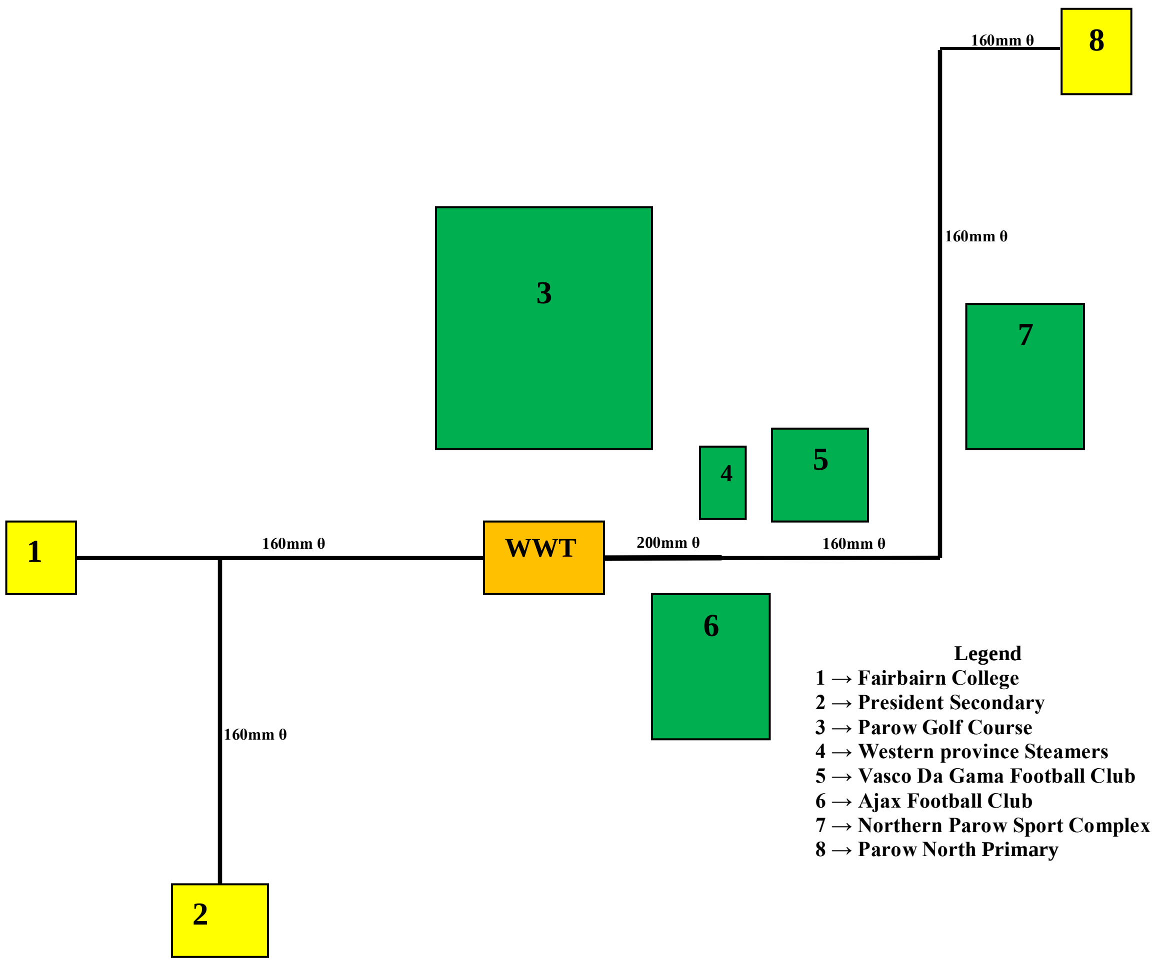


Figure 6.6: Layout of the Parow WWTW and the effluent users location

The Parow WWTW consisted of the following configuration as at April, 2007 (BVi/CoCT, 2007):

Bar screen → grit chamber → aerated activated sludge → maturation pond → gas chlorination.

Using the configuration above, the DSS was used to simulate the treatment performance of the Parow WWTW. The results obtained are discussed in the subsequent sections.

6.4.2 General Information

Figure 6.7 shows the output of the general information on Parow in Cape Town. It is located in the berg water management area.

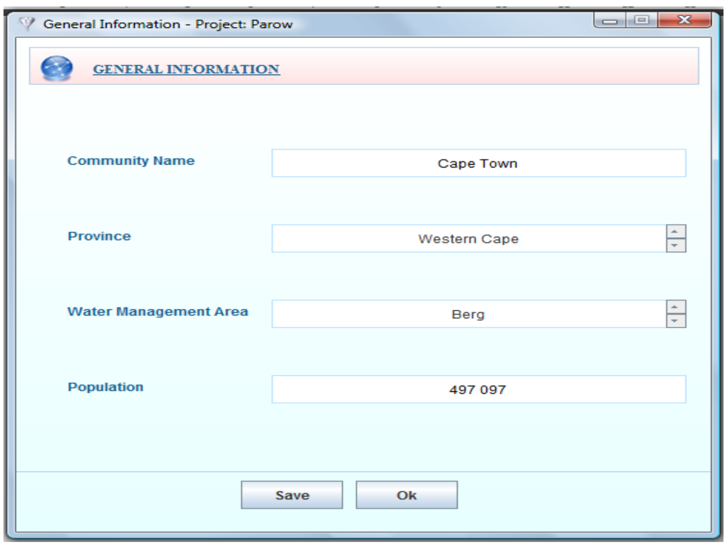


Figure 6.7: Dialog screen showing general information

6.4.3 Reuse Estimation

The annual water demand of each end user for irrigation was determined using the reuse estimation module shown in shown in Fig 6.8. Table 6.4 contains the summary of the annual water demand by each user as estimated.

Table 6.4: Treated wastewater demand at the Parow wastewater treatment plant

End user classification	Name	Summer daily demand (m^3/annum)	Annual demand (m^3/annum)
Schools	Fairbairn college	80	14400
	President secondary	80	14400
	Parow North primary	40	7200
Sports/Parks	Parow golf course	1200	216000
	Western Province steamers	5	900
	Vasco Da Gama football club	150	27000
	Ajax football club	183	32940
	Northern Parow sport complex	180	32400
Total demand		**1918**	**345240**
Dry weather flow		**1500**	**547500**
% of Dry weather flow		**128%**	**63%**

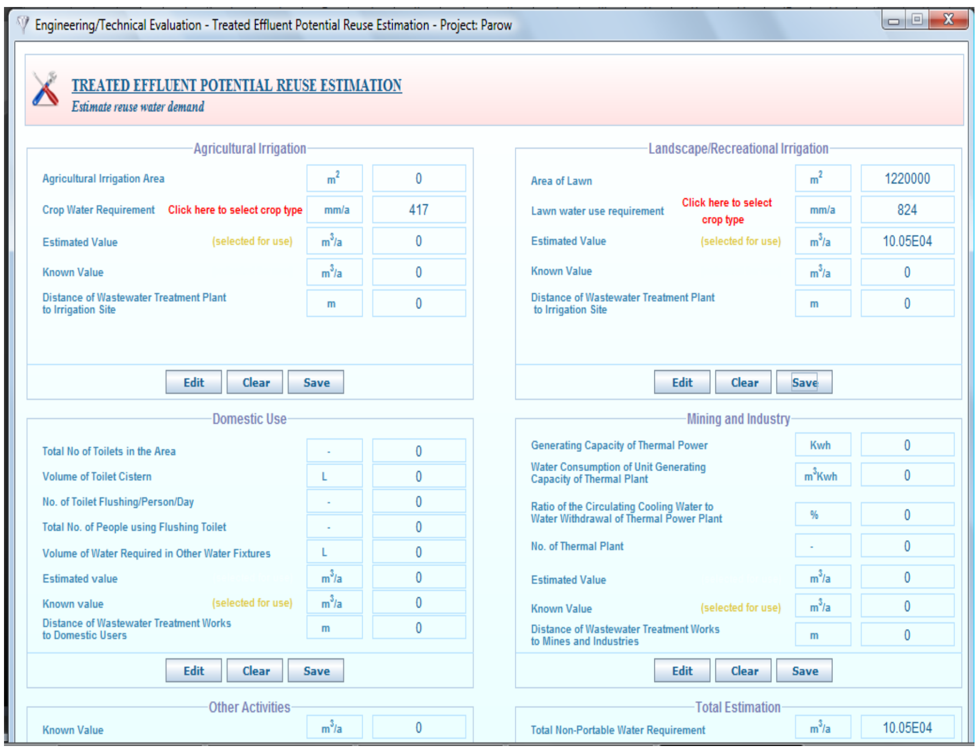


Figure 6.8: Dialog screen showing reuse estimation

6.4.4 Quality of Wastewater Source

Figure 6.9 shows the output of the quality of influent wastewater into the Parow WWTW. The quality of the raw wastewater is to be treated to the minimum water quality required for irrigation purposes.

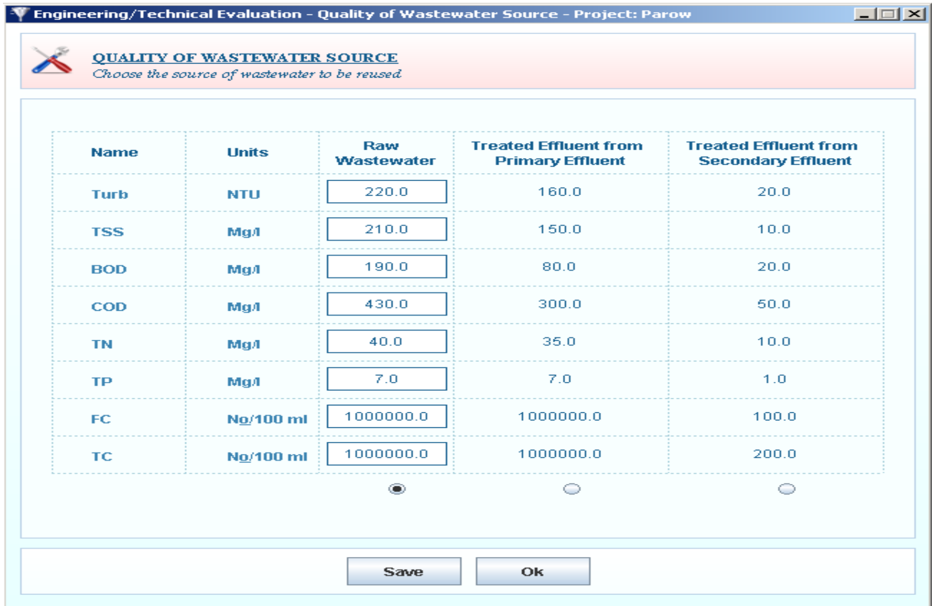


Figure 6.9: Dialog screen showing quality of wastewater to be reused

6.4.5 General Costing Information for the Treatment Train

Figure 6.10 shows the general costing information used in computing treatment train costs.

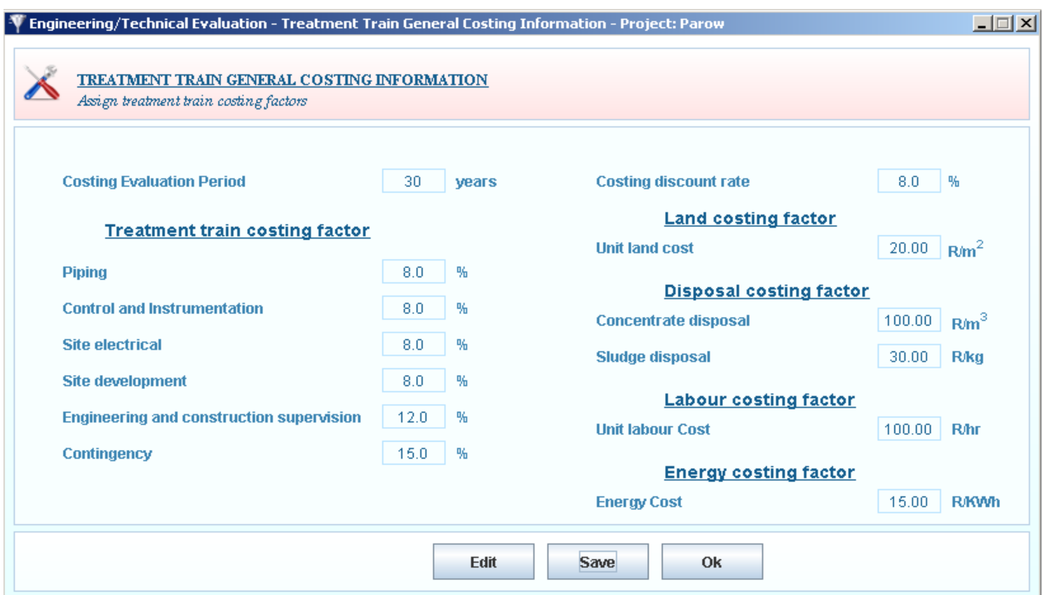


Figure 6.10: Dialog screen showing general costing information for the treatment train

6.4.6 Potential Uses and Maximum Allowable Water Quality Parameters

Since the effluent from the treatment plant is used for irrigation, only irrigation reuse is checked as shown in Figure 6.11

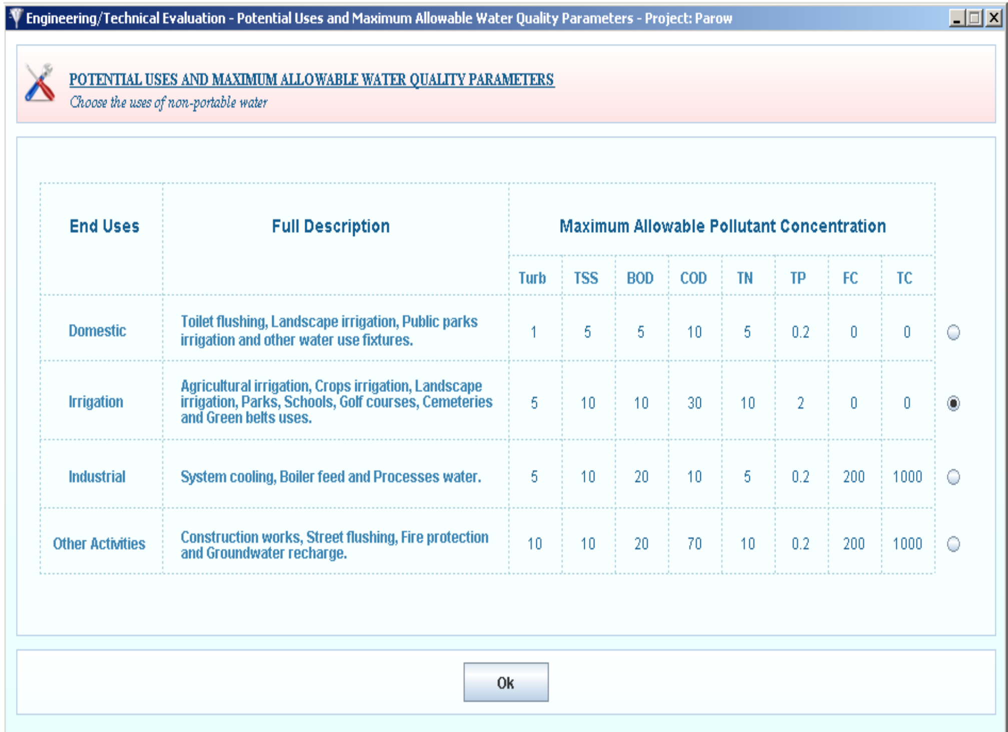


Figure 6.11: Dialog screen showing irrigation uses and maximum water quality parameters

6.4.7 Detail Information on Unit Processes

Since the primary purpose of regulatory inspections is to verify compliance with the DWEA standards, hence, the main concerns are hydraulic and organic loadings of influent flow on one hand and quality of effluent and proper disposal of sludge solids on another. Studies of individual unit processes are neglected in the monitoring process unless a particular unit process is suspected of contributing to non-compliance. As a result, plant personnel do not have data on interrelationships of unit processes needed to provide optimum plant operation. The assessment of a treatment plant requires examination of each unit process to study in detail its operation and how the process functions in the overall treatment scheme (Details of this are provided in Chapter 7).

In this analysis, all the three pollutant removal efficiencies were used. A detail of bar screen unit process is shown in Figure 6.12.

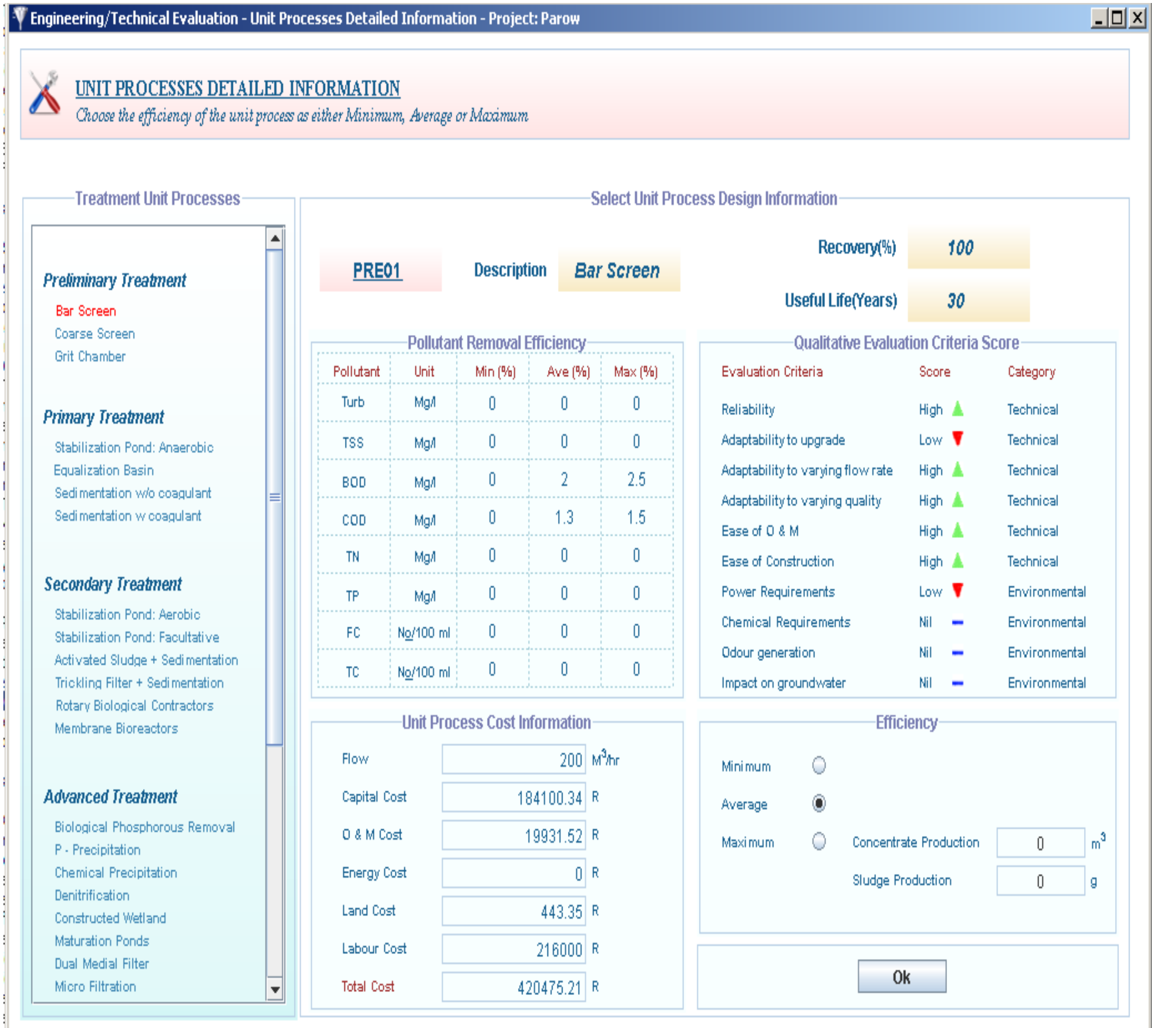


Figure 6.12: Dialog screen showing detailed information about bar screen

6.4.8 Treatment Unit Selection

Treatment Unit Selection page presents a platform for the selection of treatment units combination to make treatment train. Figure 6.13 shows the treatment unit(s) selected at preliminary, primary, secondary, advanced and disinfection treatment stages respectively.

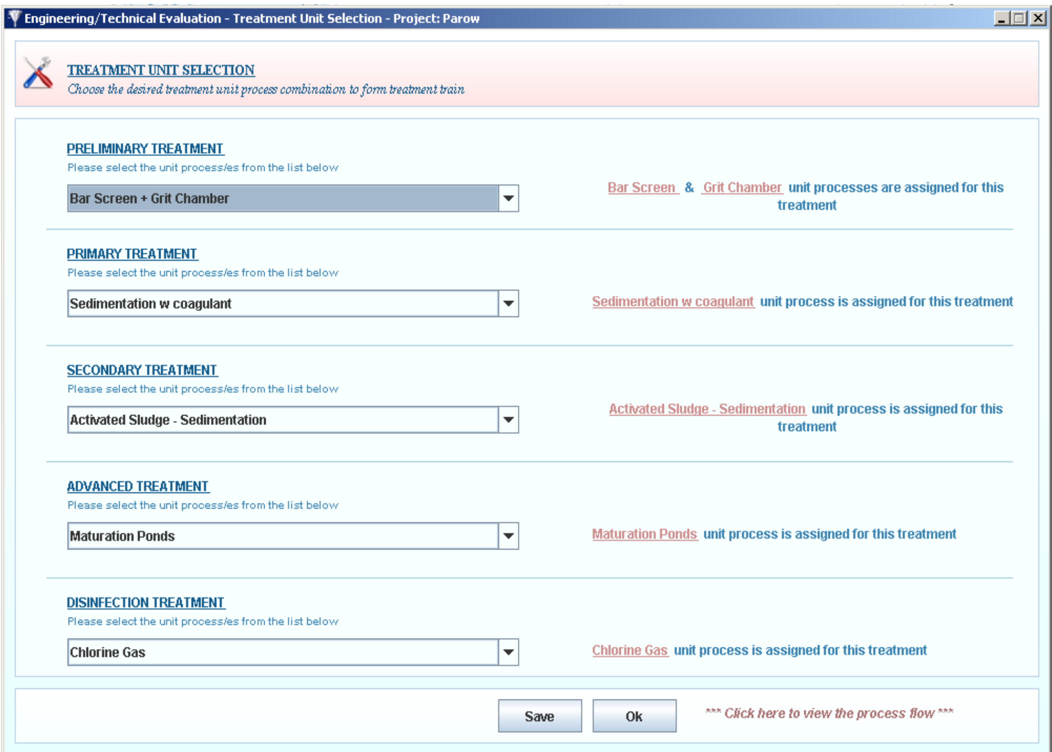


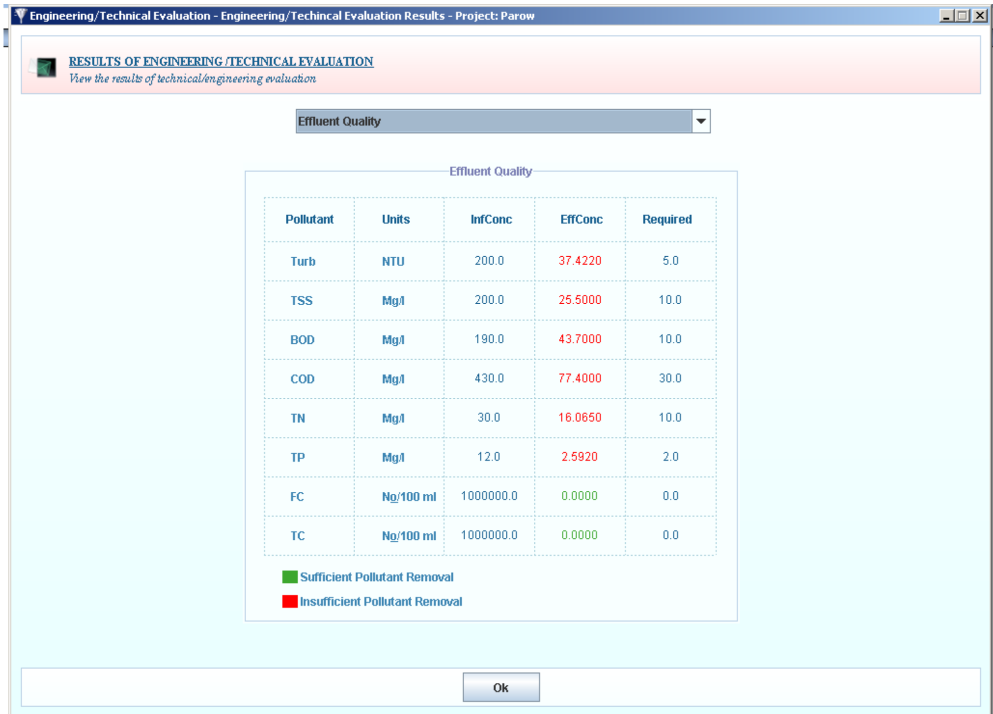
Figure 6.13: Dialog screen showing selection of treatment train

6.4.9 Results

The results of technical/economic analysis are display in three forms as effluent quality, qualitative assessment criteria score and costs, resources and products.

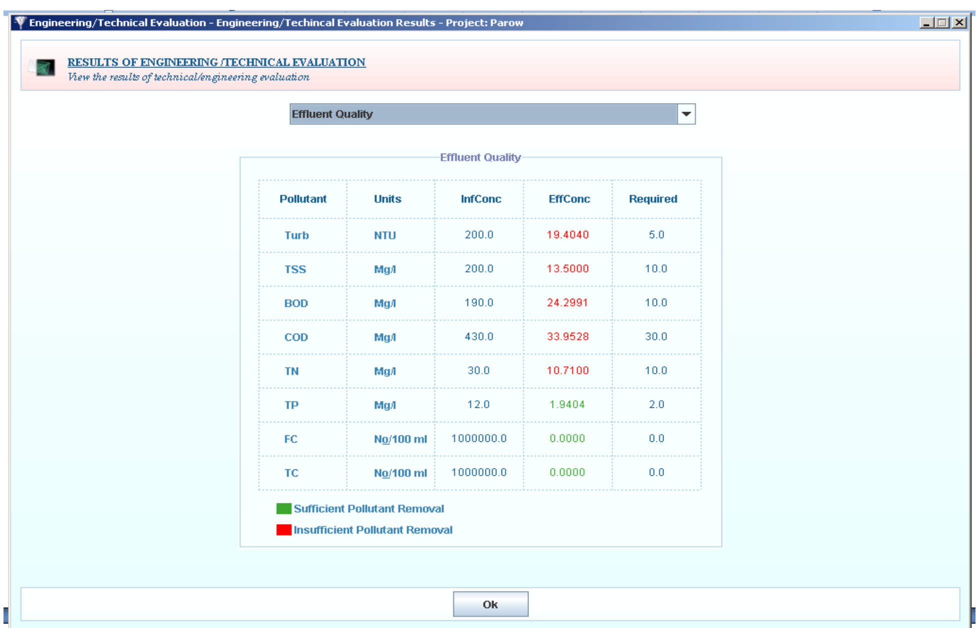
6.4.9.1 Effluent quality

The results of the quality assessment of the treatment train using minimum, average and maximum pollutant removal efficiency are shown in Figure 6.14(a), 6.14(b) and 6.14(c) respectively. In any treatment plant producing reuse effluent, it is expected that all the treatment unit processes should be operating at maximum pollutant removal efficiency. This is necessary to minimise human risks and increase public confidence on reuse project.



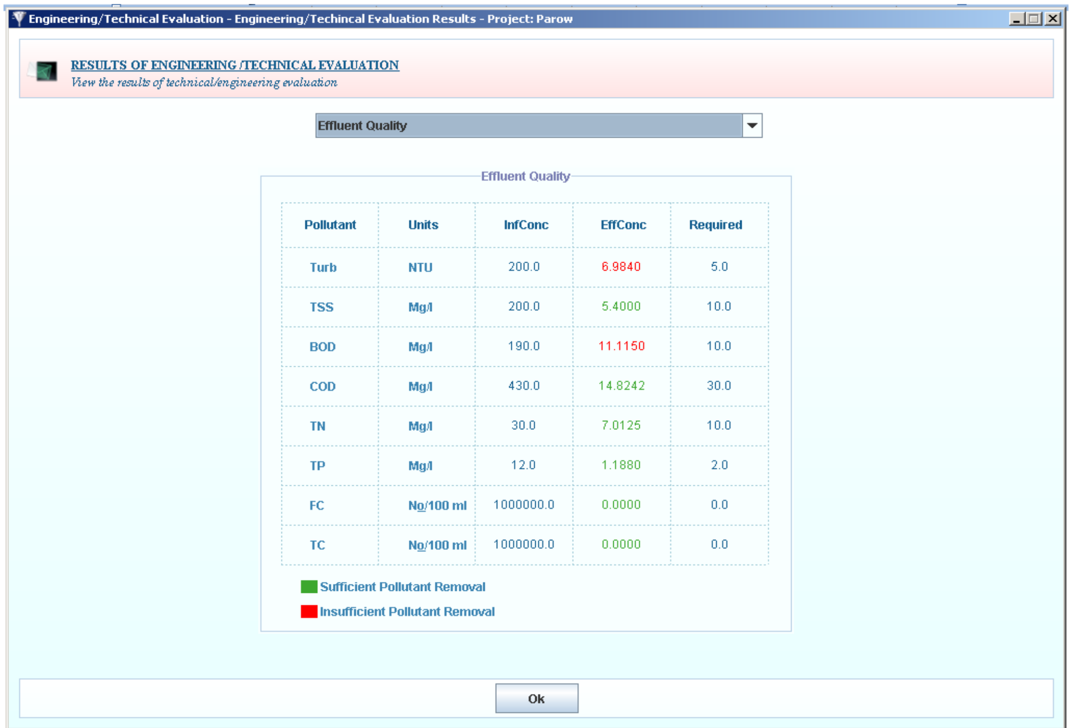
Pollutant	Units	InfConc	EffConc	Required
Turb	NTU	200.0	37.4220	5.0
TSS	Mg/l	200.0	25.5000	10.0
BOD	Mg/l	190.0	43.7000	10.0
COD	Mg/l	430.0	77.4000	30.0
TN	Mg/l	30.0	16.0650	10.0
TP	Mg/l	12.0	2.5920	2.0
FC	No/100 ml	1000000.0	0.0000	0.0
TC	No/100 ml	1000000.0	0.0000	0.0

Figure 6.14(a): Dialog screen showing effluent quality result of the Parow WWTW when treatment units are operating at minimum pollutant removal efficiency



Pollutant	Units	InfConc	EffConc	Required
Turb	NTU	200.0	19.4040	5.0
TSS	Mg/l	200.0	13.5000	10.0
BOD	Mg/l	190.0	24.2991	10.0
COD	Mg/l	430.0	33.9528	30.0
TN	Mg/l	30.0	10.7100	10.0
TP	Mg/l	12.0	1.9404	2.0
FC	No/100 ml	1000000.0	0.0000	0.0
TC	No/100 ml	1000000.0	0.0000	0.0

Figure 6.14(b): Dialog screen showing effluent quality result of the Parow WWTW when treatment units are operating at average pollutant removal efficiency



Pollutant	Units	InfConc	EffConc	Required
Turb	NTU	200.0	6.9840	5.0
TSS	Mg/l	200.0	5.4000	10.0
BOD	Mg/l	190.0	11.1150	10.0
COD	Mg/l	430.0	14.8242	30.0
TN	Mg/l	30.0	7.0125	10.0
TP	Mg/l	12.0	1.1880	2.0
FC	No/100 ml	1000000.0	0.0000	0.0
TC	No/100 ml	1000000.0	0.0000	0.0

Figure 6.14(c): Dialog screen showing effluent quality result of the Parow WWTW when treatment units are operating at maximum pollutant removal efficiency

When the actual performance of the Parow wastewater treatment works (CoCT, 2006) was compared to the result of the DSS, Chemical Oxygen Demand and faecal coliforms removal was similar at average and maximum values. However, the DSS over estimates the Total Suspended Solids and under estimates Total Nitrogen and Total Phosphorus as shown in Table 6.5. As stated in Section 6.4.7, study of individual unit process performances are often neglected in the monitoring process. As a result, plant personnel do not have data on the unit process pollutant removal efficiencies (i.e. minimum, average or maximum). Hence, selecting operating efficiency for an existing treatment train requires good knowledge of each unit's process performance. The DSS thus provides suitable information when data of this nature is unavailable.

Table 6.5: Quality of the Parow WWTW treated effluent in 2006 compared with values obtained using the DSS

Wastewater quality parameters measured	Unit	2006 values			DSS		
		Min	Ave	Max	Min	Ave	Max
Turbidity (Turb)	NTU	-	-	-	37.40	19.40	6.98
Total Suspended Solids (TSS)	mg/L	2.00	14.00	59.00	25.50	13.50	5.40
Biochemical Oxygen Demand (BOD)	mg/L	-	-	-	43.70	24.29	11.12
Chemical Oxygen Demand (COD)	mg/L	31.00	59.00	165.00	77.40	33.95	14.82
Total Nitrogen (TN)	mg/L	0.20	4.90	28.00	16.07	10.71	7.01
Total Phosphorus (TP)	mg/L	4.70	8.10	15.30	2.59	1.94	1.19
Faecal Coliforms (FC)	No/100mL	0.00	10.00	200000.00	0.00	0.00	0.00
Total Coliforms (TC)	No/100mL	-	-	-	0.00	0.00	0.00

6.4.9.2 Qualitative assessment criteria score

Qualitative assessment score of Parow WWTW is shown in Figure 6.15. Under technical criteria, reliability; adaptability to varying flow; adaptability to vary quality; are high while adaptability to upgrade is low. Other technical criteria (ease of construction and ease of O & M) are on average. Under environmental qualitative criteria, power and chemical requirements are low while impact on groundwater is high. The general evaluating score is 0.73. This is a good qualitative score.

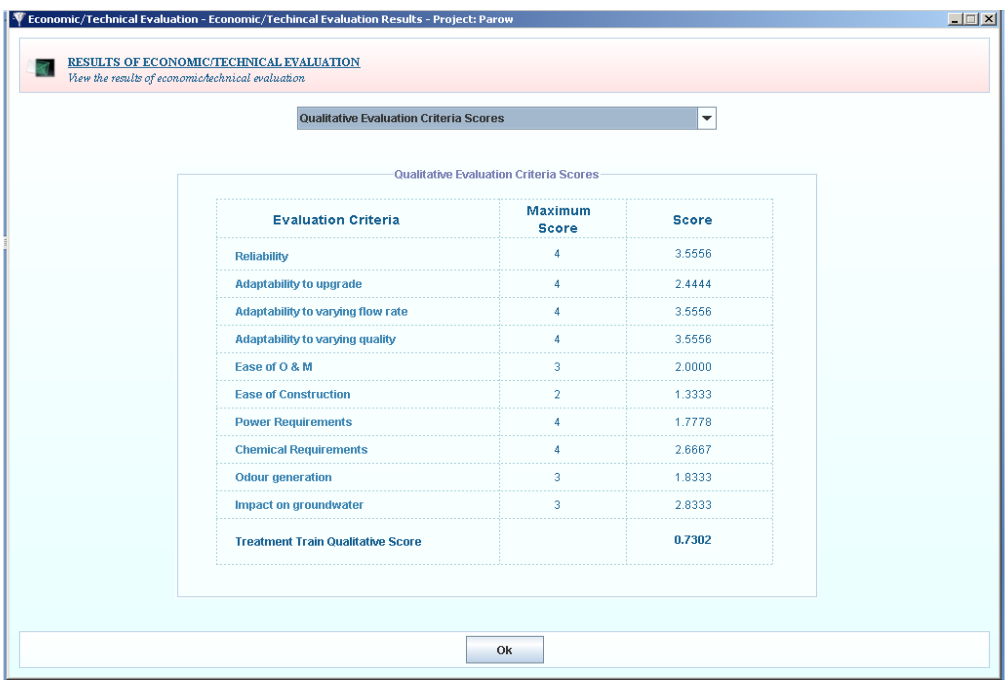
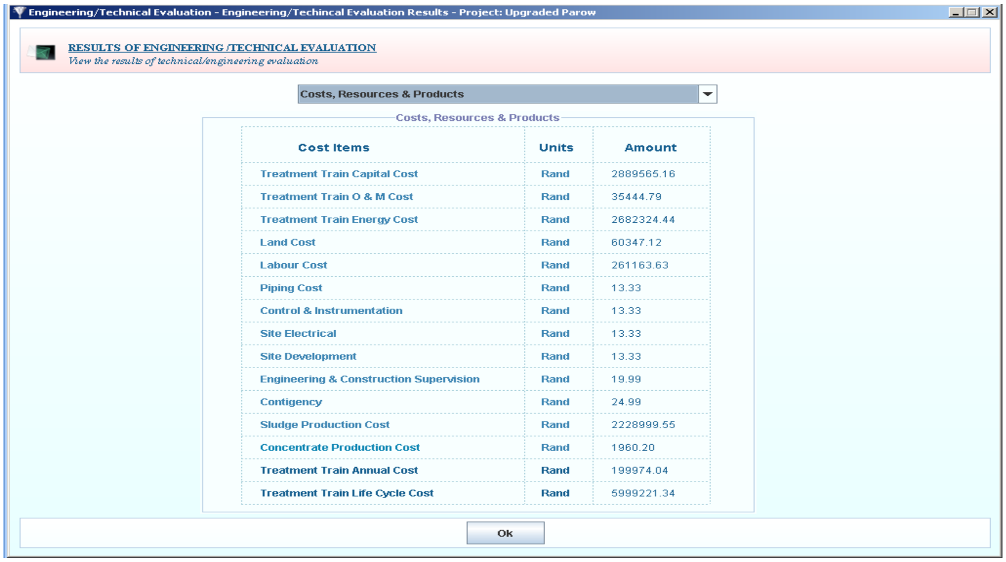


Figure 6.15: Dialog screen showing the Parow WWTW qualitative score

6.4.9.3 Treatment costs

Using equivalent Rand value of 2009, the cost of Parow WWTW is shown in Figure 6.16.

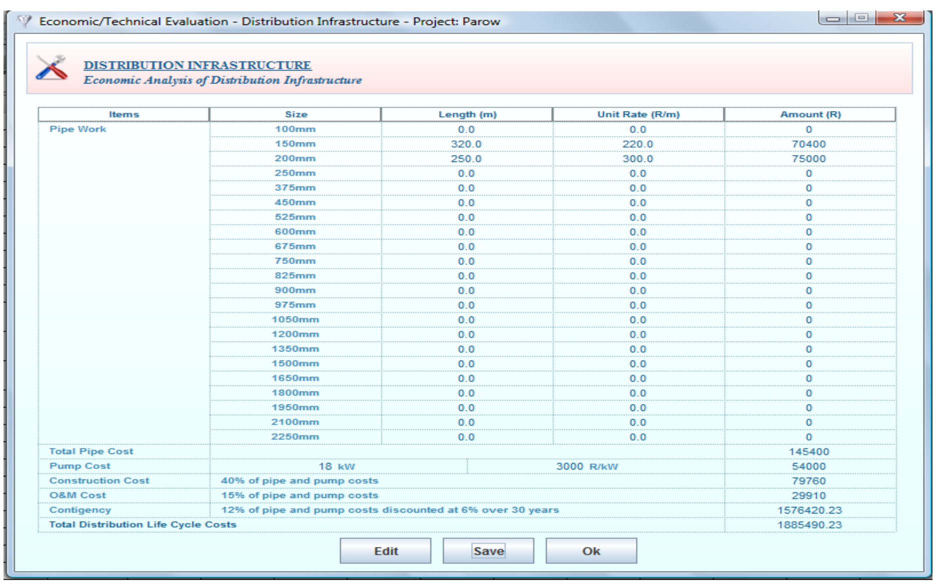


Cost Items	Units	Amount
Treatment Train Capital Cost	Rand	2889565.16
Treatment Train O & M Cost	Rand	35444.79
Treatment Train Energy Cost	Rand	2682324.44
Land Cost	Rand	60347.12
Labour Cost	Rand	261163.63
Piping Cost	Rand	13.33
Control & Instrumentation	Rand	13.33
Site Electrical	Rand	13.33
Site Development	Rand	13.33
Engineering & Construction Supervision	Rand	19.99
Contigency	Rand	24.99
Sludge Production Cost	Rand	2228999.55
Concentrate Production Cost	Rand	1960.20
Treatment Train Annual Cost	Rand	199974.04
Treatment Train Life Cycle Cost	Rand	5999221.34

Figure 6.16: Dialog screen showing existing Parow WWTW costs (30 years life span)

6.4.9.4 Distribution infrastructure costs

Using equivalent Rand value of 2009, the cost of distribution infrastructure is shown in Figure 6.17.



Items	Size	Length (m)	Unit Rate (R/m)	Amount (R)
Pipe Work	100mm	0.0	0.0	0
	150mm	320.0	220.0	70400
	200mm	250.0	300.0	75000
	250mm	0.0	0.0	0
	375mm	0.0	0.0	0
	450mm	0.0	0.0	0
	525mm	0.0	0.0	0
	600mm	0.0	0.0	0
	675mm	0.0	0.0	0
	750mm	0.0	0.0	0
	825mm	0.0	0.0	0
	900mm	0.0	0.0	0
	975mm	0.0	0.0	0
	1050mm	0.0	0.0	0
	1200mm	0.0	0.0	0
	1350mm	0.0	0.0	0
	1500mm	0.0	0.0	0
	1650mm	0.0	0.0	0
	1800mm	0.0	0.0	0
	1950mm	0.0	0.0	0
	2100mm	0.0	0.0	0
	2250mm	0.0	0.0	0
Total Pipe Cost				145400
Pump Cost	18 kW		3000 R/kW	54000
Construction Cost	40% of pipe and pump costs			79760
O&M Cost	15% of pipe and pump costs			29910
Contigency	12% of pipe and pump costs discounted at 6% over 30 years			1576420.23
Total Distribution Life Cycle Costs				1885490.23

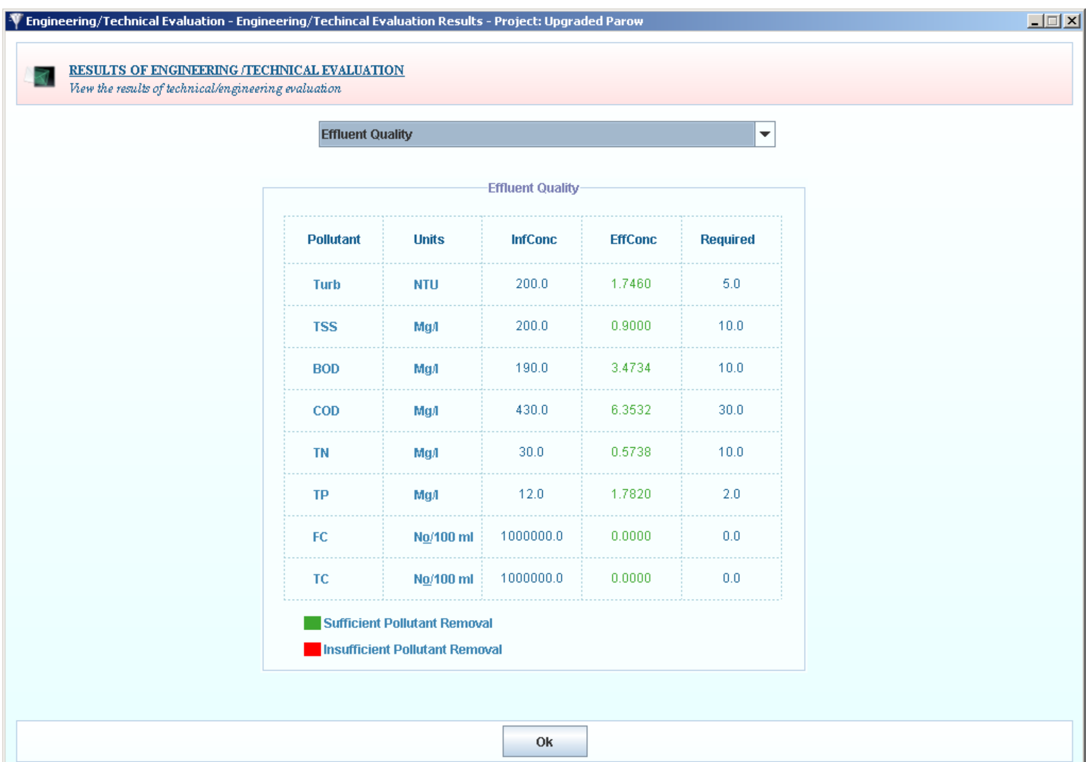
Figure 6.17: Dialog screen showing distribution infrastructure costs (30 years life span)

6.4.10 Upgrading Parow WWTW

As a result of an increase in wastewater flow into the Parow WWTW and increased interest in the reuse of treated wastewater effluent, the CoCT proposed an upgrading of the existing treatment train in order to meet the quality of effluent that could be utilised for landscape irrigation or restricted irrigation. The proposed upgrade at this time was the inclusion of a dual media filter into the existing treatment train configuration i.e.:

Bar screen → grit chamber → aerated activated sludge → maturation pond → <u>dual medial filter</u> → gas chlorination

Using the DSS, the quality of treated wastewater effluent for the treatment train above is predicted and the result is shown in Figure 6.18.

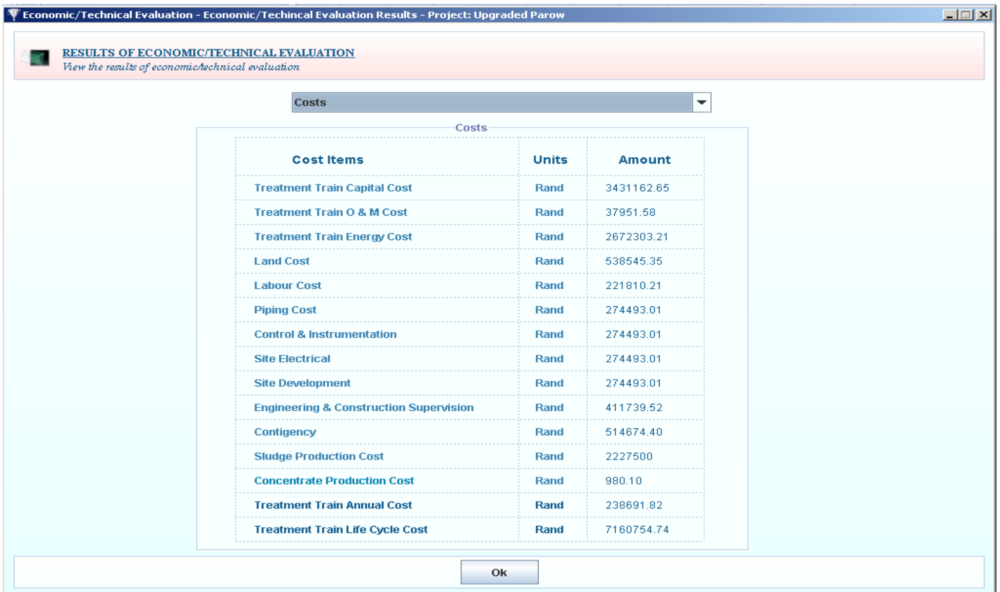


Pollutant	Units	InfConc	EffConc	Required
Turb	NTU	200.0	1.7460	5.0
TSS	Mg/l	200.0	0.9000	10.0
BOD	Mg/l	190.0	3.4734	10.0
COD	Mg/l	430.0	6.3532	30.0
TN	Mg/l	30.0	0.5738	10.0
TP	Mg/l	12.0	1.7820	2.0
FC	No/100 ml	1000000.0	0.0000	0.0
TC	No/100 ml	1000000.0	0.0000	0.0

Figure 6.18: Dialog screen showing effluent quality result of the upgraded Parow WWTW at maximum pollutant removal efficiency

Using an assumption that all unit processes in the proposed upgrade of Parow WWTW will operate at the maximum pollutant removal efficiency, the quality of effluent obtained meets the water quality requirement for all reuse purposes as shown in Figure 6.18.

Using equivalent Rand value of 2009, the cost of new cost of Parow WWTW with additional treatment unit (dual media filter) is shown in Figure 6.19.



Cost Items	Units	Amount
Treatment Train Capital Cost	Rand	3431162.65
Treatment Train O & M Cost	Rand	37951.58
Treatment Train Energy Cost	Rand	2672303.21
Land Cost	Rand	538545.35
Labour Cost	Rand	221810.21
Piping Cost	Rand	274493.01
Control & Instrumentation	Rand	274493.01
Site Electrical	Rand	274493.01
Site Development	Rand	274493.01
Engineering & Construction Supervision	Rand	411739.52
Contigency	Rand	514674.40
Sludge Production Cost	Rand	2227500
Concentrate Production Cost	Rand	980.10
Treatment Train Annual Cost	Rand	238691.82
Treatment Train Life Cycle Cost	Rand	7160754.74

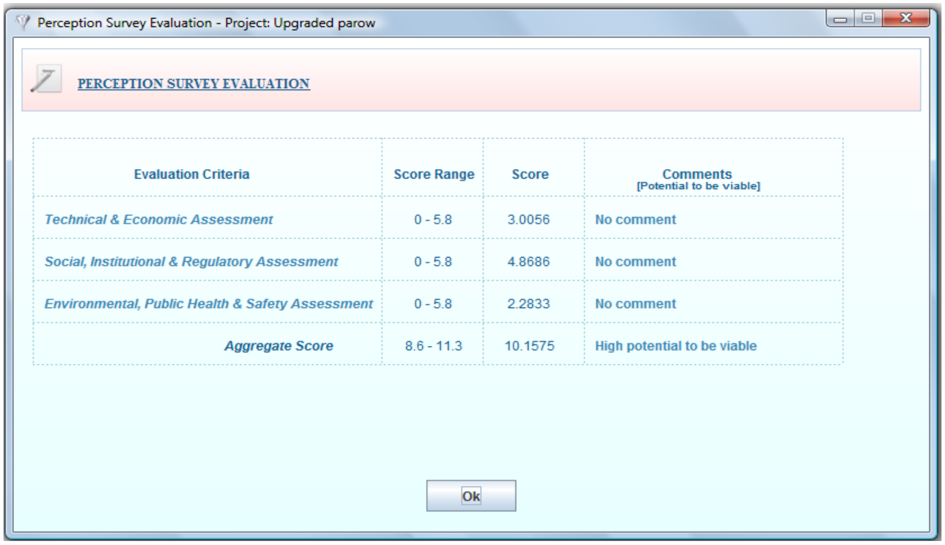
Figure 6.19: Dialog screen showing Upgraded Parow WWTW costs (30 years life span)

6.4.11 Perception Module

The perception module of the developed DSS is divided into treated effluent service provider's perception and potential treated effluent user's perception. In this analysis, questionnaire administered at the Goldfields gold mine, Driefontein (Ilemobade *et al.*, 2009) were used in testing the service provider's perception module while hypothetical values were used for potential treated effluent users.

6.4.11.1 Treated Effluent Service Provider's Perception

The result of the service provider's perception is shown in Figure 6.20. The result shows that there is *high potential for reuse to be viable* if implemented (See Table 5.15).

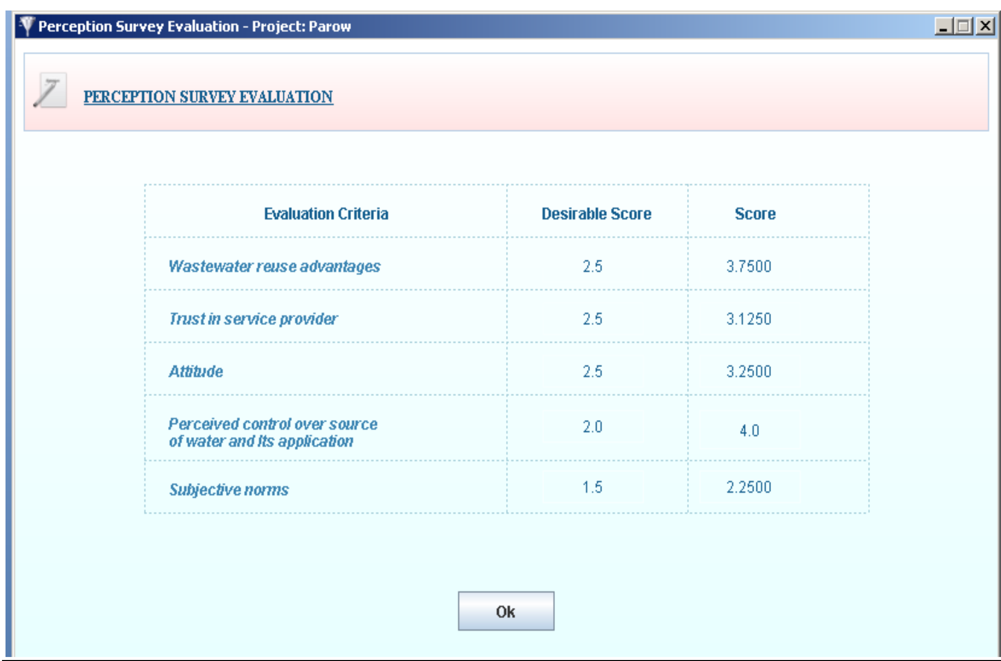


Evaluation Criteria	Score Range	Score	Comments [Potential to be viable]
Technical & Economic Assessment	0 - 5.8	3.0056	No comment
Social, Institutional & Regulatory Assessment	0 - 5.8	4.8686	No comment
Environmental, Public Health & Safety Assessment	0 - 5.8	2.2833	No comment
Aggregate Score	8.6 - 11.3	10.1575	High potential to be viable

Figure 6.20: Dialog screen showing service provider's perception

6.4.11.2 Treated Effluent Potential User's Perception

Using a hypothetical scenario to evaluate potential user's perception, the result obtained is shown in Figure 6.21.



Evaluation Criteria	Desirable Score	Score
Wastewater reuse advantages	2.5	3.7500
Trust in service provider	2.5	3.1250
Attitude	2.5	3.2500
Perceived control over source of water and its application	2.0	4.0
Subjective norms	1.5	2.2500

Figure 6.21: Dialog screen showing potential user's perception

6.5 Summary of the DSS application to Parow WWTW

Table 6.6 shows the summary of the result obtained from the DSS analysis as applied to the Parow WWTW.

Table 6.6: Summary of the DSS final results

Parameters	Items	Result	Remark
Qualitative	Reliability	3.56	Excellent
	Adaptability to upgrade	2.44	Good
	Adaptability to varying flow rate and quality	3.56	Excellent
	Adaptability to varying quality	3.56	Excellent
	Ease of operation and maintenance	2.00	Good
	Ease of construction	1.33	Excellent
	Power requirements	1.78	Fair
	Chemical requirements	2.67	Good
	Odour generation	1.83	Fair
	Impact on groundwater	2.83	Excellent
Quantitative			
1. *Water Quality*	Turbidity (NTU)	1.75	Satisfactory[+]
	Total Suspended Solids (mg/l)	0.90	Satisfactory
	Biochemical Oxygen Demand (mg/l)	0.47	Satisfactory
	Chemical Oxygen Demand (mg/l)	0.35	Satisfactory
	Total Nitrogen (mg/l)	0.57	Satisfactory
	Total Phosphorus (mg/l)	1.78	Satisfactory
	Faecal Coliforms (No/100ml)	0.00	Satisfactory
	Total Coliforms (No/100ml)	0.00	Satisfactory
2. Treatment Costs	Existing treatment cost	R 5 999 221.34	Sanitary cost[*]
	Upgraded treatment cost	R 7 160 754.74	
	Treatment cost difference	**R 1 161 533.40**	**Extra cost of supplying treated wastewater**
3. Distribution Costs	**Distribution infrastructure Life Cycle cost**	**R 1 885 490.23**	**Extra cost of supplying treated wastewater**
Total cost of recycled water for 30 years at 6% interest rate		**R3 047 023.63**	**Total extra cost of supplying treated wastewater**
Annual recycled water consumption		**547500Kl**	

[*] Municipality collects sanitary cost from all potable water users as a percentage of potable water supplies.

[+] Quality meets the recommendation of USEPA guidelines on wastewater reuse for irrigation.

If the treated wastewater consumers are charged with an average tariff of R2.00/kl as against an average potable water tariff of R4.55/Kl minimum charge on every Kiloliter of potable water used above basic free water in the City of CapeTown, annual revenue will equal R1 095 000.00 with a payback period of less than three years.

6.6 Summary

Testing of the developed DSS using a case study of Parow wastewater treatment works in Cape Town showed the tool to be versatile and provide a good assessment of both qualitative and quantitative criteria in the selection treatment trains for water reuse. The result of the technical assessment indicates that a good knowledge of pollutant removal efficiency of each unit process in the existing treatment train is a prerequisite for successful application of the DSS to the existing WWTWs. The perception module provides a quick assessment of potential user's concerns on reuse and service providers capacity in term of triple bottom line attribute of sustainability.

CHAPTER 7

SUGGESTED OPERATIONAL GUIDELINES FOR NON-POTABLE WATER REUSE IN SOUTH AFRICA

7.1 Introduction

It is very important to manage the operation of recycled water systems in such a way that it will not adversely affect public health and the environment. Safety measures must be undertaken to ensure that the consumer's health requirements are met and at the same time, operational and maintenance personnel are not at risk. Recycled water management systems should meet the following short to long term health and environmental performance objectives:

- reduction of risks to public health;
- protection of irrigated lands;
- protection of groundwater and surface water resources; and
- protection of community amenities.

In order to meet the objectives listed above, there must be comprehensive standards/guidelines for the operation and monitoring of recycled water systems. These standards must be well enforced by the regulatory body (DWEA in this case).

Monitoring activities for recycled water use projects are of two different types viz à viz process control and compliance monitoring. Monitoring is carried out to provide data to support the operation and maintenance of the system, in order to achieve an excellent performance. It includes monitoring of treatment plants, recycled water distribution systems, reuse water application devices, environmental aspects (such as quality of the receiving water body and irrigated soil), agricultural aspects (such as productivity and yield) and health-related problems. In addition to providing data for process control, it also generates information for project revision and updating as well for further research and development (Richard and Ivanildo, 1997). Responsibility for WWTWs monitoring typically belongs to the operating agency (e.g. municipality water and sanitation department).

Compliance monitoring is required to meet regulatory requirements and cannot be performed by the same agency operating the WWTW. This responsibility is performed by DWEA that possesses the legal authority to enforce compliance with quality standards, codes of practice and other pertinent legislation. A successful monitoring programme should provide adequate coverage of all aspect of wastewater treatment. It should be conducted timely in order to provide operators and decision makers with fresh and up-to-date information that allows the application of prompt remedial measures during critical situations (Richard and Ivanildo, 1997). The purpose of this section is to suggest a comprehensive guidelines that can be use to effectively operate water reuse programme in South Africa.

7.2 Overview of Wastewater Treatment Operation/Performance in South Africa

The quality of discharges from wastewater treatment plants in South Africa has become a matter of national importance and priority. The National Water Services Regulation Strategy (DWAF, 2008) provides a clear statement of strategic intent to regulate the water and sanitation services sector in South Africa. The driving force of this strategy is the mitigation of risk associated with the management of water and sanitation facilities and the development of more comprehensive and effective regulation for the country. The three main programmes identified to mitigate risks are (DWAF, 2008):

- concentrated regulatory efforts to address compliance and performance problems in priority municipalities, particularly where risks pose threats to health and the environment;
- a national drinking water quality regulatory initiative to manage potentially serious risks associated with unsafe drinking water; and
- a national wastewater discharge regulation initiative to manage potentially serious risks to health and the environment.

In line with international good practice, DWEA embarked on the assessment of all wastewater treatment plants in South Africa in 2008 (Manus and van der Merwe-Botha, 2010). This assessment is aimed at developing the following two-pronged regulatory approach to raise the performance of wastewater treatment plants and effluent quality:

- an approach that is based on a risk profile of all wastewater treatment plants and that targets the plants that have the greatest impacts on the receiving environment;
- an incentive-based approach that recognises excellence in the wastewater industry and that encourages service providers (i.e. municipalities) to work towards the achievement of Green Drop Certification which acknowledges the state of excellence in wastewater services. A Purple Drop Certification is issued if a service provider fails to comply with a predetermined level of green drop.

The above two-pronged approach to wastewater treatment plant assessment allows for incentive, punitive or assisted measures to be taken depending on the specific circumstances of non-compliance by the service provider.

Manus and van der Merwe-Botha (2010) reported the findings on the assessment of wastewater treatment plants carried out in the nine provinces of South Africa during November 2008 to August 2009. A summary of their report is highlighted in section 7.2.1 to 7.2.4.

7.2.1 Design Capacity of Municipal Wastewater Treatment Works in South Africa (Manus and van der Merwe-Botha 2010)

Figure7.1 shows the breakdown of WWTWs design capacity under the management of a municipality.

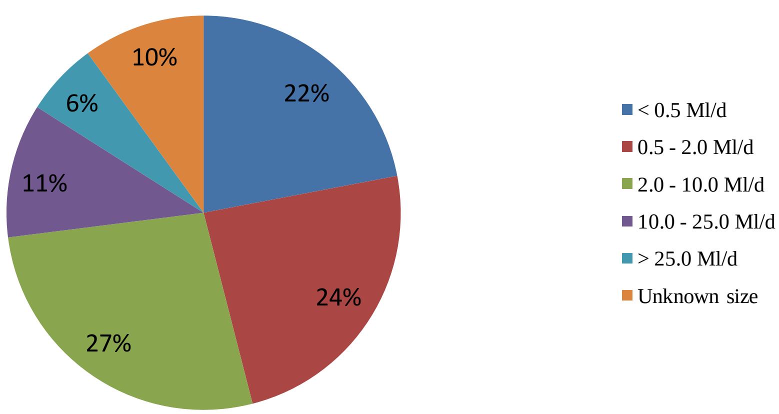


Figure 7.1: Breakdown of design of municipal WWTWs according to plant size

7.2.2 Design Capacity versus Daily Inflow into Municipal WWTWS (Manus and van der Merwe-Botha 2010)

All the 848 surveyed WWTWs have a total hydraulic design capacity of 6 554 Ml/d (i.e. 2 392 210 Ml/a) and receive a total inflow of 5 830 Ml/d (i.e. 2 127 950 Ml/a). This indicates that the nation has an overall excess of 724 Ml/d (264 260 Ml/a). The distribution of this hydraulic loading is shown in Table 7.1.

Table 7.1: A comparison of plant design capacity and daily inflow into WWTWs in South Africa (Manus and van der Merwe-Botha 2010)

Province	Plant Design Capacity (Ml/d)					Total Plant Design Capacity (Ml/d)	Total Plant Daily Flow in Size (Ml/d)					Total Daily Inflow (Ml/d)
	Micro Size	Small Size	Medium Size	Large Size	Macro Size		Micro Size	Small Size	Medium Size	Large Size	Macro Size	
EC	6	38	149	87	192	473	7	71	98	87	140	404
FS	2	32	158	197	121	510	7	47	141	111	97	404
GP	0	5	58	161	2171	2395	0	6	50	166	2209	2432
KZN	7	33	162	230	683	1116	7	63	126	176	480	852
LP	1	7	155	10	28	201	2	58	78	0	26	163
MP	2	22	130	128	56	338	5	28	118	115	0	266
NC	3	6	78	16	30	148	10	25	38	26	35	133
NW	0	6	125	58	123	312	0	56	53	61	65	235
WC	7	3	209	110	693	1060	11	75	120	80	656	942
Total	**28**	**208**	**1225**	**997**	**4097**	**6554**	**49**	**430**	**822**	**821**	**3707**	**5830**

EC = Eastern Cape; FS = Free State; GP = Gauteng; KZN = KwaZulu Natal; LP = Limpopo; MP = Mpumalanga; NC = Northern Cape; NW = North West; WC = Western Cape

In the study by (Manus and van der Merwe-Botha 2010), data in Table 7.1 was compromised by the number of WWTWs where design and/or daily flow information was absent. Cases of insufficient data were mostly found in the provinces of the Free State, Eastern Cape, Limpopo and North West. In bridging the gap of missing data, the following assumptions were made:

- for plants where there was no capacity information, capacity of 2 Ml/d was assumed
- for plants without flow information, 80% of design capacity was assumed
- where there was no monitoring information were found, the plant was categorised as non-compliance

Table 7.1 shows that all the micro plants and majority of the small size plants handle flows larger than their design capacity. However, all the large and macro size plants are operating within their hydraulic capacity. Northern Cape and Gauteng (the province with significant data) have the highest incidence of daily flow exceeding the design capacity. This may likely be the case in other provinces where data is not available.

7.2.3 Effluent Quality Compliance (Manus and van der Merwe-Botha 2010)

Based on the available final effluent monitoring data from November 2008 to August 2009, majority of the WWTWs fail to meet at least one or more of the required effluent discharge standards. Most of the non-compliant plants are either operating at maximum or exceeding the design capacity of the plant. Figure 7.2 shows the trend of compliance in all provinces.

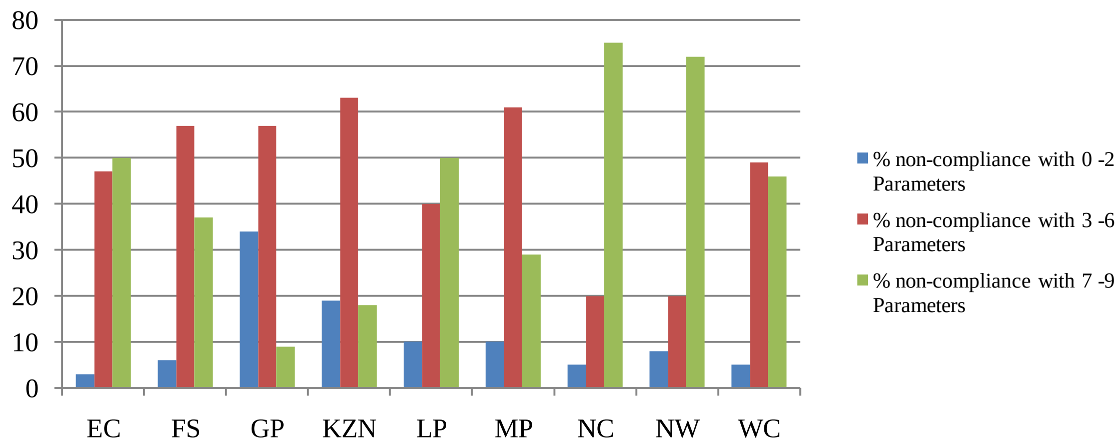


Figure 7.2: Non-compliance of WWTWs with effluent discharge standards (Manus and van der Merwe-Botha 2010)

From Figure 7.2, Northern Cape and North West provinces have the highest levels of non-compliance with 7-9 parameters (over 70%) while Gauteng province has less than 10% non-compliance in this category.

7.2.4 Wastewater Treatment Plants Personnel (Manus and van der Merwe-Botha 2010)

The underlying causes of non-compliance are often underpinned by the lack of qualified personnel to manage WWTWs. Figure 7.3 shows the non-compliance in terms of Supervisor, plant operators and Maintenance supports as required by the National Water Act (Gazette 28557 of 24/02/2006).

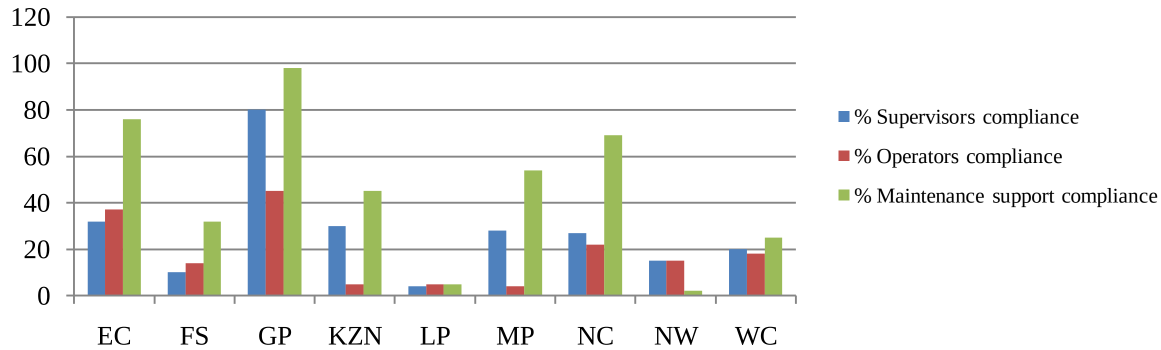


Figure 7.3: Compliance on the mandatory personnel at WWTWs (Manus and van der Merwe-Botha 2010)

The current general situation in the operation and management of WWTWs in South Africa as summarised above clearly demands urgent attention. However, in order to address and improve the performance of municipal wastewater service providers, the South Africa government through the DWEA introduces *Green Drop Certification* process.

7.3 First Order Assessment and Green Drop Certificate Initiatives

First Order Assessment and Green Drop Certification of municipal wastewater treatment works are government initiative through DWEA as the first step in multi-barrier system of ensuring safe drinking water quality. While First Order Assessment is geared towards information gathering to classify wastewater treatment works in terms of its potential to have high risks, Green Drop Certification process is an incentive measure of DWEA to municipalities with excellent wastewater treatment works performance. This initiative is aimed at solving the problems of non-compliance of municipal wastewater treatment service providers with the South African Water Acts of treating wastewater to a disposable quality that will minimize risks to receiving water bodies and human health. This process is driven by strengthening the regulatory approach whilst at the same time refocusing the Local Government in a manner that is more responsive to regulatory imperatives. (DWEA, 2009).

A national roll out of both the First Order Assessment and the Green Drop process from August 2008 to September, 2009 have campaigned successfully to channel the consumer's voice, to raise political awareness and to bring about positive changes to wastewater treatment and at the same time, setting the platform for more efficient forward planning and investment in wastewater services facilities and skills (DWEA, 2010).

The First Order Assessment provides a scientific and verifiable status of municipal wastewater treatment plants that will reveal any risk associated with a plant. This form the basis of regulatory intervention by prioritizing the higher risk plants and applying the Enforcement Protocol for Organ of State (a business process geared at solution formulation and rectifying non compliance situations). The risk rating of each plant within a municipality is calculated using cumulative risk rating (CRR) express as follows:

$$CRR = WF_1 \times WF_2 + WF_3 + WF_4 \qquad 7.1$$

Where WF are weighting factors assigned to four high risks areas:

WF_1 = Design capacity of plant also represent hydraulic loading onto receiving water body

WF_2 = Flow amount exceeding, on and below capacity

WF_3 = Number of non-compliance trend (i.e. effluent compliance as discharged to receiving water body)

WF_4 = Compliance/non compliance (i.e. technical skills – supervisory, process control and maintenance)

The Green Drop Assessment is based on the scoring criteria listed in Table 7.2.

Table 7.2: Green drop record card scoring criteria

Criteria	Score	Symbol	Description	Requirements (& Weighting)
Adequacy of process control, maintenance and management skill	100% (10)	A	Fully complies with all requirements.	1. Treatment works complying with Reg. 2834 of water Act., in terms of Classification and Registration. (20%). 2. Process controllers are complying with skills requirements of Reg. 2834 of
	80%-90% (8-9)	B	Complies with all requirements except 1.	
	70% (7)	C	Not complying with 2 requirements.	
	50% (5)	D	Not complying with criteria No. 2 or complying with No. 2	

Criteria	Score	Symbol	Description	Requirements (& Weighting)
			and none other.	Water Act. (50%). 3. Availability of skilled maintenance skills. (10%). 4. Operation and maintenance manual is in place. (20%).
	30% (3-4)	E	Not complying with criteria No 1 & 2 or No. 2 & 4.	
	10%-20% (1-2)	F	Not complying with the majority of the requirements.	
	0% (and lack of information	G	Not complying with any of the requirements or the complete lack of information.	
Efficient of wastewater Quality Monitoring Programme	100%(10)	A	Fully complies with all requirements.	1. Details of an effective Operation Monitoring Programme. 2. Details of an effective Compliance Monitoring Programme. 3. Proof of sufficient samples and determinants taken from sample sites.
	70%(7)	B	Complying with all requirements except 1.	
	60%(6)	C	Not complying with requirement No. 2 and another requirement. Or not complying with any other 3 requirement.	
	30%(3)	E	Only complying with 1 requirement. (1 or 2).	
	15%(1.5)	F	Not complying with majority of the criteria. Only complying with 1 requirement.	
	0%(and lack of information)	G	Not complying with any one of the requirements or complete lack of information.	
Credibility of Wastewater Sample Analysis	100%(10)	A	Fully complies with all requirements.	1. Proof to be provided of the laboratory used. 2. Laboratory is either accredited or participates in accredited proficiency scheme (obtaining an acceptable z-score). 3. Proof that analysis results are used to improve process controlling.
	70%(7)	B	Complying with all requirements except for requirement No. 1.	
	60%(6)	C	Complying with all requirements except for requirement No. 3	
	30%(3)	E	Not complying with requirement No. 2 or not complying with requirements No. 1 & 2.	
	15%(1.5)	F	Only complying with requirement No. 3	
	0%(and lack of information)	G	Not complying with any one of the requirements or complete lack of information.	
Regular submission of wastewater quality results to DWEA	100%(12/12months)	A	Fully complied with criterion	1. Results must be submitted 12 months of the year.
	0%(<10months)	G	Less than 12 sets of data submitted to DWEA. No data submitted.	
Wastewater compliance with license conditions/General authorizations or special limits.	100%(35)	A	Fully complied with criteria.	1. Proof of wastewater quality compliance data for the past 12 months and copy of standards used. 2. Provide figures per determinants; number of
	80%(28)	C	Complies with most criteria except 1.	
	60%(21)	D	Does not comply with criteria 1 & 2.	
	20%(7)	E	Does not comply with criteria	

Criteria	Score	Symbol	Description	Requirements (& Weighting)
			3	analysis per determinants & the number of non complying analysis per determinants. 3. % compliance per determinant (measured against overall compliance %).
	0% (0)	G	Did not comply with both sub-criteria or failed to submit sufficient data for assessment purposes.	
Wastewater quality failure response management	100%(20)	A	Fully comply with criteria.	1. Proof of a documented effluent quality incident management protocol (or protocol similar in function) specifying roles and responsibilities. 2. Provide evidence of implementation.
	605(12)	C	Have evidence to proof incident management control, but has no documented protocol.	
	40%(8)	E	Has a documented protocol in place but not evidence to proof implementation.	
	0% (0)	G	Not complying with criteria or failed to submit sufficient information for assessment purposes.	
Wastewater treatment capacity	100%(5)	A	Fully complies with criteria.	
	80%(4)	B	Complies with all criteria except one.	
	60%(3)	C	Not complying with 1 criterion.	
	40%(2)	E	Not complying with 2 criteria or criterion 2.	
	20%(1)	F	Only complying with one criterion	
	0%(0)	G	Not complying with criteria or failed to submit sufficient information for assessment purposes.	

When the criteria presented in Table 7.2 was used in 2008-2009 to assess municipal wastewater treatment works in South Africa, only 7 (Ethekwini, City of Johannesburg, City of CapeTown, City of Tshwane, Ekurhuleni, Mbombela & Silulumanzi and George Municipalities) out of 169 Water Service Authorities managed to obtain Green Drop status for the facilities they are managing. Spanning across the 7 Water Service Authorities are 32 wastewater treatment works that obtained Green Drop Certificates out of 449 wastewater treatment works assessed.

There must be a paradigm shift in the operation and management of WWTWs in order to guarantee the sustainable implementation of recycled water. The next sections provide suggested guidelines for the operation of wastewater reuse in South Africa.

7.4 Suggested Operational Guidelines for Wastewater Reuse

Different hazards could occur due to WWTWs failures. From the public health and environment standpoint, it is reasonable that a high standard of reliability should be required for a system producing reclaimed water for uses where direct or indirect human contact is likely. As discussed in Section 3.4.1, a high standard of reliability, similar to water treatment plants, is required at wastewater reclamation plants. Therefore, water reuse requires strict conformity to all applicable water quality standards.

Several elements are combined together to make up a reclaimed water system's treatment and distribution. These include the power supply, individual treatment units, the maintenance program, and the operating personnel. Backup systems are important in maintaining reliability in the event of failure of vital components. Critical units within this system include the disinfection system, power supply, and various treatment unit processes (USEPA, 2004).

For reclaimed water production, EPA Class I reliability is recommended as a minimum criteria. EPA Class I reliability requires redundant facilities to prevent treatment abnormality during power and equipment failures, flooding, peak loads, and maintenance shutdowns. Reliability for water reuse should also consider (USEPA, 2004):

- operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems ;
- instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions;
- a comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol;
- adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal and supplemental storage to ensure that the supply can match user demands;

- a strict industrial pre-treatment program and strong enforcement to prevent the illicit disposal of hazardous or other similar material that may interfere with the treatment and intended use of the reclaimed water.

Using the above list and additional literatures which are referenced in the following sections, suggested guidelines for the operation of non-potable reuse are presented below:

7.4.1 Operator Training and Competence

No matter how sophisticated the automation of a plant is, mechanical equipment are subject to breakdown. Hence, qualified and well-trained operators are necessary to ensure the production of reclaimed water of the required quality. Plant operators are considered to be the most critical technical personnel in the wastewater treatment system.

The knowledge, skills, and abilities that an operator must possess vary considerably depending on the complexity of the plant. In general, an operator must be familiar with the following:

- the function of each unit in the plant;
- how each unit accomplishes its function;
- how to evaluate the operation of each function; and
- how each unit fits into the overall plant process.

The National Water Act (Gazette 28557 of 24/02/2006) requires operator certification as a reasonable means to expect competent operation. Frequent training via continuing education courses or other means enhances operator competence. Since actions of the system operator have the potential to adversely or positively affect reclaimed water quality, a knowledgeable and well trained operator is critical to the sustainable generation of good reclaimed water quality. Consideration should be given to provide special training and certification for reclaimed water operations staff.

7.4.2 Instrumentation and Control

According to USEPA (2004), Major considerations in developing an instrumentation/control system for a reclamation facility include:

- ability to analyze appropriate quality parameters;
- ability to maintain, calibrate, and verify accuracy of on-line instruments;
- monitoring and control of treatment process performance;
- monitoring and control of reclaimed water distribution;

In a water reuse system, the potential uses of the reclaimed water determine the degree of instrument sophistication and operator attention required. Each water reclamation plant is unique, with its own requirements for an integrated monitoring and control instrumentation system. The process of selecting monitoring instrumentation should address aspects such as frequency of reporting, parameters to be measured, sample point locations, sensing techniques, future requirements, availability of trained staff, frequency of maintenance, availability of spare parts, and instrument reliability. Such systems should be designed to detect operational problems during both routine and emergency operations. If an operating problem arises, activation of a signal or alarm permits personnel to correct the problem before an undesirable situation is created.

System controls may be manual, automated, or a combination of manual and automated systems. For manual control, operations staff members are required to physically carry out all work tasks, such as closing and opening valves and starting and stopping pumps. For automated control, limited operator input is required except for the initial input of operating parameters into the control system. In an automated control system, the system automatically performs operations such as the closing and opening of valves and the starting and stopping of pumps.

7.4.3 Effluent Quality Assurance and Monitoring

An effluent quality assurance for a reclaimed project involves the selection of appropriate parameters to monitor and handling of the necessary sampling and analysis in an acceptable manner. Standard procedures for sample analysis may be found in the Handbook for the

Operation of Wastewater Treatment Works (WISA/WRC/ERWAT, 2002). Sampling techniques, frequency, and location are critical elements of monitoring and quality assurance.

A sample is a part or piece taken from a larger entity and presented as being representative of the whole. The objective of sampling is to collect a portion of the effluent of sufficient volume to be conveniently handled in the laboratory and still be a representative of the quality of the effluent being examined. Samples can either be *grab* or *composite* type depending on the method of sampling.

Grab samples are collected at a particular instant and represent conditions existing at that single moment while composite samples represent conditions over a long period of time (WEF, 2008). Samples can be collected manually and automatically. Process control sampling and testing is used to evaluate the performance of the unit process. During testing, Turbidity, Total Suspended Solids, Biochemical Oxygen Demand, Chemical Oxygen Demand, pH, Total Nitrogen, Total Phosphorus, Faecal Coliforms and Total Coliforms testing are routinely accomplished. Figure 7.4 shows typical sampling points in a treatment plant.

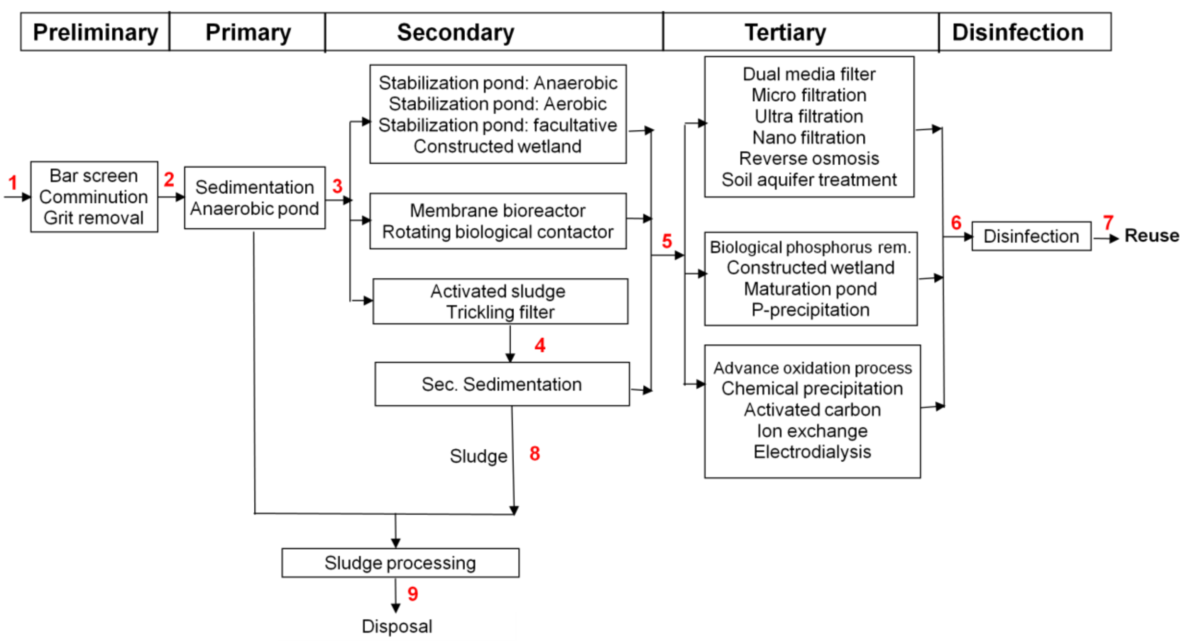


Figure 7.4: Typical sampling locations for the treatment plants

The recommended volume of sample to be taken, frequency and test to be carried out at each sample point are shown in Table 7.3.

As stated earlier, tests conducted on the sample at each sampling point can be used to assess the performance of each unit process. As a guide to judge the performance of each unit process, Table 7.4 shows the percentage pollutant removal (minimum, average or maximum) of each unit process classified as.

The general requirements of any reuse permit should ideally specify minimum sampling and testing that must be performed on the plant discharge. The permit will also specify the frequency of sampling, sample type, and length of time for composite samples. Unless a specific method is required by the permit, all sample preservation and analysis must be in compliance.

Table 7.3: Sample volume, tests and frequency of test at each sample point of Figure 7.4 (USEPA, 2004; Dettrick and Gallagher, 2002)

Sample point	Sample volume (ml)	Tests to be carried out	Frequency of test
1	100 - 500	Turbidity, Turb	continuous
	100 - 500	Total Suspended Solids, TSS	daily
	100 - 500	Biochemical Oxygen Demand, BOD	daily
	50 - 100	Chemical Oxygen Demand, COD	weekly
	50 - 100	pH	daily
	50 - 100	Total Nitrogen, TN	weekly
	50 - 100	Total Phosphorus, TP	weekly
	50 - 100	Faecal Coliforms, FC	weekly
	50 - 100	Total Coliforms, TC	weekly
2	100 - 500	Total Suspended Solids, TSS	bi-monthly
3	100 - 500	Total Suspended Solids, TSS	weekly
	50 - 100	Biochemical Oxygen Demand, BOD	weekly
	50 - 100	Chemical Oxygen Demand, COD	weekly
4	100 - 500	Total Suspended Solids, TSS	daily
	100 - 500	Biochemical Oxygen Demand, BOD	daily
	50 - 100	Chemical Oxygen Demand, COD	weekly
	50 - 100	pH	daily
	50 - 100	Total Nitrogen, TN	weekly
	50 - 100	Total Phosphorus, TP	weekly
	50 - 100	Faecal Coliforms, FC	weekly
	50 - 100	Total Coliforms, TC	weekly
5	100 - 500	Turbidity, Turb	continuous
	100 - 500	Total Suspended Solids, TSS	weekly
	50 - 100	Biochemical Oxygen Demand, BOD	weekly

Sample point	**Sample volume (ml)**	**Tests to be carried out**	**Frequency of test**
	50 - 100	Chemical Oxygen Demand, COD	weekly
	50 - 100	pH	daily
	50 - 100	Total Nitrogen, TN	weekly
	50 - 100	Total Phosphorus, TP	weekly
	50 – 100	Faecal Coliforms, FC	daily
	50 -100	Total Coliforms, TC	daily
6	100 - 500	Turbidity, Turb	continuous
	100 - 500	Total Suspended Solids, TSS	weekly
	50 - 100	Biochemical Oxygen Demand, BOD	weekly
	50 - 100	Chemical Oxygen Demand, COD	weekly
	50 - 100	pH	daily
	50 - 100	Total Nitrogen, TN	weekly
	50 - 100	Total Phosphorus, TP	weekly
	50 - 100	Faecal Coliforms, FC	daily
	50 - 100	Total Coliforms, TC	daily
	100 - 500	Total Suspended Solids, TSS	weekly
	50 - 100	Biochemical Oxygen Demand, BOD	weekly
	50 - 100	Chemical Oxygen Demand, COD	weekly
	50 - 100	pH	daily
	50 - 100	Total Nitrogen, TN	weekly
	50 - 100	Total Phosphorus, TP	weekly
	50 - 100	Faecal Coliforms, FC	daily
	50 - 100	Total Coliforms, TC	daily
	200	Residual Chlorine	continuous

Table 7.4: Unit process pollutant removal efficiencies (Cheremisinoff, 2002; Ahmed *et al.*, 2002; ESCWA, 2003 and Joksimovic, 2006).

Unit Process	Unit Process Pollutant Removal Efficiencies (%)																							
	Turb			TSS			BOD			COD			TN			TP			FC			TC		
	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
Bar screen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coarse screen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grit chamber	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pond: Anaerobic	< 15	15-50	> 50	< 30	30-45	> 45	< 40	40-65	> 65	< 30	30-60	> 60	> 30	30-50	> 50	< 5	5-7	> 7	< 30	30-50	> 60	<20	20-35	>35
Pond: Aerobic	<50	50-60	> 60	< 30	30-45	> 45	< 40	40-60	> 60	< 35	35-40	> 40	< 25	25-45	> 45	< 20	20-40	> 40	< 10	10-15	> 15	< 5	15-10	> 10
Pond: Facultative	< 40	40-50	> 50	< 50	50-70	> 85	< 50	50-70	> 70	< 60	60-80	> 80	< 20	20-40	> 40	< 25	25-50	> 50	< 10	10-15	> 15	< 5	5-10	> 10
Equalization basin	-	-	-	< 5	5-10	> 15	< 4	4-12	> 12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sedimentation	< 50	50-70	> 70	< 60	60-70	> 70	< 40	40-50	> 50	< 40	40-50	> 50	< 3	3-15	> 15	< 60	60-70	> 70	< 10	10-15	> 15	< 5	5-10	> 10
Activated sludge + Sec. sedimentation	< 10	10-40	> 40	< 50	50-70	> 70	< 50	50-70	> 70	< 60	60-80	> 80	< 10	10-30	> 30	<10	10-23	> 23	< 20	20-35	> 35	< 15	15-30	> 30
Trickling filter + Sec. sedimentation	< 20	20-30	> 30	< 50	50-70	> 70	< 50	50-70	> 70	< 65	65-80	> 80	< 20	20-30	>30	< 20	20-30	> 30	< 60	60-80	> 80	< 50	50-60	> 60
Rotary biological contactor	< 50	50-70	> 70	< 35	35-60	> 60	< 35	35-60	> 60	< 65	65-70	> 70	< 20	20-30	> 30	< 20	20-30	> 30	< 60	60-80	> 80	< 50	50-60	> 60
Membrane bioreactor	< 90	90-92	> 92	< 90	90-92	> 92	< 90	90-92	> 92	> 90	90-92	> 92	< 30	30-40	> 40	<60	60-70	> 70	< 80	80-85	> 90	< 70	70-75	> 75
Biological Phosphorus removal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	< 90	90-95	> 95	-	-	-	-	-	-
P- precipitation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	< 90	90-95	> 95	-	-	-	-	-	-
Chem. precipitation	< 20	20-30	> 30	< 40	40-60	> 60	< 20	20-30	> 30	< 15	15-35	> 35	< 5	5-8	> 8	< 10	10-15	> 15	< 10	10-20	> 30	< 5	5-15	> 15
Denitrification	-	-	-	-	-	-	-	-	-	-	-	-	< 90	90-95	> 95	-	-	-	-	-	-	-	-	-
Constructed wetland	< 10	10-15	> 15	< 60	60-75	> 75	< 25	25-35	> 35	< 10	10-15	> 15	< 50	50-60	> 60	< 80	80-85	> 85	-	-	-	-	-	-
Maturation pond	< 30	30-45	> 45	< 15	15-25	> 25	< 8	8-13	> 13	< 10	10-20	>20	< 30	30-40	> 40	< 20	20-30	> 30	< 30	30-50	> 50	< 20	20-35	> 35
Dual medial filter	< 80	80-90	> 90	< 80	80-90	> 90	< 65	65-75	> 75	< 60	60-70	> 70	< 5	5-10	> 10	< 5	5-10	> 10	< 90	90-93	> 93	< 80	80-85	> 85
Micro filtration	< 80	80-90	> 90	< 80	80-90	> 90	< 65	65-75	> 75	< 60	60-70	> 70	< 5	5-10	> 10	< 5	5-10	> 10	< 90	90-93	> 95	< 80	80-85	> 85
Ultra filtration	< 80	80-90	> 90	< 80	80-90	> 90	< 65	65-75	> 75	< 60	60-70	> 70	< 5	5-10	> 10	< 5	5-10	> 10	< 90	90-93	> 95	< 80	80-85	> 85
Nano filtration	< 30	30-50	> 50	< 80	80-90	> 90	< 20	20-35	> 35	< 60	60-70	> 70	< 40	40	> 40	< 80	80-90	> 90	< 90	90-95	> 95	< 90	90-93	> 93
Reverse osmosis	< 30	30-50	> 50	< 80	80-90	> 90	< 20	20-35	> 35	< 60	60-70	> 70	< 40	40	> 40	< 80	80-90	> 90	< 90	90-95	> 95	< 90	90-93	> 93
Soil aquifer treatment	< 85	85	>85	< 80	80-90	> 95	< 85	85	>85	< 85	85	> 85	< 85	85	> 85	< 80	80-90	> 90	< 70	70-75	> 80	< 65	65-70	> 75
Activated carbon	< 20	20-40	> 20	< 40	40-45	> 45	< 40	40-45	> 45	< 20	30-30	> 40	0	0	0	< 8	8-15	> 15	< 15	15-30	> 30	< 10	10-20	> 20

Unit Process	Unit Process Pollutant Removal Efficiencies (%)																							
	Turb			TSS			BOD			COD			TN			TP			FC			TC		
	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
Ion exchange	< 10	10-20	> 20	< 40	40-45	> 45	< 10	10-20	> 20	0	0	0	< 60	60-70	> 70	< 70	70-80	> 80	0	0	0	0	0	0
Advanced oxidation ponds	< 70	70-80	> 90	0	0	0	< 70	70-80	> 90	< 70	70-80	> 80	0	0	0	0	0	0	< 60	60-70	> 80	< 55	55-65	> 65
Electrodialysis	< 70	70-80	> 80	0	0	0	0	0	0	0	0	0	< 40	40-50	> 50	< 40	40-50	> 50	< 60	60-70	> 70	< 55	55-65	> 65
Chlorine gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	100	100	100	100	100
Chlorine dioxide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	100	100	100	100	100
Ozone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	< 90	90-95	> 95	< 90	90-95	> 95
UV Radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	< 60	60-70	> 70	< 55	55-65	> 65

7.4.4 Emergency/Supplemental Storage Facilities

Wastewater is continuously generated through residential and industrial activities. Hence, treatment plants also treat wastewater continuously unless there is a breakdown. Prior to the breakdown of major component(s) of a treatment plant, there is need to provide emergency storage to retain reclaimed water of unacceptable quality for re-treatment in order to safeguard public health and the environment. Usually, piping within a treatment plant is done in such a way that an emergency diversion is provided to convey reclaimed water of unacceptable quality to a temporary storage. At a later time, the diverted wastewaters are pumped back to the treatment plant for re-treatment.

Also, reclaimed water that cannot be used immediately may be stored or disposed of. Supplemental storage is provided to ensure that the reclaimed water supply can match user's seasonal demands. Reclaimed water must be treated and preserved to maintain its quality during storage. Storing reclaimed water can result in a change in quality, particularly microbiological quality. Therefore, if reclaimed water is stored, the quality should be tested regularly and any hazards managed accordingly. The frequency of testing and need for subsequent treatment will have to be decided on the basis of the level of risk at each site. Reclaimed water to be stored should have adequate chlorine residual and the circulation process to minimize stagnation and to maximize the distribution of the disinfection process.

7.4.5 Inspection and Approval of Recycled Water Facilities

DWEA is saddled with the responsibility of issuing permits to operate and periodically inspect wastewater treatment plants (National Water Act, 1998). The inspection of WWTWs by the DWEA is to ensure compliance with the DWEA standards for effluent discharge in order to protect public health and the ecosystem of the receiving watercourse. Therefore, the main concerns in the inspection of WWTWs are influent hydraulic and organic loadings, quality of effluent, and proper disposal of sludge solids. The inspection of recycled water facilities should, in addition, include the assessment of both the recycled water service provider's facilities and user's facilities. The inspection of service provider's facilities should include a detail examination of each unit process, its operation and how the process functions in the overall treatment scheme. In the user's facilities, the inspector should look out for improper connections, unclear markings, insufficient depths of pipe installation and possible overloading (i.e. altering soil permeability, pH, electrical conductivity, cation exchange capacity, etc) of the irrigated land. Follow-up inspections are routine, and in some cases, fixed interval (e.g. semi-annual) inspections and random inspections are planned.

7.4.5.1 Inspection of Recycled Water Service Provider's Facility

In order to undertake an inspection of a recycled water service provider's facility, it is imperative that the inspector must understand the complex nature of various unit processes involved in the treatment of wastewater. The inspector must be trained in flow measurement, sampling, laboratory testing, and record keeping. A summary of an inspection procedure for WWTWs producing recycled water is shown in Table 7.4.

Table 7.5: Inspection procedure for wastewater treatment plants (Boyd and Mbelu, 2009)

Classification	Facilities for inspection	What to look for
WWTW configuration	***Flow diagram*** – this is necessary in order to understand how the WWTW has been structured and should be operated. It must be drawn and make available on site.	a flow diagram of the WWTW
	Design capacity – this enable plans to be made for future development. It answers question of how much of wastewater can still be accommodated.	confirm the design capacity
Screen	***Manual/automatic screen*** – screens are used to remove debris from raw wastewater	• screens that are free of debris • hand rake and wheelbarrow that are easily accessible and in working condition • unusual sounds or vibrations • maintenance schedule • screening that are washed and return to WWTW
Grit removal	***Manual/automatic operated grit removal*** – Grit material can include sand, silt, glass, small stones as well as other large-sized organic and inorganic substances. It is essential to protect moving mechanical equipment and pumps from abrasion	• channels that are clean of grit • channels that are in working order, i.e. one that can be used while the other is closed for grit removal • a spade and container that are easily accessible
	Automate de-gritters – a pump is required to remove a slurry of grit	• a pump in working order
	Screenings and grit disposal – if left lying around will cause nuisance conditions such as odours and will encourage fly breeding	• non nuisance conditions (odours and files) • grit or screenings lying around • covered bins that are used for storage of grit • proof that grit and screenings buried on site are covered daily

Classification	Facilities for inspection	What to look for
Flow	***Flow metering*** – WWTW is design to a specific volume of wastewater per day. It is important to know how much wastewater is entering so as not to overload the plant	• flow measurement • knowledge of flow in relation to design capacity • the flow mechanism and determine whether it is in working order and is calibrated
	Flow balancing **-** Flow balancing, also called flow equalization, is used to overcome the operational problems caused by flow rate variations and to improve the performance of the downstream unit processes	• mixers – are they working? • aerators – are they working, if in place? • pumps – are they working? • odours – are odours controlled?
Primary sedimentation	***Primary sedimentation tank (PST)*** **-** The main purpose of primary sedimentation is to allow separation of the solid and liquid phase fractions in the wastewater.	• inflow that should be light grey in colour • overflow at the weirs that is similar where more than one PST is present • weirs in good condition • scum or floating sludge layer • layer of fats/grease/oil • a schedule for desludging and check that it is implemented • records of process sampling
Pond systems	***0xidation ponds*** **-** Pond systems are relatively shallow bodies of wastewater in which the self-purification of processes of water are used under controlled conditions to purify raw or settled wastewater.	• ponds operated in series • the presence of short-circuiting (water is flowing through a course. This means the detention time is inadequate) • aerators **-** are they working if present? • evidence of desludging **-** is it done periodically to a schedule and is sludge correctly disposed of? • area around the ponds – is it well maintained? • visible erosion around the ponds
Trickling filter (TF)	***Trickling filter*** – Trickling filter utilize microorganisms that grow on a medium (i.e. stones) to remove organic matter found in wastewater	• access to the top of the filter • movement of the rotating distributor arm – is it smooth? • distribution of wastewater to the filter media through the rotating distributor arm – is it even? • filter media – is it free of ponding? • underdrains **-** are they clear of any obstructions?
Rotating biological contactors (RBC)	***Rotating biological contactors*** **-** it utilize microorganisms that grow on disc system to remove organic matter found in wastewater	• the motor **-** is it working? • the disk system – does it rotate freely at a steady rate? • the sludge return pump **-** is it working? • the ammeter **-** does it fluctuate as the disk turns? • floating sludge in the final settling tank?
Activated sludge (ASP)	***Activated sludge*** – activated sludge is a biological process of developing an activated mass of microorganisms capable of stabilizing waste aerobically. Visual observation of the ASP is very important. The colour, smell and appearance of the biomass give a good indication of whether the ASP is working well	• records of the sludge age • scum on the surface • records of the Mixed Liquid Suspended Solid (MLSS) (mg/l) • records of the Dissolved Oxygen (DO) • dark brown biomass (colour) • an earthy smell

Classification	Facilities for inspection	What to look for
		• clean chemical dosing area • records of daily process monitoring as appropriate to the ASP • on-line equipment - is it in working order and calibrated; are calibration certificates available? • aerators - are they in working order? • recycling - is it taking place and is a record of the correct ratio of inflow to sludge recycle maintained?
Secondary sedimentation	***Secondary sedimentation*** – secondary sedimentation is used after the TF and ASP. Sludge from TF and ASP is in suspension and must be settled out in the clarifier to produce two streams, i.e. the sludge and the clear effluent.	• trends of the Sludge Volume Index (SVI) test • clean effluent weirs/channel clean launders • operational desludging equipment • limited scum on the surface of the clarifier • an operational scum draw-off system • clear overflow
Constructed wetlands	***Constructed wetlands*** - artificial or constructed wetlands consist of a bed of granular material through which the effluent can flow without too much hydraulic resistance.	• reeds are planted • reed growth is controlled using a schedule • selective seeding and planting is undertaken • periodically • samples are taken according to relevant authorization • herbicidal and insecticidal treatment is practiced
Maturation ponds	***Maturation ponds*** - maturation ponds give a final 'polish' to effluents. They are used to improve the bacteriological quality of the final effluent and can also act as a buffer in the event of a breakdown at the works	• overflow is clear • no erosion is observed • the banks of the ponds are protected against erosion
Membrane filtrations	Membrane filtration – membrane filtrations are used to remove dissolved organic and inorganic compounds from secondary effluent.	• permeate flows uniformly through the membrane • records of membrane cleaning • pumps are working perfectly • methods of concentrate management and disposal
Chemical disinfection	***Chemical disinfection*** - the goal of disinfection is to remove pathogenic microorganisms	• the dosing equipment is in working order • no chlorine can be smelled • relevant training has been given to the Process Controller/s • residual chlorine level is being measured in the final effluent • the contact tank is clean (i.e. not sludged up) and free of algae • final effluent samples are taken in accordance with water use authorization

The primary purpose of regulatory inspections is to verify compliance with the DWAF standards. During inspection, water samples must be taken at sampling points 1, 5, 6 and 7 in Figure 7.5 for laboratory analysis to determine the operation efficiency by monitoring unit processes listed in Table 7.3. These points give a good representative of influent wastewater, secondary treatment, tertiary treatment and final effluent (after disinfection).

Beyond the treatment of effluent is the management of sludge produced. In most cases, the aerobic digestion method is used in treating the sludge produced from wastewater. The purpose of anaerobic sludge digestion is to stabilize bulky, odorous raw sludge to relatively inert materials that can be readily dewatered without obnoxious odours. Overall performance of sludge digester is determined by volatile solid reduction, gas production and composition. Operational controls include temperature of the digesting sludge, mixing in high rate digesters, rate of raw sludge feed, and solid retention time. Careful consideration is given to all unit operations that discharge flow back to the head of the plant.

7.4.5.2 Wastewater Reuse Quality for Different Non-potable Uses

Table 7.6 show the suggested guidelines for reclaimed water quality for various types of water reuse in South Africa.

Table 7.6: Suggested guidelines for water reuse in South Africa

Types of reuse	Reclaimed water quality	Reclaimed water monitoring
Domestic uses	• pH = 6 – 9 • TSS ≤ 5 mg/l • Turb ≤ 1 TNU • BOD ≤ 5 mg/l • COD ≤ 10 mg/l • TN ≤ 5 mg/l • TP ≤ 0.2 mg/l • FC ≤ 0 • TC ≤ 0 • CL_2 residual ≤ 1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Disinfection – daily • Turbidity - continuous • CL_2 residual - continuous • Coliforms – daily • Nutrient, toxicant and salinity – regularly
Irrigation uses	• pH = 6 – 9 • TSS ≤ 10 mg/l • Turb ≤ 5 TNU • BOD ≤ 10 mg/l • COD ≤ 30 mg/l • TN ≤ 10 mg/l • TP ≤ 2 mg/l • FC ≤ 0 • TC ≤ 0 • CL_2 residual ≤ 1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Turbidity - continuous • CL_2 residual - continuous • Coliforms – daily • Nutrient, toxicant and salinity – regularly
Industrial uses	• pH = 6 – 9 • TSS ≤ 10 mg/l • Turb ≤ 5 TNU	• pH – weekly • BOD – weekly • TSS – weekly

Types of reuse	Reclaimed water quality	Reclaimed water monitoring
	• BOD ≤ 20 mg/l • COD ≤ 10 mg/l • TN ≤ 5 mg/l • TP ≤ 0.2 mg/l • FC ≤ 200 cfu/100ml • TC ≤ 200 cfu/100ml • CL_2 residual ≤ 1 mg/l	• Turbidity - continuous • CL_2 residual - continuous • Coliforms – weekly • Nutrient, toxicant and salinity – regularly
Other activities	• pH = 6 – 9 • TSS ≤ 10 mg/l • Turb ≤ 10 TNU • BOD ≤ 20 mg/l • COD ≤ 70 mg/l • TN ≤ 10 mg/l • TP ≤ 0.2 mg/l • FC ≤ 200 cfu/100ml • TC ≤ 200 cfu/100ml • CL_2 residual ≤ 1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Turbidity - continuous • CL_2 residual - continuous • Coliforms – weekly • Nutrient, toxicant and salinity – regularly

Based on the sections above, the list below represents potential uses of wastewater in South Africa.

- ***Domestic Use*** - toilet flushing, landscape irrigation, public park irrigation and other water use fixtures;
- ***Irrigation*** - Agricultural irrigation, crops irrigation, landscape irrigation, parks, schools, golf courses, cemeteries and green belt uses;
- ***Industrial*** – System cooling, boiler feed and processes water; and
- ***Other Activities*** – construction works, street flushing, fire protection and groundwater recharge.

In addition to the guidelines in Table 7.6, guidelines for the maximum concentration of trace elements in soils under natural conditions are presented in Table 7.7. It suggested that for monitoring purposes, the soil and vegetation is sampled and analysed. The only satisfactory safeguard is the sampling and analysis of soil and vegetation before irrigation commences and regular monitoring during the life of the irrigation scheme.

Table 7.7: Recommended maximum concentrations of metals in irrigation waters (Dettrick and Gallagher, 2002 adapted from ANZECC/ARMCANZ 2000)

Elements	Suggested soil CCL[1] (kg/ha)	LTV[2] over 100 years mg/L	STV[3] over 20 years mg/L	Plant effects
Aluminium (Al)	ND[4]	5	20	Toxic at pH < 5.5
Arsenic (As)	20	0.1	2	toxicity varies depending on species
Beryllium (Be)	ND	0.1	0.5	toxicity varies depending on species
Boron (B)	ND	0.5	<0.5 - 15	toxicity varies depending on species
Cadmium (Cd)	2	0.01	0.05	toxic at low conc. bio-accumulation issues
Chromium (CrVI)	ND	0.1	1	low toxicity
Cobalt Co)	ND	0.05	0.1	toxic at high concentration
Copper (Cu)	140	0.2	5	toxic at high concentration
Fluoride (F)	ND	1	2	not active in neutral to alkaline soils
Iron (Fe)	ND	0.2	10	not toxic in aerated soils.
Lead (Pb)	260	5	2	low toxicity, inhibits growth at high conc.
Lithium (Li)	ND	2.5	2.5	0.075 mg/L if used on citrus crops
Manganese (Mg)	ND	0.2	10	toxicity depends on Fe/Mn ration and soil pH
Mercury (Hg)	2	0.002	0.002	No guideline at the time
Molybdenum (Mo)	ND	0.01	0.05	low toxicity to plants, toxic to animals fed crops grown on high avail. Mo
Nickel (Ni)	85	0.2	2	toxicity increases with soil pH < 7
Selenium (Se)	10	0.02	0.05	toxic to plants. Toxic to animals fed on high Se pasture
Uranium (U)	ND	0.01	0.1	
Vanadium (Vn)	ND	0.1	0.5	toxic to plants
Zinc (Zn)	300	2	5	pH dependant. Higher level on pH 7 +

CCL[1] = Cumulative contaminant loading limit – is the maximum contaminant loading in soil, defined in kg/ha, above which site specific risk assessment is required if contaminant addition is planned (assuming application rate of 1000mm / year, inorganic contaminants in top 150 mm of soil profile & soil bulk density is 1300 kg/m3) .

LTV[2] = long term trigger value – is the maximum concentration (mg/L) of contaminant in irrigation water which can be tolerated given 100 years of irrigation.

STV[3] = short term trigger value – is the maximum concentration of contaminant that can be tolerated over 20 years assuming same annual irrigation loading assumptions as LTV

ND[4] = Not determined insufficient background data to calculate CCL

7.4.6 Approval and Regulating of Recycled Water User's Facilities

In order to manage wastewater reuse scheme in an ecologically sustainable manner and protect environment and public health, it is necessary that the design, installation, operation and maintenance of wastewater user's facilities are regulated. All plumbing items and devices (i.e., pipes, pumps, outlets, and valve boxes) used must be approved through special procedures. To ease approval process, all non-potable water systems must be distinctly set apart from the potable system. The methods most commonly used are unique sizing, colorings, labeling and markings. The Number of items that must be carefully monitored or verified under this category are:

- the level of knowledge of irrigation users on the regulations governing reclaimed water installation and usage;
- all modifications on the plumbing system that must be submitted to the regulatory agency;
- detecting and recording of any breaks in the transmission main;
- random inspection of user sites to detect any faulty equipment or unauthorised use; and;
- installing monitoring stations throughout the system to test pressure, chlorine residual and other water quality parameters.

Regulating the volume of wastewater used by consumers to avoid overuse is another important factor that must be considered when planning reuse scheme. Overuse of recycled water has been experienced in Florida when more and more utilities implemented recycled programmes with great incentives of “No payment or low flat rates” to encouraged users. This practice caused a great increase in consumer’s base with poor efficient use of the resource as many reclaimed water users used more reclaimed water than was necessary for optimum plant growth TRCC/WRWG/WCI (2003). Due to inefficient use of reclaimed water and extreme drought of 200-2001, the utilities began to run short of reclaimed water that angered customers who had been promised an unlimited supply of reclaimed water during drought. As a result, rate systems became more common.

Reclaimed water use and overuse are difficult to control without adequate metering system that takes into consideration volumetric changes in consumption rather than flat rate billing. The Southwest Florida Water Management District conducted a study in 2002, the findings of the study indicated that on an average, 534 gallons of recycled water is used per day by single family metered residence while unmetered residence used 980 gallons per day (SWFWMD, 2002). In the city of CapeTown, all recycled water consumers are metered with flat rate billing shown in Table 7.8.

Table 7.8: Unit cost of recycled water in the City of CapeTown (Ilemobade et al., 2009)

Wastewater Treatment Work	Unit Costs of Producing Treated Effluent (R/Kl)*
Athlone	2.30
Bellvile	1.72
Cape Flats	2.31
Gordon's Bay	2.58
Kraaifontein	1.66
Macassar	1.22
Mitchels Plain	2.08
Parow	1.21
Potsdam	2.00
Scottsdene	2.34
Westfleur (Atlantis)	2.28
Wildevoelvlei	2.04
Zandvliet	2.42
Average Cost	**2.00**

**Cost redeemed at an average interest rate of 6% over 25 years*

In order to avoid overuse of reclaimed water, the following measures should be taken:

- encourage metering and volume-based rate structures;
- rationalising reclaimed water and;
- reducing the reclaimed system pressure.

7.5 Summary

For any reuse project to be successful and well embraced by user, it must operate within a regulated framework. This chapter provides suggested guidelines for the operation, inspection and regulation of reuse water facilities in South Africa. This will minimise potential human risks and environmental pollution of reuse project.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Thesis Summary

South Africa as a nation is approaching the limits of her available freshwater supplies while at the same time the demands on water resources for household, commercial, industrial, and agricultural purposes are greatly increasing. Coupled with this problem, is the continuous pollution of sensitive surface water sources through indiscriminate disposal of poorly treated wastewater. Wastewater reuse via dual reticulation systems has become an attractive option for conserving and extending available water supplies.

The practice of water reuse is an age old practice that has grown tremendously in the last century due to rapid growth in population, urbanization, agriculture, industrial development and natural occurrences such as drought. International evidence of the growth in water reuse practices and challenges are presented in Chapter 1. As reuse is gaining popularity, so do the challenges to the successful implementation of water reuse as experienced internationally. In light of this, there is need to develop tools that would enable decision makers (water resources planners, water service providers, engineering companies, water management bodies, etc.) assess the critical factors that govern reuse in order to facilitate successful implementation. The aim of this research was to develop a decision support tool for assessing the feasibility of implementing dual water reticulation systems in South Africa. A thorough feasibility study should be tackled from a multidisciplinary approach by considering the different aspects of the proposed project such as technical, economical, environmental, sociological, and health and safety issues. All these factors contribute to the final decision and success of any dual water reticulation project and their due consideration will lead to a reliable decision. The DSS achieves a balance between the social, economic, and environmental attributes involved in implementing wastewater reuse via dual reticulation systems.

The flowchart representing the layout of this thesis is shown below.

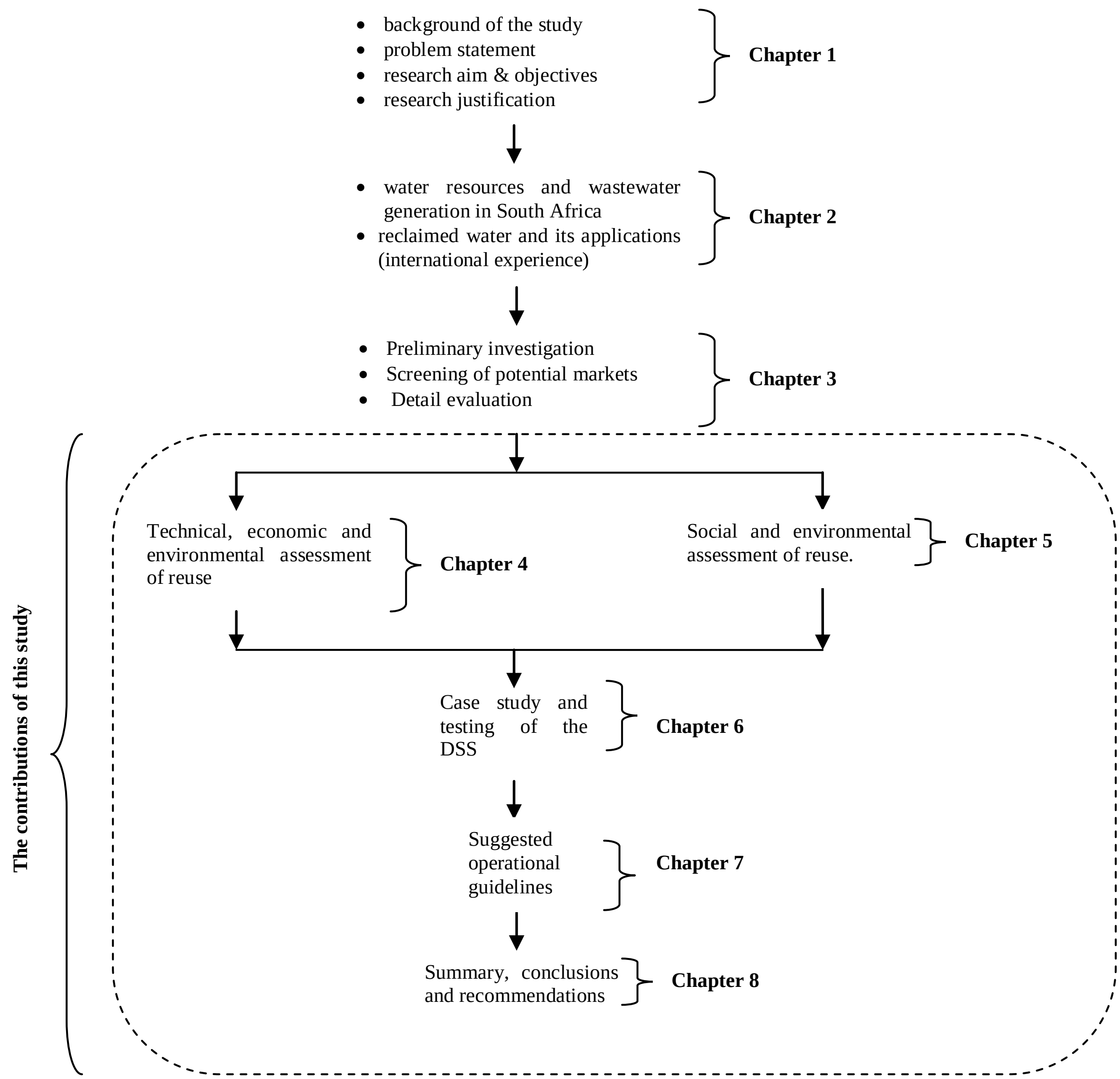


Figure 8.1: Flow chart of the dissertation layout

A review of South Africa water resources and international water reuse practices is presented in Chapter 2. South Africa is a semi-arid region with limited available water resources. Reuse water sources identified in literature are rain water, stormwater, saline water, brackish water, greywater and municipal wastewater. Of these, the most commonly used sources of reclaimed water are municipal wastewater, greywater and saline water (in coastal regions). All these sources have different qualities and require different levels of treatment to meet potential non-potable uses. The intended reuse application is the major factor influencing the level of treatment needed. However, the need to protect the public health and the environment also drives the level of treatment. Generally, the most popular non-potable water activities include irrigation of non-edible crops, industrial use, toilet flushing, general cleaning, surface water replenishment and groundwater recharge. Of all these uses, agricultural irrigation is the most popular. All non-potable water reuse applications are discussed in Chapter 2.

Chapter 3 discusses the planning of wastewater reuse projects. The starting point for planning reuse is to group activities into preliminary investigations, screening of potential markets and detailed assessment of a selected market. Sequentially, activities build on one another until enough information is available to embark on reuse project.

The cost effectiveness of water reuse projects was found to be directly related to the volume of reclaimed water used; the more water utilized, the more cost-effective the project. In this sense, irrigation generally provides the highest potential for water reuse. Depending on the need for the resource, there is a minimum flow that determines if a water reuse project is cost-effective. This level, although difficult to specify, could be in the range of a flow corresponding to 10,000 - 20,000 inhabitants-equivalents, or the same as the water needed to irrigate a golf course or a crop extension of 3,500,000 m^2 (AQUAREC, 2006). The different water reuse options should be compared to the non-reuse existing alternatives. Besides treatment costs, other aspects such as the decrease in wastewater discharge to environment or the increase in the crop yield due to irrigation with treated water (or decrease in the needed fertiliser amount) should be considered.

Good engineering proposals without economic justification are often uneconomical. The approach adopted in this research as the most suitable is the Life Cycle Cost (LCC) of wastewater treatment trains that meet the treatment quality required for specified non-potable use. LCC is a summation of cost estimates from inception to disposal for both equipment and projects. The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives to achieve the lowest long-term cost of ownership. LCC results are presented in net present value (NPV) format by considering the capital cost of a project, operation and maintenance, energy cost, replacement, the salvage value and the time value of money.

DWEA has set economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability as objectives against which strategies of water institutions or consumers should be measured. The DSS developed in this research employed TBL approach in the assessment of these objectives. The TBL approach utilises the followings: *goals* to be achieved, *criteria* which determine whether the *goals* are achieved, *assessment questions/statements* by which each *criterion* is measured and a range of *scores* for measuring each *assessment question/statement*. Chapter 4 and Chapter 5 fulfils objective number 3 of this research (and thus present an original contribution to knowledge) by explaining the framework used in the development of the DSS. It explains the various components of the DSS and the governing parameters of the multi-criteria approach used. The framework provides a robust structure for evaluating reuse feasibility and is designed to provide decision-makers with a valuable tool that uses both quantitative and qualitative criteria that cut across technical/economic, social and environmental attributes of sustainability.

Chapter 4 begins with the methodology adopted in estimating the volume of treated wastewater needed in agricultural irrigation, urban, domestic, mining and industry and in other activities. This computation provides a platform for justifying a reuse project economically by providing the quantitative volume of recycled water needed for various activities.

Treatment train assessment criteria used in this research were adapted from MOSTWATER (Dinesh and Dandy, 2003) and WTRNet (Joksimovic, 2006) where the assessment criteria for each unit process making the treatment train is classified into technical, environmental and economic types. The technical criteria considered are performance, reliability, adaptability to upgrade, varying flow rate, change in water quality, ease of O&M and ease of construction. The environmental criteria considered are power and chemical requirements, odour generation and impact on groundwater; while economic criteria relate to the project costs (i.e. capital cost, annual operating and maintenance cost or lifecycle (cost incurred throughout the useful life of the project)). Of these criteria, those calculated are pollutant removal efficiency, cost, land area requirements and energy requirements, while the other items are considered as qualitative. The criteria for the 33 unit processes in the knowledge base were derived from literature.

Chapter 5 contains the methodology for the social and institutional assessment adopted in developing the perception module of the DSS. Modelling of respondents' perceptions was done using Ajzen's Theory of Planned Behaviour (Ajzen, 1985). Six hypotheses were tested using this model and its application to potential institutional and domestic respondents. The constructs that primarily influence intention to accept wastewater reuse amongst institutional consumers are firstly, their *attitude towards wastewater reuse* and secondly, their ability to exercise some degree of *control over the source of water and its application* within their institution. Secondary influences (which are not as strong as primary influences) are the institutions appreciation of the *advantages of reuse on the environment* and *trust in the service provider* to provide a reliable and efficient service. However, *physical quality satisfaction* of the treated wastewater and *subjective norms* has minimal to no influence on potential institutions respondents' intention to accept wastewater reuse. For domestic respondents, the constructs that primarily influence intention to accept wastewater reuse amongst domestic respondents are firstly, their appreciation of the *advantages of reuse on the environment* and secondly, their ability to exercise some degree of *control over the source of water and its application*. Respondents *attitude towards wastewater reuse* and *trust in the service provider* to provide a reliable and efficient service also have a strong influence on intention to accept wastewater reuse. The only secondary influence is the subjective norms of the respondents. Similar to what was obtained in institutional respondents, *physical quality satisfaction* has no influence potential domestic respondents' intention to accept wastewater reuse.

Based on the results of TPB analyses on potential institutional and domestic respondents, the perception module in the DSS was developed with different weight assigned to the constructs statements according to their influence on intention to accept wastewater reuse. Also a holistic approach that incorporates the triple bottom line attributes of sustainably was employed in developing questionnaire for assessing the regulatory institution and service provider in the DSS.

Another important aspect of this research is to test the developed Decision Support System. This objective was fulfilled in Chapter 6. This Chapter starts with the brief description of the DSS structure. The DSS was developed using the Java^{TM} programming language. A user-friendly interface was designed to provide interactive access to input, processing and output modules. The DSS incorporates the following modules: *General information (e.g. community name and water management area), pre-feasibility form, technical/economic assessment (e.g. treated effluent potential reuse estimation and quality of wastewater source)* and *perception survey assessment (potential users and service providers/decision makers)*.

Testing of the developed DSS using a case study of the Parow wastewater treatment works in Cape Town showed it to be versatile and to provide a good assessment of both qualitative and quantitative criteria of the selected treatment trains. When the actual technical performance of the Parow wastewater treatment works was compared to the result of the DSS, Chemical Oxygen Demand and faecal coliforms removal was similar at average and maximum values. However, the DSS over estimates the Total Suspended Solids and under estimates Total Nitrogen and Total Phosphorus. In the current WWTWs monitoring procedure, plant personnel do not have performance data on the unit process pollutant removal efficiency (i.e. minimum, average or maximum). Hence, selecting operating efficiency for an existing treatment train requires good knowledge of each unit's process performance. The DSS thus provides a suitable information when data of this nature is not available.

DSS qualitative assessment score for Parow WWTW under technical (i.e. reliability, adaptability to varying flow, adaptability to vary quality, adaptability to upgrade, ease of construction and ease of O & M) and environmental (i.e. power, chemical requirements and impact on groundwater) was obtained as 0.73 out of a maximum score of 1.00. This could be interpreted as a good qualitative score. Further testing of the DSS perception module using questionnaire administered at the Goldfields gold mine, Driefontein shows that there is *high potential for reuse to be viable* if implemented.

In order to guarantee reliability that will minimize risks to human health and safety and environmental pollution, close monitoring of all elements within a water reclamation system is imperative. Chapter 7 presents suggested guidelines for water reuse project operation in South Africa.

8.2 Conclusions

This section concludes with reference to the objectives of this study which validate the original contribution of this thesis:

i. To investigate from local and international experience, the critical parameters and processes that influenced the feasibility and sustainability of implementing dual water reticulation systems. This was achieved through extensive literature survey reported in Chapters 2 and 3.

ii. Based on these critical parameters and processes, to develop a framework for assessing the feasibility of implementing dual water reticulation systems in South Africa. This was achieved in Chapters 4 and Chapter 5 by explaining the robust framework employed in developing a valuable tool that uses both qualitative and quantitative criteria that cut across technical/economic, social and environmental attributes of sustainability.

iii. To test the developed planning tool using existing wastewater treatment works, potential non-potable water users and quality requirements for various end uses of reclaimed water. This was achieved in Chapters 6 using the Parow wastewater treatment Works in Cape Town as a case study.

iv. To suggest operational guidelines that will guide service providers and consumers of reclaimed water. This was achieved in Chapters 7.

8.3 Limitations of the Developed Decision Support System

The followings are the limitations of the developed Decision Support System:

i. The treatment process selection module of the DSS is not a dynamic program and hence, does not analyze nor adjust treatment train processes in response to variable influent conditions which often occur in practical situations.

ii. The DSS does not automatically build the treatment trains to be evaluated. The building of treatment trains must be done by a user who is familiar with these processes and their general capabilities.

iii. The user should validate the reasonableness of all construction and operational costs as well as performance data for all processes prior to planning treatment trains. This is because the equation representing these costs and processes were generated based on literature survey and hence, may not adequately represent all local conditions.

iv. Different unit processes that form a treatment train operate at different pollutant removal efficiencies (i.e. minimum, average or maximum). Hence, selecting pollutant removal efficiency for an existing treatment unit requires good knowledge of the existing treatment plant operation. This information is not readily available in many existing treatment plants because analysis of influent and effluent are rarely done.

8.4 Future Research

Future research is recommended in the following areas:

i. The perception study in the CoCT was conducted with a statistically small sample (N = 16) that could not be used in the revised TPB model (Chapter 6). It is recommended that a follow up survey be carried out when the number of institutional consumers using non-potable water has increased substantially. Thereafter, the data may be analysed using the revised Ajzen's TPB and may be compared with the results obtained for the potential institutional respondents at Limpopo and understanding their unique perceptions would provide a significant step in decision-making regarding non-potable water reuse for irrigation and other agricultural purposes.

ii. The factor(s) responsible for a low questionnaire response rate in the agricultural sector should be investigated. This sector is a major stakeholder among non-potable water users.

iii. This study attempts to analyse potential respondents' perception in order to predict intended behaviour. A further study will be to correlate predicted behaviour with actual behaviour.

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APPENDIX A COST FUNCTIONS USED IN THE QUANTITATIVE ESTIMATION OF ECONOMIC/TECHNICAL ASSESSMENT

Table B.1: Cost functions used in the quantitative estimation of economic/ technical assessment (Joksimovic, 2006; Ahmed *et al*, 2002; ESCWA, 2003)

Costing Items	**Useful Life (yrs)**	**Capital Cost (ZAR)**	**Land Cost (ZAR/m^2)**	**Labour Cost (ZAR/m^2)**	**O&M Cost (ZAR)**	**Energy Cost (ZAR)**	**Replacement Cost (ZAR)**
A. Unit Process							
Bar Screen	30	$1.21 \times 10^4 Q^{0.5138}$	$0.1262 Q^{0.9755} m^2$	6 person hrs/month	$1.31 \times 10^3 Q^{0.5138}$	0	0
Coarse Screen	30	$1.94 \times 10^4 Q^{0.5138}$	$0.1262 Q^{0.9755} m^2$	6 person hrs/month	0.10 X Capital Cost	0.01kwh/m^3	0
Grit Chamber	30	$2.24 \times 10^4 Q^{0.4426}$	$4 \times 10^{-5} Q^2 + 0.0938Q + 67.5$	12 person hrs/month	0.10 X Capital Cost	0.01kwh/m^3	0
Stabilization Pond: Anaerobic	15	$7.31 \times 10^3 Q^{0.6566}$	$1.04 \times 10^2 Q^{0.9607}$ m^2	16 person hrs/month	$290 Q^{0.7977}$	0	0.5 CC
Equalization Basin	30	$5.04 \times 10^4 Q^{0.52}$	$\frac{Q}{SOR} = \frac{20 \times Q}{3} m^2$	14 person hrs/month	0.02 X Capital Cost	0	0
Sedimentation w/o coagulant	30	$1.5 \times 10^4 (20 \times Q)^{0.446}$	$\frac{Q}{SOR} = \frac{20 \times Q}{3} m^2$	14 person hrs/month	0.02 X Capital Cost	1.75 kwh/m^3.yr	0
Sedimentation w coagulant	30	$2.7 \times 10^4 (20 \times Q)^{0.321}$	$\frac{Q}{SOR} = \frac{20 \times Q}{6} m^2$	14 person hrs/month	$1.4 \times 10^3 (20 \times Q)^{0.5146}$	1.75 kwh/m^3.yr	0
Stabilization Pond: Aerobic	30	$5.6019 \times 10^0 Q^{0.6836}$	$1.11 \times 10^1 Q^{0.9453} m^2$	16 person hrs/month	0.20 X Capital Cost	0	0
Stabilization Pond: Facultative	30	$5.35 \times 10^3 Q^{0.6837}$	$1.11 \times 10^2 Q^{0.9453} m^2$	16 person hrs/month	0.20 X Capital Cost	0	0
Activated Sludge + Sedimentation	30	$9.1 \times 10^4 Q^{0.5184}$	$10.767 Q^{0.9705} m^2$	14 person hrs/month	0.10 X Capital Cost	300 kwh/m^3.yr	0
Trickling Filter + Sedimentation	30	$4.7 \times 10^3 (20 \times Q)^{0.7361}$	$5.93 Q^{0.9581} m^2$	14 person hrs/month	$9.4 \times 10^2 (20 \times Q)^{0.82}$	75 kwh/m^3.yr	0
Rotary Biological Contractors	30	$5.97 \times 10^3 Q^{0.8}$	0.6 Q m^2	40 person hrs/month	$8.45 \times 10^2 Q^{0.9228}$	75 kwh/m^3.yr	0
Membrane Bioreactors	30	$7.62 \times 10^3 (Q)^{0.75}$	7.2 Q m^2	60 person hrs/month	$320 Q^{0.6928}$	0.6 kwh/m^3	0
Biological Phosphorous Removal	30	$9.82 \times 10^3 Q^{0.5221}$	1.2 Q m^2	0	$396 Q^{0.5959}$	2.5 kwh/m^3	0
P – Precipitation	20	$1.13 \times 10^3 (20 \times Q)^{0.345}$	75 m^2	0	0.4 X Capital Cost	0.1 kwh/m^3	0.34 CC
Chemical Precipitation	20	$9.82 \times 10^3 Q^{0.554}$	85 m^2	0	0.4 X Capital Cost	7.0 kwh/m^3	0.34 CC
Denitrification	30	$9.82 \times 10^2 Q^{0.5221}$	1.2 Q m^2	0	$396 Q^{0.5959}$	0.5 kwh/m^3	0
Constructed Wetland	30	$3.55 \times 10^4 Q^{0.3926}$	120 Q m^2	14 person hrs/month	0.40 X Capital Cost	0	0
Maturation Ponds	15	$3.6 \times 10^3 Q^{1.014}$	124 Q m^2	14 person hrs/month	$743.5 Q^{0.7364}$	0	0.5 CC
Dual Media Filter	20	$5.54 \times 10^3 Q^{0.634}$	$0.4217 Q^{0.6029} m^2$	18 person hrs/month	0.20 X Capital Cost	1.0 kwh/m^3	0.34 CC
Micro Filtration	20	$5.36 \times 10^3 Q^{0.6}$	$0.4217 Q^{0.6029} m^2$	18person hrs/month	0.20 X Capital Cost	0.3 kwh/m^3	0.34 CC
Ultra Filtration	20	$5.36 \times 10^3 Q^{0.6}$	$0.4217 Q^{0.6029} m^2$	18 person hrs/month	0.20 X Capital Cost	0.3 kwh/m^3	0.34 CC
Nano Filtration	20	$9.4 \times 10^3 (Q)^{0.845}$	$0.3255 Q^{0.4311} m^2$	14 person hrs/month	0.20 X Capital Cost	2.5 kwh/m^3	0.34 CC
Reverse Osmosis	20	$9.4 \times 10^3 (Q)^{0.845}$	$0.3255 Q^{0.4311} m^2$	14 person hrs/month	0.20 X Capital Cost	1 kwh/m^3	0.34 CC
Soil Aquifer Treatment	40	180Q	$0.9065 Q^{0.969} m^2$	250 person hrs/month	2.2 X Capital Cost	0.24 kwh/m^3	0
Activated Carbon	20	$2.67 \times 10^3 (Q)^{0.8386}$	$0.365 Q^{0.423} m^2$	18 person hrs/month	0.09 X Capital Cost	0.5 kwh/m^3	0.34 CC
Ion Exchange	30	$4.9 \times 10^3 (Q)^{1.15}$	Q X 0.004 m^2	110 person hrs/month	0.10 X Capital Cost	175 kwh/m^3.yr	0
Advanced Oxidation Ponds	30	$1.4 \times 10^4 (Q)^{0.78}$	0.4 m^2/m^3/Hr	16 person hrs/month	$549 (Q)^{1.1}$	2.5kwh/m^3	0

Costing Items	Useful Life (yrs)	Capital Cost (ZAR)	Land Cost (ZAR/m^2)	Labour Cost (ZAR/m^2)	O&M Cost (ZAR)	Energy Cost (ZAR)	Replacement Cost (ZAR)
Electrodialysis	30	$5.8 \times 10^3 (Q)^{1.116}$	0.004 m^2/m^3	14 person hrs/month	0.10 X Capital Cost	175 kwh/m^3.yr	0
Chlorine Gas	15	$2.45 \times 10^4 (Q)^{0.5}$	15 m^2	30 person hrs/month	0.1 × Capital Cost	0	0.5 CC
Chlorine Dioxide	15	$3.85 \times 10^4 (Q)^{0.40}$	10 m^2	25 person hrs/month	0.1 X Capital Cost	0	0.5 CC
Ozone	15	$1.25 \times 10^4 Q^{0.7326}$	50 m^2	12 person hrs/month	$319 Q^{0.8916}$	0.57kwh/m^3	0.5 CC
UV Radiation	20	$2.4 \times 10^3 (20 \times Q)^{0.568}$	$2.4 \times 10^3 (Q)^{0.3368} m^2$	13 person hrs/month	0.198/m^3	0.043kwh/m^3	0.34 CC
B. Distribution							
Pipe	30	$f(Q,)$					
Pump	30	$f(Q)$					

APPENDIX B UNIT PROCESS DETAILED INFORMATION

PRELIMINARY TREATMENT

ID PRE01
Name Bar Screen
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	Low	High	High	High	High	Low	Nil	Nil	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum (%)			0	0				
	Average (%)	0	0	2	1.3	0	0	0	0
	Maximum (%)			2.5	1.5				

ID PRE02
Name Coarse Screen
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	Low	Low	Low	Low	Low	Low	Nil	High	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum (%)		0	2	1				
	Average (%)	0	5	4	2	0	0	0	0
	Maximum (%)		15	6	3				

ID PRE03
Name Grit Chamber
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	Low	High	Medium	Low	Low	Low	Nil	High	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	1							
	Average	2	0	0	0	0	0	0	0
	Maximum	3							

PRIMARY TREATMENT

ID	**PRI01**								
Name	**Stabilization Pond: Anaerobic**								
Recovery (%)	**100**								
Useful Life	**15 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
Low	Low	Medium	Medium	High	High	Low	Nil	High	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	15	30	40	30	25	5	30	20
	Average	70	45	65	58	48	7	50	35
	Maximum	75	60	90	85	70	10	60	45

ID	**PRI02**								
Name	**Equalization Basin**								
Recovery (%)	**100**								
Useful Life	**30 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	Low	High	High	High	High	Low	Nil	Medium	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	0	5	4	0	0	0	0	0
	Average		10	12					
	Maximum		15	15					

ID	**PRI03**								
Name	**Sedimentation W/O Coagulant**								
Recovery (%)	**99**								
Useful Life	**30 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	Low	Medium	Low	Medium	Medium	Low	Nil	Medium	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	0	30	20	20	5	5	0	0
	Average		50	25	25	7	8		
	Maximum		60	30	30	9	15		

ID **PRI04**
Name **Sedimentation W Coagulant**
Recovery (%) **99**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Medium	Low	Medium	High	Low	Medium	High	Medium	Medium	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	50	60	40	40	0	60	10	5
	Average	70	70	50	50	15	70	15	10
	Maximum	80	80	60	60	30	90	30	20

SECONDARY TREATMENT

ID **SEC01**
Name **Stabilization Pond: Aerobic**
Recovery (%) **99**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Low	Low	Medium	Medium	High	High	Low	Nil	High	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	50	30	40	35	25	20	10	5
	Average	60	45	60	40	45	40	15	10
	Maximum	75	60	80	60	60	50	30	20

ID **SEC02**
Name **Stabilization Pond: Facultative**
Recovery (%) **99**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Low	Low	Medium	Medium	High	High	Low	Nil	High	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/5100mL
Removal efficiency	Minimum	40	50	50	60	20	25	10	10
	Average	50	70	70	80	40	50	15	20
	Maximum	60	85	85	90	60	70	30	

ID **SEC03**
Name **Activated Sludge + Sedimentation**
Recovery (%) **99**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	High	High	High	Medium	Medium	High	Low	Low	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	10	50	50	60	10	10	20	15
	Average	40	70	70	80	30	23	35	30
	Maximum	70	85	85	90	50	45	50	45

ID **SEC04**
Name **Trickling Filter + Sedimentation**
Recovery (%) **99**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Medium	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	20	50	50	65	20	20	60	50
	Average	30	70	70	80	30	30	80	60
	Maximum	45	85	85	90	40	40	90	75

ID **SEC05**
Name **Rotary Biological Contractor**
Recovery (%) **99**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	High	Medium	High	Medium	Medium	High	Nil	Low	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	50	35	35	65	20	20	60	50
	Average	70	60	60	70	30	30	80	60
	Maximum	85	70	70	85	35	40	90	75

ID SEC06
Name Membrane Bioreactors
Recovery (%) 99
Useful Life 30 years

Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	Medium	High	Low	Low	High	Low	Medium	Low

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	90	90	90	90	30	60	80	70
	Average	92	92	92	92	40	70	85	75
	Maximum	95	95	95	95	50	80	90	80

ADVANCED TREATMENT

ID ADV01
Name Biological Phosphorous Removal
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
Medium	High	Medium	Medium	High	High	Low	Nil	Medium	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum						90		
	Average	0	0	0	0	0	95	0	0
	Maximum						98		

ID ADV01
Name P - Precipitation
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	High	High	High	High	Low	Medium	Nil	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum						90		
	Average	0	0	0	0	0	95	0	0
	Maximum						98		

ID ADV03
Name Chemical Precipitation
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	High	Medium	Medium	High	High	Medium	High	Nil	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	20	40	20	15	5	10	10	5
	Average	30	60	30	35	8	15	20	15
	Maximum	50	80	40	50	13	30	40	20

ID ADV04
Name Denitrification
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Medium	High	Medium	Medium	High	High	Low	Nil	Low	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum					90			
	Average	0	0	0	0	95	0	0	0
	Maximum					98			

ID ADV05
Name Constructed Wetland
Recovery (%) 100
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Medium	Low	Medium	Medium	High	High	Nil	Nil	Low	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	10	60	25	10	50	80		
	Average	15	75	35	15	60	85	0	0
	Maximum	40	85	50	20	80	90		

ID	**ADV06**								
Name	**Maturation Ponds**								
Recovery (%)	**100**								
Useful Life	**15 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
Medium	Low	Medium	Medium	High	High	Low	Nil	Low	Nil

Pollutant Removal										
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	30	15	8	10	30	20	30	20
	Average	45	25	13	20	40	30	50	35
	Maximum	60	40	20	30	45	40	70	50

ID	**ADV07**								
Name	**Dual medial Filter**								
Recovery (%)	**100**								
Useful Life	**20 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	Medium	Medium	Low	Medium	High	Low	Nil	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	80	80	65	60	5	6	90	80
	Average	90	90	75	70	10	10	93	85
	Maximum	95	95	80	75	12	12	95	90

ID	**ADV08**								
Name	**Micro Filtration**								
Recovery (%)	**85**								
Useful Life	**20 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	Medium	Medium	Low	Medium	High	Low	Nil	Nil

Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	85	80	65	60	5	6	90	80
	Average	90	90	75	70	10	10	93	85
	Maximum	95	95	80	75	12	12	95	90

ID	**ADV09**								
Name	**Ultra Filtration**								
Recovery (%)	**85**								
Useful Life	**20 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	Medium	Medium	Low	Medium	High	Low	Nil	Nil
Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	80	80	65	60	5	6	90	80
	Average	90	90	75	70	10	10	93	85
	Maximum	95	95	80	75	12	12	95	90

ID	**ADV10**								
Name	**Nano Filtration**								
Recovery (%)	**83**								
Useful Life	**20 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	Medium	Medium	Low	Medium	High	Low	Nil	Nil
Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	30	80	20	60	40	80	90	90
	Average	50	90	35	70	40	90	95	93
	Maximum	70	95	50	75	40	95	98	95

ID	**ADV11**								
Name	**Reverse Osmosis**								
Recovery (%)	**80**								
Useful Life	**20 years**								
Evaluation Criteria Score									
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**
High	High	Medium	Medium	Low	Medium	High	Low	Nil	Nil
Pollutant Removal									
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	30	80	20	60	40	80	90	90
	Average	50	90	35	70	40	90	95	93
	Maximum	70	95	50	75	40	95	98	95

ID ADV12
Name Soil Aquifer Treatment
Recovery (%) 100
Useful Life 40 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	Medium	High	Medium	High	High	Low	Nil	Low	Medium

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	85	80	85	85	85	80	70	65
	Average	85	90	85	85	85	90	75	70
	Maximum	85	95	85	85	85	95	80	75

ID ADV13
Name Activated carbon
Recovery (%) 100
Useful Life 20 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	Low	Low	Low	Low	Low	High	Low	Medium	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	20	40	40	20		8	15	10
	Average	40	45	45	30	0	15	30	20
	Maximum	60	50	50	40		25	40	30

ID ADV14
Name Ion Exchange
Recovery (%) 90
Useful Life 30 years

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Low	Medium	Low	Low	Low	Medium	High	High	Nil	Low

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	10	40	10		60	70		
	Average	20	45	20	0	70	80	0	0
	Maximum	30	50	30		80	90		

ID **ADV15**
Name **Advanced Oxidation Pond**
Recovery (%) **100**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Medium	Medium	High	Medium	Medium	High	High	High	Nil	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	70		70	70			60	55
	Average	80	0	80	80	0	0	70	65
	Maximum	90		90	90			80	75

ID **ADV16**
Name **Electrodialysis**
Recovery (%) **100**
Useful Life **30 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
Medium	Medium	Low	Medium	Medium	High	High	High	Nil	Nil

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum	70				40	40	60	55
	Average	80	0	0	0	50	50	70	65
	Maximum	90				60	60	80	75

DISINFECTION

ID **DIS01**
Name **Chlorine Gas**
Recovery (%) **100**
Useful Life **15 years**

Evaluation Criteria Score

Reliability	Adaptability to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O&M	Ease of construction	Power requirement	Chemical requirement	Odour generation	Impact on groundwater
High	Medium	High	High	Medium	Low	Low	Medium	Low	Low

Pollutant Removal

Pollutant		Turb	SS	BOD	COD	TN	TP	FC	TC
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL
Removal efficiency	Minimum							100	100
	Average	0	0	0	0	0	0	100	100
	Maximum							100	100

ID DIS02
Name Chlorine Gas
Recovery (%) 100
Useful Life 15 years

Evaluation Criteria Score										
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**	
High	Medium	High	High	Medium	Low	Low	High	Nil	Low	
Pollutant Removal										
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL	
Removal efficiency	Minimum	0	0	0	0	0	0	100	100	
	Average							100	100	
	Maximum							100	100	

ID DIS03
Name Ozone
Recovery (%) 100
Useful Life 15 years

Evaluation Criteria Score										
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**	
High	High	High	High	Low	Medium	High	Nil	Nil	Nil	
Pollutant Removal										
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL	
Removal efficiency	Minimum	0	0	0	0	0	0	90	90	
	Average							95	92	
	Maximum							98	95	

ID DIS04
Name UV Radiation
Recovery (%) 100
Useful Life 15 years

Evaluation Criteria Score										
Reliability	**Adaptability to upgrade**	**Adaptability to varying flow**	**Adaptability to varying quality**	**Ease of O&M**	**Ease of construction**	**Power requirement**	**Chemical requirement**	**Odour generation**	**Impact on groundwater**	
High	Medium	Medium	Low	Low	Low	High	Nil	Nil	Nil	
Pollutant Removal										
Pollutant		**Turb**	**SS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Nº/100mL	Nº/100mL	
Removal efficiency	Minimum	0	0	0	0	0	0	60	55	
	Average							70	65	
	Maximum							85	80	

APPENDIX C DESICION SUPPORT SYSTEM USER MANUAL

C.1 Introduction

The methodology for dual water reticulation feasibility planning described in Chapter 4 and Chapter 5, was implemented in a user friendly tool called ***WASWARPLAMO***. ***Waswarplamo*** is an acronym for **Was**te **Wa**ter **R**euse **Pla**nning **Mo**del. It is a software tool developed to assist financiers, engineers, water resources planners and decision makers in improving their planning of successful wastewater reuse projects in South Africa communities. International records of wastewater reuse to date are characterised by both failures and successes testimonies due to several factors - technical, economic, social and institutional. ***Waswarplamo*** is a suit of computer programs that incorporate all these factors in its analysis to assist decision makers to successful implement reuse schemes through improved strategies.

C.2 Target User Audience

This manual is intended to supply basic information about the operation of ***Waswarplamo***. It provides an overview of the information display and editing conventions that have been adopted as well as the functions performed by each of the program's commands and dialogs. It is assumed that the users of ***Waswarplamo*** will have some background in wastewater treatment and reuse planning. It is also assumed that users will be familiar with the MS-Windows operating system, and have basic keyboard and mouse skills. This manual is not intended to be a tutorial in either wastewater treatment or the MS-Windows system.

Waswarplamo's main use is as a tool for persons with some technical background to screen possible wastewater treatment options appropriate to meet water quality requirements for non-potable uses. The performance and cost of a large number of possible combinations of wastewater treatment processes to form treatment trains can be estimated with ***Waswarplamo*** for any location in South Africa. ***Waswarplamo*** should therefore alleviate the problem of overlooking good processes for wastewater treatment, and help screen treatment technologies that are inappropriate to producing required water quality. It is hoped that design errors can be significantly reduced or eliminated via the use of ***Waswarplamo*** by persons with some background in wastewater treatment.

C.3 System Requirements

Waswarplamo was written using Java® for IBM-PC compatible computers running Microsoft Windows ® 98 or later version. Recommended minimum Random Access Memory (RAM) is 1024MB (1GB) and screen resolution is 1024 x 768; True Colour (24 bit), 60 Hz (refresh rate) is required to install ***Waswarplamo***. The system must have Java environment, the latest version can be downloaded at "http://java.com/download.

C.4 Installation of *Waswarplamo*

i. In the compact disk that contains the DSS, you will find an executable file "Waswarplamo.exe". By ***clicking*** on this file, a dialogue showing information about the DSS and its developer will appear.

ii. Click next; the installation takes you to a dialogue box that introduces you to the DSS.

iii. After clicking next, you will then be directed to a window that will prompt you to enter a path to where you want to install the program; the default is "Program Files" which is the recommended destination.

iv. After clicking next, the actual installation window will appear, when it finishes, you will be prompted to proceed by clicking next where you can select where to create shortcuts.

C.5 Limitation of the program

Waswarplamo is not a dynamic program and does not directly analyze the response of a given system to variable influent conditions. ***Waswarplamo*** does not build the treatment trains to be evaluated. However, violation of acceptable engineering practices of combining treatment unit processes to form treatment trains is not allowed. The building of treatment trains must be done by a user familiar with these processes and their general capabilities.

Waswarplamo is primarily intended for use on real life wastewater treatment for non-potable reuses applications, although it can be used for theoretical or academic problems as well. While efforts have been made to provide accurate costs and performance data, the user should validate the reasonableness of all construction and operational costs as well as performance data for all processes.

C.6 Working with *Waswarplamo*

C.6.1 Welcome page

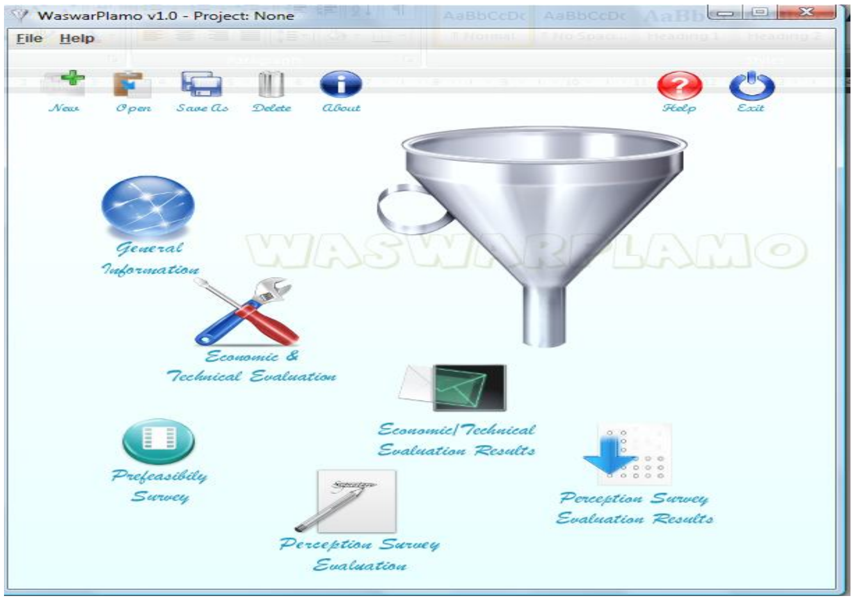


Figure C.1: *Waswarplamo*’s Welcome Page

Figure C.1 depicts ***Waswarplamo*’s Welcome Page**. The thirteen (13) buttons depicted in the figure are explained below:

: **Open New Project** – This button activates a dialogue that encourages the user to create a new project folder.

: **Open Project** – This button activates a dialogue that encourages the user to open an existing folder.

: **Save Project As** – This button activates a dialogue that encourages the user to save an existing project file in another name while retaining the previous folder.

: **Delete project** – This button activates a dialogue that encourages the use user to delete an existing project file completely.

: **About Waswarplamo** – This button activates a dialogue that takes the user to help file.

: **Help File** – This button activates a dialogue where you can read help file.

: <u>Exit</u> - This button enables user to exit ***Waswarplamo***

***<u>NOTE</u>**: You need to create or open a project file in order to use Waswarplamo's facilities (i.e. the first three buttons at the top)*

: **<u>General Information</u>** – This is the button that activates a dialog box with a set of possible actions via button as shown in Figure C.2.

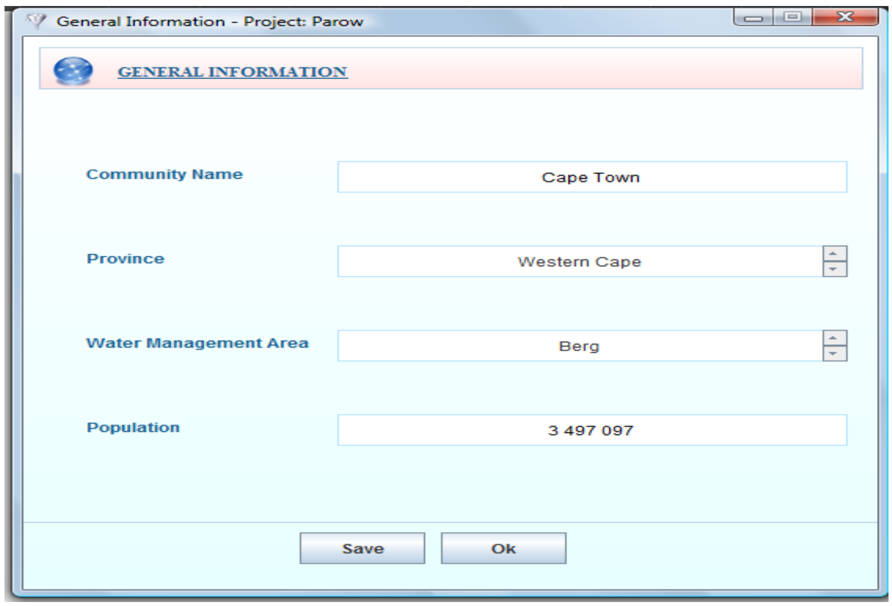


Figure C.2: General information form

Under general information, the input information is a community name its population while province and water management area is selected from the list using a drop down button.

: **<u>Prefeasibility Survey</u>** – Selecting Prefeasibility Survey button leads user to a prefeasibility questionnaire to be administered.

: **<u>Technical/Economic Assessment</u>** – Selecting Engineering/Technical Assessment button presents a dialog box with 8 sets of possible actions accessed via buttons (Figure C.3).

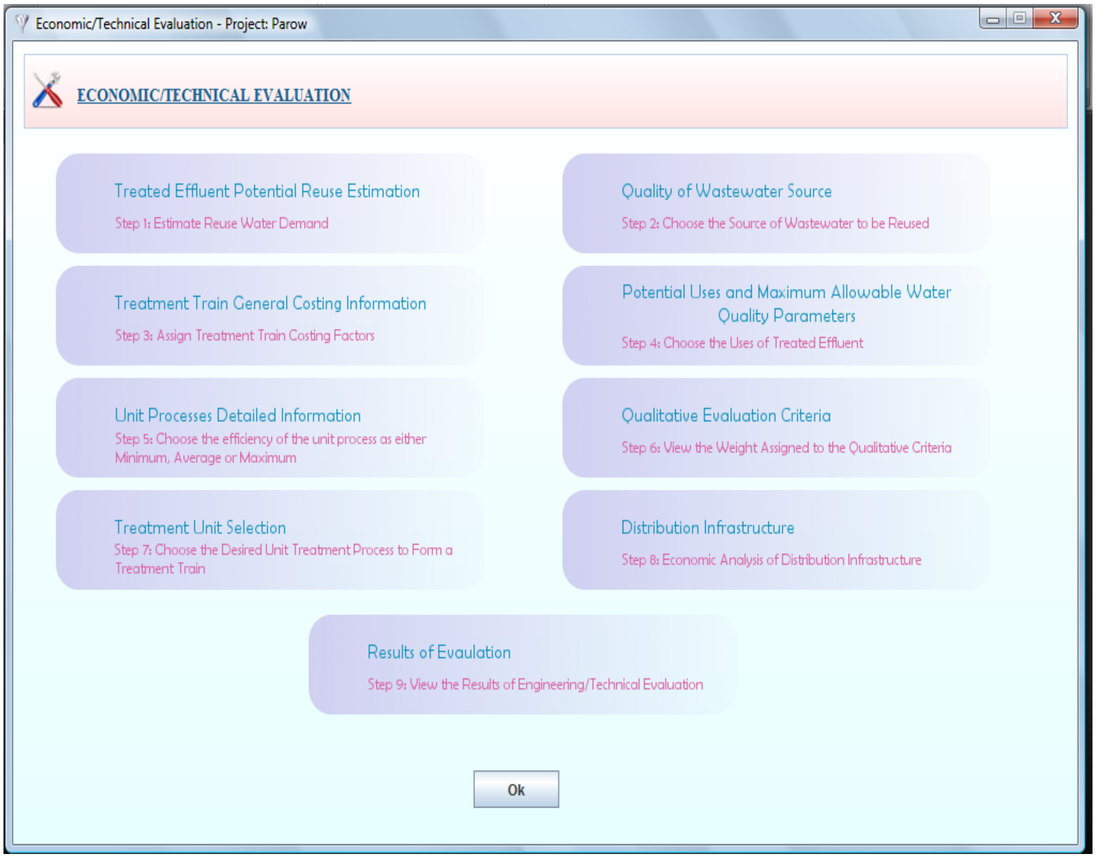
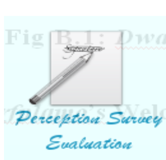


Figure C.3: Technical/Economic Assessment form

The buttons are labelled: treated effluent potential reuse estimation, quality of wastewater source, treatment train general costing information, potential uses and maximum allowable water quality parameters, unit processes detailed information, qualitative assessment, treatment unit selection and result of assessment. Details of activities involved in each button are explained in sections C1.6.2 to section C.1.6.8.



: **Perception Survey Assessment** – Selecting Perception Survey button presents a dialog box that contains two separate forms on a page. The first one contains three buttons (i.e. questionnaire, assessment procedure and results of assessment) for potential users. The second form also contains three buttons (i.e. questionnaire, assessment procedure and results of assessment) for the service providers (Figure C.4).

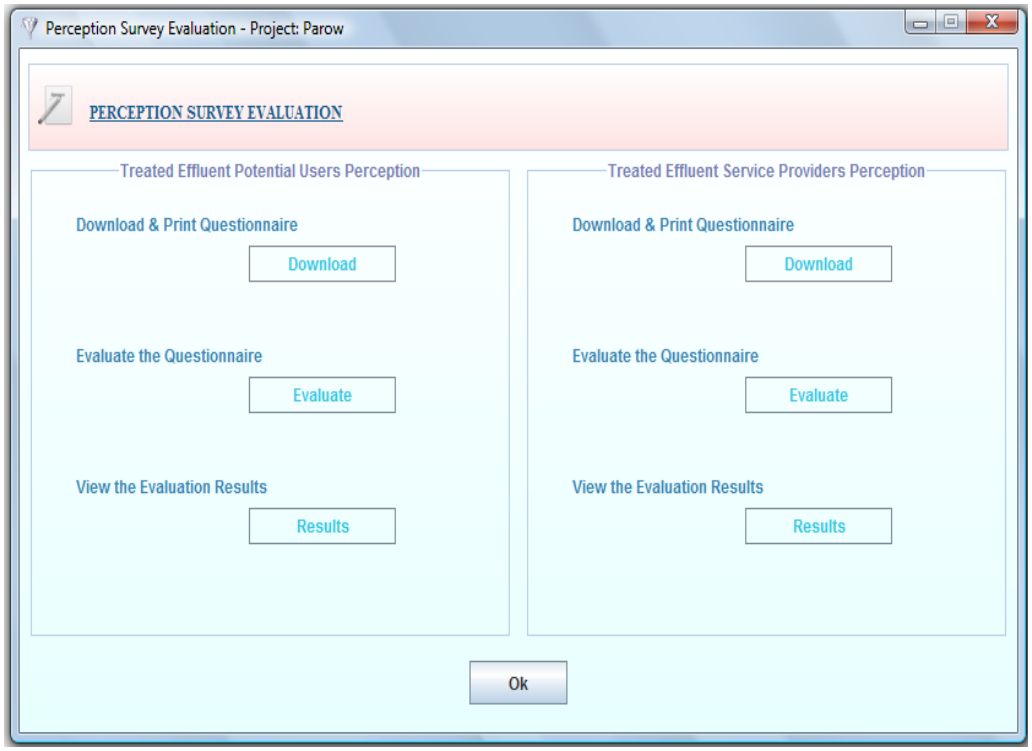


Figure C.4: Perception Survey Assessment form

: This button is used to view the result of technical and economic assessment.

: This button is used to view the result of perception survey.

NOTE: *You can also view results of each assessment under each form*

C.6.2 Treated Effluent Potential Reuse Estimation

Figure C.5 shows the ***Waswarplamo*** treated effluent potential reuse estimation form with six sections. The user is expected to input data on the first 5 sections: agricultural irrigation, landscape/recreational irrigation, domestic use, mining & industry and other uses (construction, fire fighting, aquifer recharge etc). The last section automatically sums up the values obtained from the first five sections to give the total volume of water required in all sections. Each section contains edit, clear and save buttons. When *edit button* is clicked, it opens another form that asks the user which value he/she wants to use (estimated or known value) as shown in Figure C.6. For example under agricultural irrigation, if estimated value is selected, buttons that contain agricultural irrigation area and crop water requirements are activated for the user to fill in the required information. If known value is selected, only known value button is activated while others remain inactive. *Clear button* clears all the input information or changes made; *save button* saves all the information that appears on each section and *OK button* closes the page and returns to Engineering/Technical form.

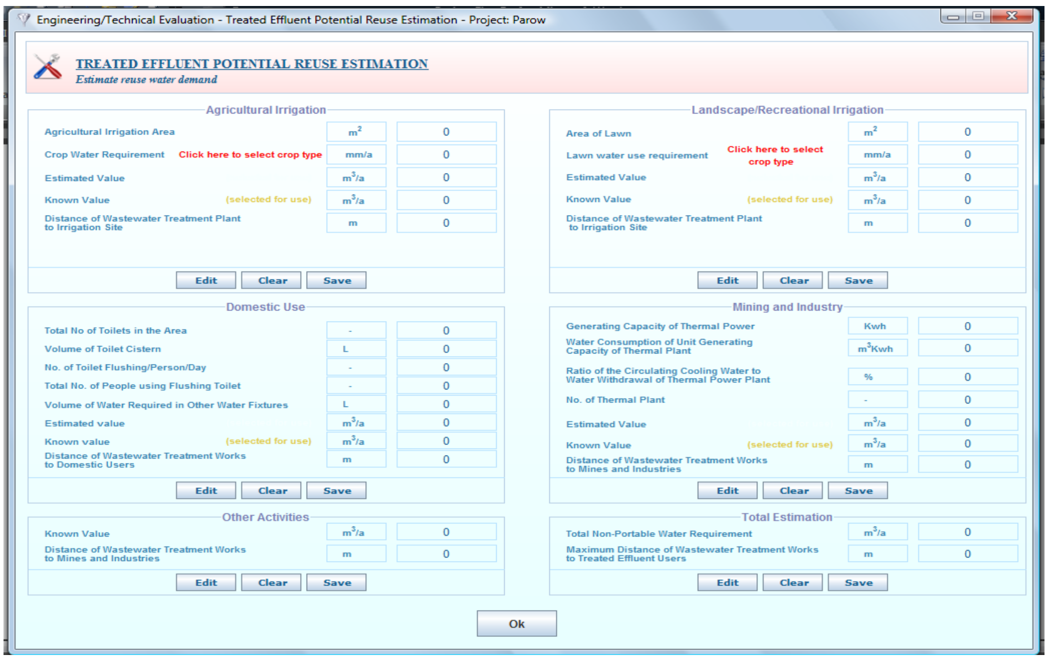


Figure C.5: Treated effluent potential reuse estimation form

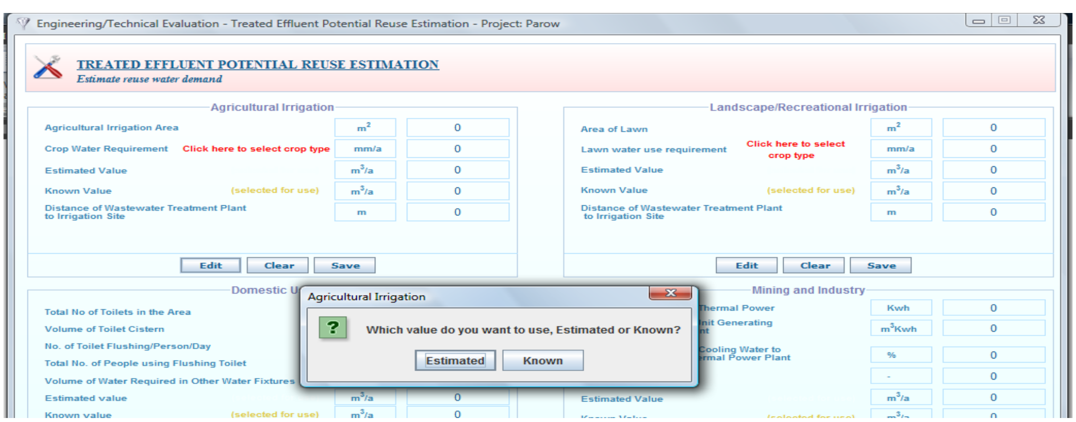


Figure C.6: Question on which value to be used form

C.6.3 Quality of Wastewater Source

Selecting Quality of Wastewater Source presents a dialog box shown in Figure C.7 with sources as raw wastewater, treated effluent from primary treatment and treated effluent from secondary treatment. When the user selects the button under the source of wastewater to be used (say raw wastewater as in Figure C.7), the button under each pollutant unlocks to allow the user to edit the default values. ***Waswarplamo*** data base contains a range of possible values for each pollutant under each source to guide users when changing the default values. The *save button* saves the information on the page and *OK button* closes the page and returns to Technical/Economic form.

Figure C.7: Quality of wastewater source form

C.6.4 Treatment Train General Costing Information

When Treatment Train General Costing Information is selected, a dialog box shown in Figure C.8 appears with a set of possible actions accessed via buttons. The first button is entitled Edit. The *Edit button* opens all values for editing, thereby allows user to review the database for each of the categories. ***Waswarplamo*** data base contains a range of possible values for treatment train costing factor while other factors accept user input values. The *save button* saves the information on the page and *OK button* closes the page and returns to Engineering/Technical form.

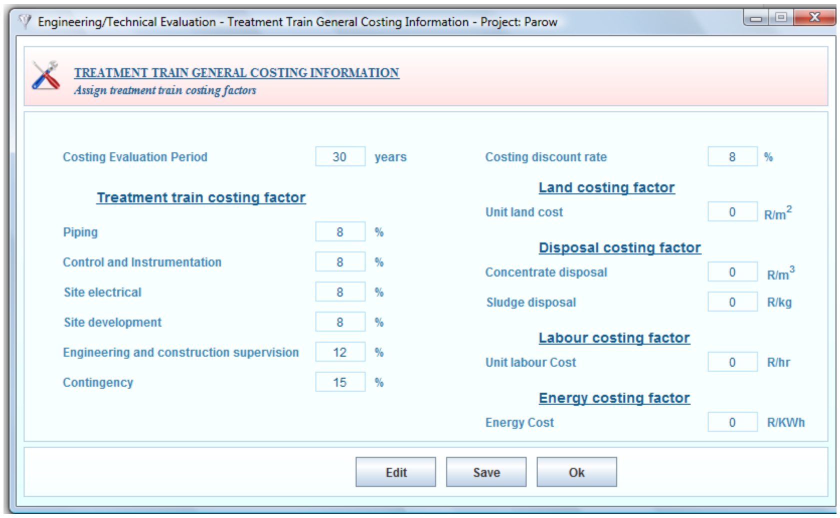


Figure C.8: Treatment train general costing information form

C.6.5 Potential Uses and Maximum Allowable Water Quality Parameters

Figure C.9 depicts a dialog box that appears when Potential Uses and Maximum Allowable Water Quality Parameters button is activated. The user is expected to click at least one of the uses before closing this page. The *save button* saves the information on the page and *OK button* closes the page and returns to Engineering/Technical form.

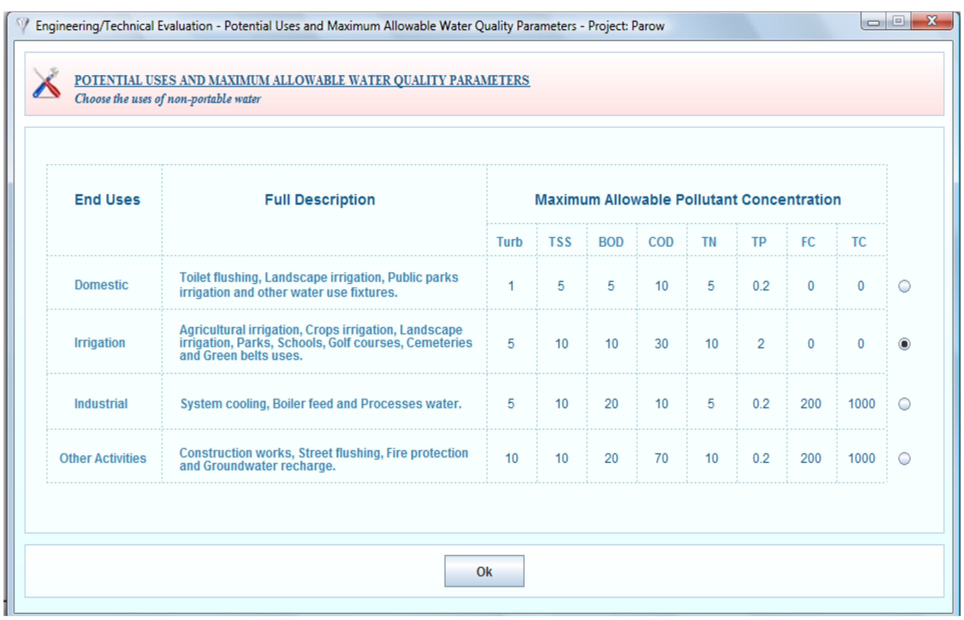


Figure C.9: Potential uses and maximum allowable water quality parameters form

C.6.6 Unit Processes Detailed Information

Selecting Unit Processes Detailed Information opens a dialog box shown in Figure C.10. The user is expected to select one of *Minimum*, *Average* or *Maximum* to indicate the operating level of the unit processes to be selected. The scroll bar on the left hand side of the form allows user to scroll up or down to select other unit processes for assessment before closing the page. Pressing the <u>*OK button*</u> closes the page and returns to Technical/Economic form.

Figure C.10: Unit processes detailed information form

C.6.7 Treatment Unit Selection

Treatment Unit Selection page presents a platform for the selection of treatment units combination to make treatment train. There are five treatment stages classified as preliminary, primary, secondary, advanced and disinfection (Figure C.11). The edit button unlocks the appropriate treatment stage for selection. For instance, if the quality of water source is primary treatment, the first two stages of treatment (preliminary treatment and primary treatment) are locked, thereby preventing user from selecting any unit process from these stages. By pressing <u>*save button*</u>, the selected unit processes become locked. To view the treatment trains, the statement "*click here to view treatment flow*" is clicked to activate the dialog box shown in Figure C.12.

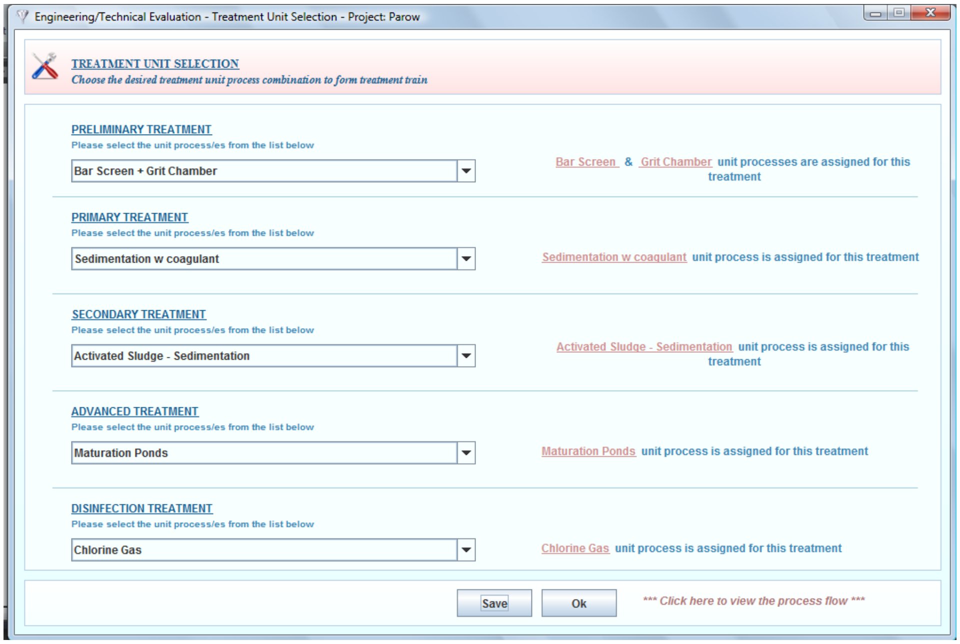


Figure C.11: Treatment unit selection form

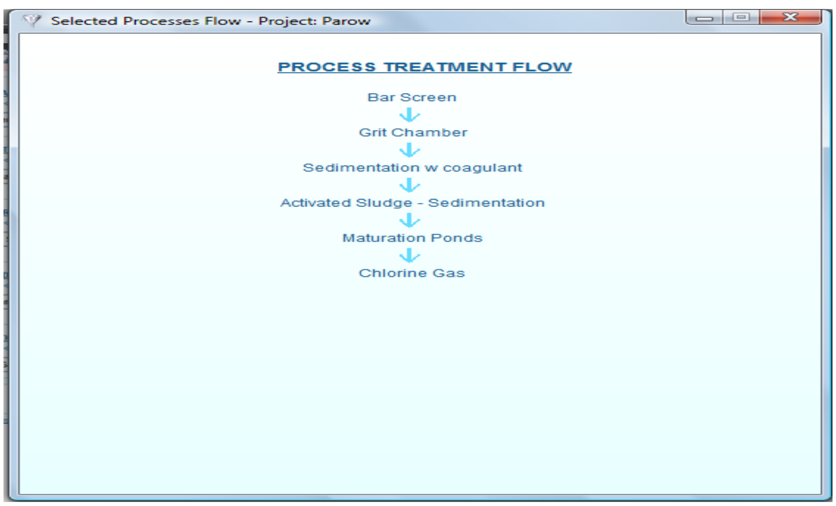
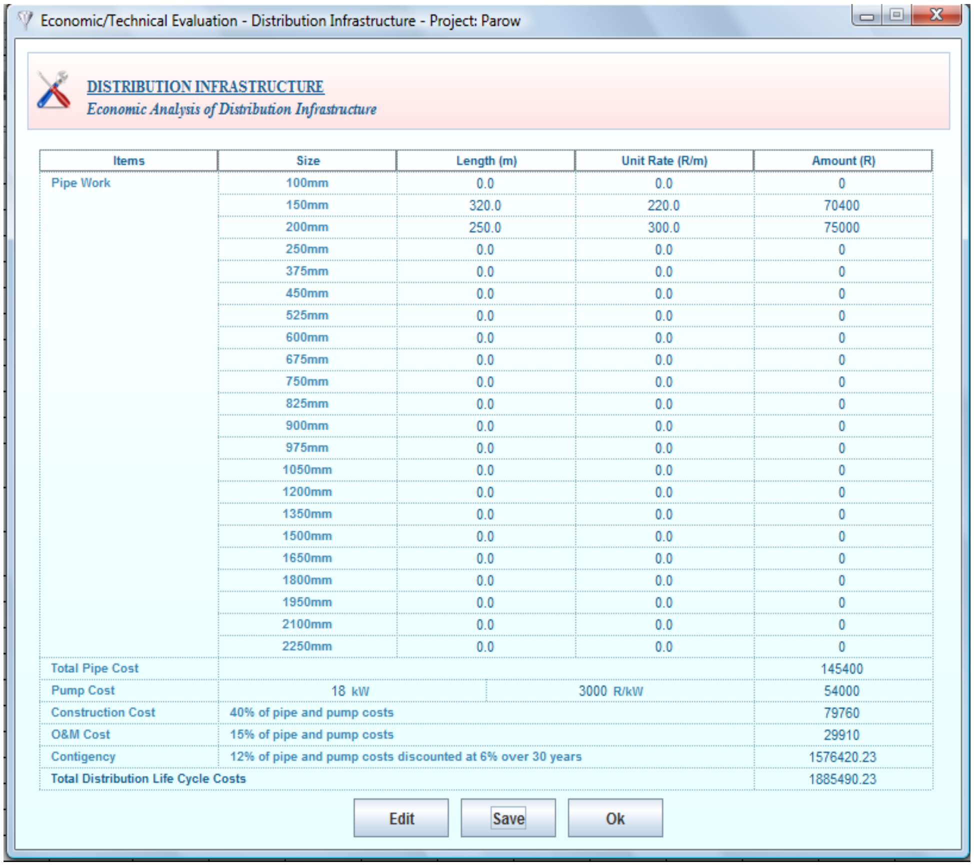


Figure C.12: Treatment train flow form

C.6.8 Distribution Infrastructure Assessment

Selecting Distribution Infrastructure assessment opens a dialog box shown in Figure C.13. The user is expected to type the length of each relevant pipe needed for the distribution on treated wastewater and the pump size based on the distribution analysis previously carried out using any suitable water distribution software. If there is need for storage facility, this is also indicated in size. Pressing the <u>*OK button*</u> closes the page and returns to Technical/Economic form.



Economic/Technical Evaluation - Distribution Infrastructure - Project: Parow

DISTRIBUTION INFRASTRUCTURE
Economic Analysis of Distribution Infrastructure

Items	Size	Length (m)	Unit Rate (R/m)	Amount (R)
Pipe Work	100mm	0.0	0.0	0
	150mm	320.0	220.0	70400
	200mm	250.0	300.0	75000
	250mm	0.0	0.0	0
	375mm	0.0	0.0	0
	450mm	0.0	0.0	0
	525mm	0.0	0.0	0
	600mm	0.0	0.0	0
	675mm	0.0	0.0	0
	750mm	0.0	0.0	0
	825mm	0.0	0.0	0
	900mm	0.0	0.0	0
	975mm	0.0	0.0	0
	1050mm	0.0	0.0	0
	1200mm	0.0	0.0	0
	1350mm	0.0	0.0	0
	1500mm	0.0	0.0	0
	1650mm	0.0	0.0	0
	1800mm	0.0	0.0	0
	1950mm	0.0	0.0	0
	2100mm	0.0	0.0	0
	2250mm	0.0	0.0	0
Total Pipe Cost				145400
Pump Cost	18 kW		3000 R/kW	54000
Construction Cost	40% of pipe and pump costs			79760
O&M Cost	15% of pipe and pump costs			29910
Contigency	12% of pipe and pump costs discounted at 6% over 30 years			1576420.23
Total Distribution Life Cycle Costs				1885490.23

Edit Save Ok

Figure C.13: Distribution infrastructure form

C.6.9 Perception Survey Assessment

Selecting Perception Survey Assessment Button presents a form shown in Figure C.14. There are two sections on this page namely *Treated Effluent Potential Users Perception*, and *Treated Effluent Service Providers Perception*. Under each section, there are questionnaire samples and a questionnaire assessment part that allows user to print and analyse each questionnaire. The user is expected to print these questionnaires and administered them in the study community. Responses from the administered questionnaires are then feed into the questionnaire assessment form by clicking on the *Evaluate the Questionnaire* button as shown in Figure C.15. The results of perception survey for potential users are viewed by pressing ***result*** button.

The user accessed and analyse *Treated Effluent Service Providers Perception* section in a manner similar to *Treated Effluent Potential Users Perception*.

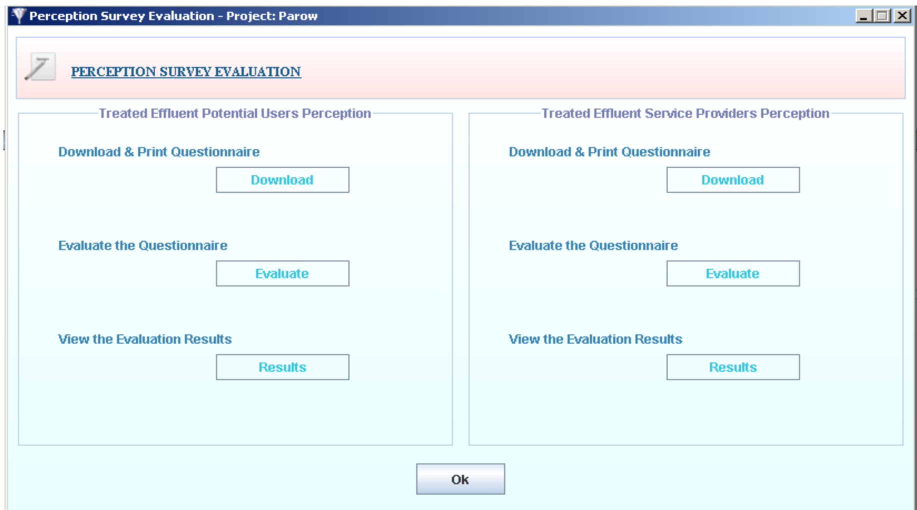


Figure C.14: Perception Survey Assessment form

Figure C.15: Questionnaire Evaluation form

APPENDIX D.1 QUESTIONNAIRE FOR INSTITUTIONAL CONSUMERS OF NON-DRINKING WATER

School of Civil and Environmental Engineering

University
of the Witwatersrand,
Johannesburg

INSTITUTIONAL NON - DRINKING WATER CONSUMER

(ATTENTION: ___________________)

We would like to request a few minutes of your time to assist this research undertaken by the University of the Witwatersrand and the Water Research Commission. The survey is investigating the feasibility of implementing dual water reticulation systems conveying drinking and non – drinking water qualities in domestic and non – domestic applications in South Africa. Your contribution in this research will immensely help. Your details are not required and your answers will be treated with confidentiality.

DEFINITION: *Non-drinking water refers to treated effluent, salinewater, treated greywater, raw surface water, etc suitable for non-drinking purposes e.g. cooling, paper making, irrigation, etc.*

For each of the following questions, please tick (√) against the option that is most applicable to you.

Section A: Background Information

1. Which of the following sectors can we classify your institution?

   ☐ Domestic ☐ Agriculture ☐ Commerce/ Industry ☐ Sport ☐ Education ☐ Public

   [x] Others (Specify _Mining________________)

2. If your institution is in Agriculture, what do you use non - drinking water for?

   ☐ Landscape irrigation ☐ Vegetable, fruit and crop irrigation

   ☐ Food processing ☐ Aquaculture

   ☐ Stock watering ☐ Others (specify) ____________________________________

3. If your institution is in Commerce/ Industry sector, what do you use non - drinking water for?

   ☐ Power generation ☐ Manufacturing ☐ Non food processing

   ☐ Trade ☐ System cooling ☐ Petroleum

   ☐ Construction ☐ Mining ☐ Others (specify) _________________________

4. If your institution is Sport, what do you use non - drinking water for?

   ☐ Irrigating golf fields ☐ Irrigating soccer fields ☐ Irrigating rugby fields

   ☐ Irrigating hockey fields ☐ Others (specify) _________________________________

5. If your institution is Education, what do you use non - drinking water for?

   ☐ Irrigating football fields ☐ Irrigating playing grounds

   ☐ Landscape irrigation ☐ Others (specify) __________________________________

6. If your institution is Public, what do you use non - drinking water for?

☐ Fire fighting ☐ Street washing ☐ Landscape irrigation (e.g. flowers, grass, trees)

☐ Public water features (e.g. water fountains) ☐ Flushing the sewer ☐ Others (specify) ___________

Section B: General information and water use pattern

1. When did your institution start using non – drinking water? ____________________________
2. What is the source of your non – drinking water supply?

   ☐ Wastewater/ Sewage

   ☐ Stormwater/ Rainwater ☐ Mine wastewater ☐ Raw water from river, lake or stream

   ☐ Salinewater (☐ seawater ☐ groundwater ☐ brackish water)

   ☐ Greywater (☐ kitchen water ☐ bath/ shower water ☐ laundry water ☐ wash basin water)
3. How far is the non – drinking water source to your institution?

   ☐ <500m ☐ 500 – 1000m ☐ 1000 -2000m ☐ 2000 – 5000m ☐ > 5000m
4. How often do you get non-drinking water?

   ☐ < Once a week ☐ About two days a week ☐ About three days a week

   ☐ About four days a week ☐ > Four days a week ☐ Always
5. What is the quantity of non-drinking water that your institution receives _±350 000m^3/month______________
6. What is your institution's opinion on the current drinking water bill?

   ☐ Expensive ☐ Affordable ☐ Cheap ☐ Free ☐ Don't know
7. What is your institution's opinion on the current non – drinking water bill?

   ☐ Expensive ☐ Affordable ☐ Cheap ☐ Free ☐ Don't know
8. What are your institution's reasons for using non – drinking water instead of drinking water?

   ☐ To conserve drinking water

   ☐ To postpone the costly investment for a new water supply source

   ☐ To postpone the costly investment on a new wastewater treatment plant

   ☐ To provide a backup water source during drought

   ☐ To reduce effluent discharges into surface water

   ☐ To improve soil productivity as the non – drinking water serves as an additional source of fertilizer

   ☐ To save money on the water bill

☐ None of the above

9. Are there any particular diseases that have resulted from the use of your non – drinking water?

   ☐ Yes   ☐ No

10. If your answer is Yes, please list them

    ____

    ____

    ____

11. Are there any incidents that have occurred due to non – drinking water use in your institution?

    ☐ Yes   ☐ No

12. If your answer is Yes, please list them

    ____

    ____

    ____

13. From your experience, please rank in the tables below, in order of priority from **1** (most important) to **7** (least important) the critical issues you would consider:

When planning non-drinking water reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

When planning a dual pipe water reticulation system for drinking use and non-drinking reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

Section C: Institutional perceptions

Statement	Strongly Opposed	Opposed	Neutral	Supportive	Strongly Supportive
The use of non – drinking water has reduced the amount of wastewater discharged to the environment					
Non - drinking water use has reduced pollution to the environment					
Non - drinking water use has reduced the depletion of groundwater and surface water resources					
The use of non – drinking water can save many South African communities from drought					
The quality of the non - drinking water used in this institution is satisfactory					
The non - drinking water this institution uses is healthy for the prescribed beneficial use(s)					
The non - drinking water this institution uses does not contain harmful chemicals					
The non - drinking water this institution uses contains bacteria & viruses that are harmful to human health					
The non - drinking water this institution uses contains human waste (faeces and urine)					
The non - drinking water this institution uses looks absolutely clear					
The non - drinking water this institution uses is disgusting					
The non - drinking water this institution uses is odourless					
We trust the health information on non - drinking water provided by the water service provider					
This institution feels personally obligated to do whatever it can do to save water					
This institution feels good when it does something positive to reduce environment pollution					
Water is a valuable resource that should be recycled					
Fruits and vegetables irrigated with non – drinking water should be labelled in the supermarket					
There is considerable savings of fertilizer on farms irrigated with recycled wastewater					
This institution is confident that the current non – drinking water treatment is efficient					
This institution would rather not use non - drinking water					
This institution would never use non drinking water even in times of shortages					
This institution would only be prepared to use non - drinking water in times of water shortages					
The government is partly responsible for water shortages					
Every household should be free to choose their source of water supply (e.g. recycled wastewater, etc.)					
Consumers have the right to know that the fruits, etc that they buy are irrigated with recycled wastewater					
This institution will use non – drinking water if other institutions are using it					
Many institutions affiliated with us support the use of non - drinking water					

APPENDIX D.2 QUESTIONNAIRE FOR WATER SERVICE REGULATORS

WATER SERVICE REGULATOR

(ATTENTION:___________________-_________)

We would like to request a few minutes of your time to assist this research undertaken by the University of the Witwatersrand and the Water Research Commission. The survey is investigating the feasibility of implementing dual water reticulation systems conveying drinking and non – drinking water qualities in domestic and non – domestic applications in South Africa. Your contribution in this research will immensely help. Your details are not required and your answers will be treated with confidentiality.

Section A: Organization Profile

1. Name of the organization:
2. Please give the name of the department in your organisation specifically dealing with non-drinking water for reuse purposes?

Section B: Operational Information

***DEFINITION**: Non-drinking water refers to treated effluent, salinewater, treated greywater, raw surface water, etc suitable for non-drinking purposes e.g. cooling, paper making, irrigation, toilet flushing, etc.*

3. In your department, is non-drinking water reuse a viable water supply option for Industrial/Commercial use?

   ☐ Power generation ☐ Manufacturing ☐ Non food processing
   ☐ Trade ☐ System cooling ☐ Petroleum
   ☐ Construction ☐ Mining ☐ Others (specify) ________________

4. In your department, is non-drinking water reuse a viable water supply option for Domestic use?

   ☐ Toilet flushing ☐ Crop/vegetable irrigation ☐ Landscape irrigation
   ☐ Others (specify) ______________

5. In your department, is non-drinking water reuse a viable water supply option for Agricultural use?

   ☐ Landscape irrigation ☐ Vegetable, fruit and crop irrigation
   ☐ Food processing ☐ Aquaculture
   ☐ Stock watering ☐ Others (specify)______________________________

6. In your department, is non-drinking water reuse a viable water supply option for Public use?

   ☐ Fire fighting ☐ Street washing ☐ Landscape irrigation (e.g. flowers, grass, trees) ☐ Public water features (e.g. water fountains) ☐ Flushing the sewer

   ☐ Others (specify) ___________

7. In your department, is non-drinking water reuse a viable water supply option for Educational use?

   ☐ Irrigating football fields ☐ Irrigating playing grounds

   ☐ Landscape irrigation ☐ Others (specify) ______________________________

8. In your department, is non-drinking water reuse a viable water supply option for Professional Sport use?

   ☐ Irrigating golf fields ☐ Irrigating soccer fields ☐ Irrigating rugby fields

   ☐ Irrigating hockey fields ☐ Others (specify) ________________________________

9. Does your organization give operating licences to Service Providers providing non – drinking water for reuse?

   ☐ Yes ☐ No

10. If your answer is Yes, please list (if any) the different types of non-drinking water for reuse operating licenses that can be applied for:

    a. ________________________________ b________________________________

11. Please list (if any) the Service Providers of non-drinking water for reuse in your area of coverage:

    a.__________________________________ b. ______________________________

12. Does your organization inspect and certify the facilities of Service Providers of non – drinking water for reuse before they begin their operations? ☐ Yes ☐ No

13. If your answer is No, is there an explanation? ______________________________________

14. Are there field officers that regularly monitor non-drinking water quality produced for reuse?

    ☐ Yes ☐ No

15. If your answer is Yes, on average, how often are monitoring exercises carried out?

    ☐ Daily ☐ Weekly ☐ Monthly ☐ Quarterly ☐ Bi – annually ☐ Annually

16. If your answer to number 15 is Yes, Do you suppose you have an adequate number of field officers and relevant equipment to carry out non-drinking water quality monitoring exercises?

    ☐ Yes ☐ No

17. Are there penalties enforceable by law for Service Providers who consistently violate minimum standards for non – drinking water quality for reuse? ☐ Yes ☐ No

18. If Yes, kindly indicate the types of penalties that may be imposed

☐ Fines ☐ Service suspension ☐ Service closure ☐ Imprisonment ☐ Others (specify __________)

19. On average, what are the typical penalties awarded defaulters?

☐ Fines ☐ Service suspension ☐ Service closure ☐ Imprisonment ☐ Others (specify _________)

20. Does your organisation provide/recommend any codes/documents for the installation/maintenance of non - drinking plumbing systems (i.e. dual reticulation systems)?

Yes ☐ No

21. Have you encountered (or heard) of any negative incidents that have occurred from non-drinking water reuse in South Africa. Briefly list (if any).

Date (dd/mm/yyyy)	**Incident**	**Solution**

22. From your experience, please rank in the tables below, in order of priority from **1** (most important) to **7** (least important) the critical issues you would consider:

When planning non-drinking water reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

When planning a dual pipe water reticulation system for drinking use and non-drinking reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

Section C: Consumer Communication and Complaints

23. How often does your organization communicate with non – drinking water reuse consumers?

☐ Not at all (*If Not at all, ignore questions 24-25)*

☐ Daily ☐ Weekly ☐ Monthly ☐ Quarterly ☐ Bi – annually ☐ Annually

24. If applicable, what is the main aim of your communication?

☐ General information ☐ Reporting on non-drinking water quality ☐ Other (Specify__________________)

25. If applicable, how does you organization communicate with these consumers?

☐ Post ☐ Radio ☐ TV ☐ News paper ☐ Internet ☐ Flyers/by hand Meetings/workshops

26. Does your organisation house any unit where complaints from non-drinking water reuse consumers can be attended to?

☐ Yes ☐ No

27. If Yes, what are the typical complaints received by this unit?

☐ Complaints relating to the physical characteristics (e.g. colour, smell, PH, etc) of the water

☐ Complaints relating to the chemical characteristics (e.g. chemicals in larger than normal quantities) of the water

☐ Complaints relating to the biological characteristics (e.g. the presence of faecal coliforms) of the water

☐ All of the above

☐ Other

(specify____)

Section D: Organisational perceptions

Statement	Strongly Opposed	Opposed	Neutral	Supportive	Strongly Supportive
The use of non – drinking water has reduced the amount of wastewater discharged to the environment					
Non - drinking water use has reduced pollution to the environment					
Non - drinking water use has reduced the depletion of groundwater and surface water resources					
The use of non – drinking water can save many South African communities from drought					
This organisation is generally satisfied with the non – drinking water service provided by various Service providers					
Water is a valuable resource that should be recycled					
Fruits and vegetables irrigated with non – drinking water (e.g. recycled wastewater) should be labelled in the supermarket					
There is considerable savings of fertilizer on farms irrigated with recycled wastewater					
This organisation would rather not recommend non - drinking water reuse					
This organisation would never recommend non drinking water even in times of shortages					
This organisation would only be prepared to recommend non - drinking water reuse in times of water shortages					
Every household should be free to choose their source of water supply (e.g. groundwater, surface water, recycled wastewater, etc.)					
Consumers have the right to know that the fruits and vegetables they are buying are irrigated with recycled wastewater					
Many organisations affiliated with us support the use of non - drinking water					

Thank you for your time and information

APPENDIX D.3 QUESTIONNAIRE FOR NON-DRINKING WATER SERVICE PROVIDERS

NON - DRINKING WATER SERVICE PROVIDER

(ATTENTION: ______________________)

We would like to request a few minutes of your time to assist this research undertaken by the University of the Witwatersrand and the Water Research Commission. The survey is investigating the feasibility of implementing dual water reticulation systems conveying drinking and non – drinking water qualities in domestic and non – domestic applications in South Africa. Your contribution in this research will immensely help. Your details are not required and your answers will be treated with confidentiality.

DEFINITION: *Non-drinking water refers to treated effluent, salinewater, treated greywater, raw surface water, etc suitable for non-drinking purposes e.g. cooling, paper making, irrigation, etc.*

For each of the following questions, please tick (√) against the option that is most applicable to you

Section A: Organisation Profile and Operational Information

1. What is the name of your organisation? ____
2. What is the source of your organisation's non – drinking water supply?

   ☐ Salinewater (☐ seawater ☐ groundwater ☐ brackish water)

   ☐ Wastewater/ Sewage

   ☐ Greywater (☐ kitchen water ☐ bath/ shower water ☐ laundry water ☐ wash basin water)

   ☐ Stormwater/ Rainwater

   ☐ Mine wastewater

   ☐ Raw water from river, lake or stream
3. About how much does it cost your organisation to treat your non - drinking water? R _______
4. Who are the consumers of your non – drinking water?

   ☐ Domestic Names of consumers:_______________________________

   ☐ Commerce/ Industry Names of consumers:_______________________________

   ☐ Agriculture Names of consumers:_______________________________

   ☐ Education Names of consumers:_______________________________

   ☐ Sport Names of consumers:_______________________________

   ☐ Public (e.g. fire-fighting, street washing, etc.)

☐ Others (specify _______) Names of consumers:______________________________

5. What is the volume of non – drinking water produced daily? ____________________
6. Is this volume of water rationed among your consumers?

   ☐ Yes ☐ No

7. Please give an approximate number of domestic households using non – drinking water produced by your organisation? ______________
8. What are your organisation's reasons for providing non – drinking water to consumers?

   ☐ To conserve drinking water

   ☐ To postpone the costly investment for a new water supply source

   ☐ To postpone the costly investment on a new wastewater treatment plant

   ☐ To provide a backup water source during drought

   ☐ To reduce effluent discharges into surface water

   ☐ To improve soil productivity as the non – drinking water serves as an additional source of fertilizer

   ☐ To save money on the water bill

   ☐ None of the above

9. Are there incentives in place for your organisation to subsidise non - drinking water supply?

   ☐ Yes ☐ No

10. If your answer is Yes, who provides the subsidy and what form of subsidies are provided?

    ☐ Government (☐ Grant ☐ Loans ☐ incentives (e.g. tax exception, reduced interest) ☐ Others (specify ___________))

    ☐ NGO's (☐ Grant ☐ Loans ☐ incentives (e.g. tax exception, reduced interest) ☐ Others (specify ___________))

    ☐ Community (☐ Grant ☐ Loans ☐ incentives (e.g. tax exception, reduced interest) ☐ Others (specify ___________))

    ☐ International Agency (☐ Grant ☐ Loans ☐ incentives (e.g. tax exception, reduced interest) Others (specify ____))

    ☐ Others (specify) ____

11. From your experience, please rank in the tables below, in order of priority from **1** (most important) to **7** (least important) the critical issues you would consider:

When <u>planning non-drinking water reuse</u>	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

When <u>planning a dual pipe water reticulation system</u> for drinking use and non-drinking reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

Section B1: Economic and Technical

Statement	Strongly opposed	Opposed	I don't know	Supportive	Strongly supportive
Our system is cost effective and affordable for the users					
The energy consumption of our system is good (i.e. fuel for pumping, chemicals for treatment, etc)					
There is a great savings of drinking water due to non-drinking water use					
There is possibility for combining several wastewater treatment works to produce treated effluent for supply					
Our system can be readily expanded to treat and supply higher flows and loads in the future					
The introduction of non – drinking water use created new jobs or economic opportunities					
Using non – drinking water has enhanced the economic growth of our consumers					
Our system's non - drinking water technology is readily available in South Africa					
Installation of the non-drinking water pipe system was easy					
Our non - drinking water system technology can meet the current effluent criteria					
Our non - drinking water system technology can meet future effluent criteria					
Advanced skill is required for normal operation of our non - drinking water system					
Our non - drinking water system has a design life of over 25 years					
The future demand for non-drinking water will keep on increasing					
The O&M staff are not exposed to any risks from the operation of the non – drinking water system					
There is insurance cover in place for both staff of the non – drinking water system and consumers in the event of system failure					

Section B2: Environmental, Public Health and Social

Statement	Strongly opposed	Opposed	I don't know	Supportive	Strongly supportive
Pumps will always be required to supply non - drinking water to consumers					
Currently, all the waste produced from the non - drinking water system is reused					
Non - drinking water use can save many South African communities from drought					
Non - drinking water use has reduced the depletion of groundwater and surface water resources					
There is a regulatory body that regularly monitors non – drinking water quality produced by this organisation					
Our organisation has received health related complaints from consumers of non - drinking water					
The use of non – drinking water has reduced the amount of wastewater discharged to the environment					
We are generally satisfied with the non – drinking water service we give to our consumers					
The non - drinking water that we use/produce looks absolutely clear					
The non - drinking water that we use/produce is disgusting					
The non - drinking water that we use/produce stains washing					
The non - drinking water that we use/produce is odourless					
We feel good when we do something positive to reduce environment pollution					
Water is a valuable resource that should be recycled					
Fruits & vegetables irrigated with non–drinking water (e.g. treated effluent) should be labelled in the shops					
There is considerable savings of fertilizer on farms irrigated with recycled wastewater					

Public education campaigns have been conducted by us to provide information about non – drinking water					
The non – drinking water system is generally accepted and embraced by the consumers					
The consumers were well mobilized for the non – drinking water project before it was implemented					
Use of non – drinking water does not violate any known cultural, historic or archaeological beliefs in our area					
Non – drinking water supply has tremendously improved the organisational capacity of the local community					
It is mandatory to use non – drinking water in this area					

APPENDIX D.4 QUESTIONNAIRE FOR POTENTIAL DOMESTIC NON-DRINKING WATER CONSUMERS

POTENTIAL DOMESTIC NON - DRINKING WATER CONSUMER

We would like to request a few minutes of your time to assist this research undertaken by the University of the Witwatersrand and Water Research Commission. The survey is investigating the feasibility of implementing dual water reticulation systems conveying drinking and non – drinking water qualities for domestic and non domestic applications in South Africa. Your contribution in this research will immensely help and your answer will be treated with confidentiality.

DEFINITION: *Non-drinking water refers to treated effluent, salinewater, treated greywater, raw surface water, etc suitable for non-drinking purposes e.g. toilet flushing, irrigation, general washing etc.*

For each of the following questions, please tick (√) against the option that is most applicable to you

Section A: Water Supply Information

1. What is the source of your drinking water?

   ☐ Borehole ☐ Well ☐ River ☐ Lake ☐ Rain ☐ Sea ☐ I don't know ☐ Others (specify ________)

2. Through what means do you access the drinking water?

   ☐ Tap from municipality ☐ Hand pump ☐ I buy from a water vendor ☐ Water tanker to my tank

3. Where is your access point for drinking water located?

   ☐ In the house ☐ Inside the yard ☐ on the street ☐ others (specify ________________)

4. If your drinking water tap is not in your house, what is its approximate distance to your house?

   ☐ <100m ☐ 101 – 500m ☐ 500 – 1000m ☐ >1000m

5. If your drinking water tap is not in your house, what is the total time spent fetching water each day?

   ☐ <15 mins ☐ 15 – 30 mins ☐ 30 – 60 mins ☐ 1 – 2 hrs ☐ > 2 hrs

6. Do you have drinking water supply all the time? ☐ Yes ☐ No

7. If your answer is No, on average, how often do you get drinking water?____ hour(s) a day

   ☐ < Once a week ☐ About two days a week ☐ About three days a week

   ☐ About four days a week ☐ > Four days a week

8. Do you know the reason(s) for not getting drinking water supply all the time? ☐ Yes ☐ No

9. If your answer is yes, please list the reason(s)

____

____

____

10. Do you think the source of drinking water could run out? ☐ Yes ☐ No
11. If your answer is yes, please list your reason(s)

    ____

    ____

    ____

12. Estimate the quantity of drinking water used in each house (**check water bill**) ___________ litres
13. What is your opinion of the current drinking water bill? ☐ Expensive ☐ Affordable Cheap ☐ Free
14. Tick the items you currently use drinking water for:

    ☐ Cooking ☐ Bathing ☐ Car washing ☐ Construction
    ☐ Drinking ☐ Toilet flushing ☐ General cleaning
    ☐ Irrigating food crops ☐ Irrigating grass & flowers ☐ Dust prevention/ suppression
    ☐ Swimming ☐ Laundry ☐ Aquaculture (e.g. fishing)
15. What type of toilet is available for your use?

    ☐ Flush toilet ☐ VIP/ Pit toilet ☐ Chemical toilet ☐ Bucket toilet ☐ Others (specify _________)

Section B: Non Drinking Water Supply

16. Have you heard about water recycling/reclamation using dual water reticulation? ☐ Yes ☐ No
17. If your answer is yes, which of the following words best describes your first reaction to water recycling/reclamation?

    ☐ Disgusting ☐ Unhealthy & dangerous ☐ good & OK ☐ Environmentally friendly
18. Which items are you comfortable using non – drinking water for:

    ☐ Cooking ☐ Bathing ☐ Car washing Construction
    ☐ Drinking ☐ Toilet flushing ☐ General cleaning ☐ Dust prevention
    ☐ Irrigating food crops ☐ Laundry ☐ Swimming ☐ Irrigating grass & flowers
    ☐ Aquaculture (e.g. fishing) ☐ None of the above
19. Which of the following non drinking water source will you preferred to use for your non – drinking water purposes?

    ☐ Wastewater/ Sewage ☐ Mine wastewater ☐ Raw water from river, lake or stream

☐ Stormwater/ Rainwater ☐ Salinewater (☐ seawater ☐ groundwater ☐ brackish water)

☐ Greywater (☐ kitchen water ☐ bath/ shower water ☐ laundry water ☐ wash basin water)

20. Where does wastewater from your bath, wash basin and/ or washing machine drain to?

☐ Sewer ☐ into the street ☐ into the garden ☐ septic tank ☐ Others (specify ____)

21. What do you think is the reason(s) for using recycled/reclaimed water for non-drinking uses?

☐ To conserve drinking water

☐ To postpone the costly investment for a new water supply source or new wastewater treatment plant

☐ To provide a backup water source during drought

☐ To reduce effluent discharges into surface water

☐ To improve soil productivity as the non – drinking water serves as an additional source of fertilizer

☐ To save money on the water bill

☐ Other (Please specify ____)

22. From your perception, please rank in the tables below, in order of priority from **1** (most important) to **7** (least important) the critical issues you would consider:

When planning non-drinking water reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

When planning a dual pipe water reticulation system for drinking use and non-drinking reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

Section B: Perceptions

Statement	Strongly Opposed	Opposed	Neutral	Supportive	Strongly Supportive
The use of non – drinking water can reduce the amount of wastewater discharged to the environment					
Non - drinking water use can reduced the depletion of groundwater and surface water resources					
The use of non – drinking water can save my community from drought					
I will use non - drinking water if the quality can be proof to be satisfactory					
I will use non - drinking water if it looks absolutely clear					
I will use non - drinking water if it is not disgusting or irritating					
I will use non - drinking water if it does not stains washing					
I will use non - drinking water if it is odourless					
I trust municipality to provide non - drinking water that is safe and does not constitute health risk					
I feel personally obligated to do whatever I can to save water					
Water is a valuable resource that should be recycled					
I would have preferred not to use non - drinking water					
I would only be prepared to use non - drinking water in times of water shortages					
The government is partly responsible for water shortages					
I have the right to adequate drinking water supply					
I have the right to know if any fruits or vegetables are irrigated with recycled wastewater					
Fruits and vegetables irrigated with non – drinking water should be labelled in the supermarket					
I will use non – drinking water if others are using it					
Most people who are close to me support the use of non - drinking water					
Non – drinking water use is an option for the poor and the rich					

Section D: Personal Data (Optional)

1. Respondent's gender: ☐ Male ☐ Female
2. Respondent's race ☐ Black ☐ White ☐ Indian/ Asian ☐ Coloured
3. Respondent's age ☐ 18 – 30 ☐ 31 – 40 ☐ 41 - 50 ☐ 51 - 60 ☐ >60
4. Marital status ☐ Single ☐ Married ☐ Married + Children ☐ Divorced ☐ ____________
5. Highest academic qualification ☐ <Matric ☐ Matric ☐ Diploma ☐ BA, BSc, ☐ MA, MSc, PhD
6. Type of your house? ☐ Traditional ☐ RDP ☐ Shack/informal ☐ Flat/Town house ☐ Stand alone house
7. Number of people in your household? ☐ 1 - 2 ☐ 3 - 4 ☐ 5 - 6 ☐ > 6
8. Approximate monthly income ☐ <R2000 ☐ R2000 – R5000 ☐ R5000 - R10000 ☐ >10000

Thank you for your time and information.

APPENDIX D.5 QUESTIONNAIRE FOR POTENTIAL INSTITUTIONAL NON-DRINKING WATER CONSUMERS

POTENTIAL DOMESTIC NON - DRINKING WATER CONSUMER

We would like to request a few minutes of your time to assist this research undertaken by the University of the Witwatersrand and the Water Research Commission. The survey is investigating the feasibility of implementing dual water reticulation systems conveying drinking and non – drinking water qualities for domestic and non – domestic applications in South Africa. Your contribution in this research will immensely help. Your details are not required and your answers will be treated with confidentiality.

DEFINITION: *Non-drinking water refers to treated effluent, salinewater, treated greywater, raw surface water, etc suitable for non-drinking purposes e.g. cooling, paper making, irrigation, etc.*

For each of the following questions, please tick (√) against the option that is most applicable to you.

Section A: Background Information

7. Which of the following sectors can we classify your institution?

   ☐ Domestic ☐ Agriculture ☐ Commerce/ Industry ☐ Sport ☐ Education ☐ Public

   ☐ Others (Specify ________________)

8. If your institution is in Agriculture, what do you use water for?

   ☐ Landscape irrigation ☐ Vegetable, fruit and crop irrigation

   ☐ Food processing ☐ Aquaculture

   ☐ Stock watering ☐ Others (specify ____)

9. If your institution is in Commerce/ Industry sector, what do you use water for?

   ☐ Power generation ☐ Manufacturing ☐ Non food processing

   ☐ Trade ☐ System cooling ☐ Petroleum

   ☐ Construction ☐ Mining ☐ Others (specify) __________________________

10. If your institution is Sport, what do you use water for?

    ☐ Irrigating golf fields ☐ Irrigating soccer fields ☐ Irrigating rugby fields

    ☐ Irrigating hockey fields ☐ Others (specify) ____

11. If your institution is Education, what do you use water for?

    ☐ Irrigating football fields ☐ Irrigating playing grounds

    ☐ Landscape irrigation ☐ Others (specify) ____

12. If your institution is Public, what do you use water for?

☐ Fire fighting ☐ Street washing ☐ Landscape irrigation (e.g. flowers, grass, trees)

☐ Public water features (e.g. water fountains) ☐ Flushing the sewer ☐ Others (specify) ______

Section B: Water Supply Information

23. What is the source of water to your institution?

☐ Borehole ☐ Well ☐ River ☐ Lake ☐ Rain ☐ Sea ☐ I don't know ☐ Others (specify _______________)

24. Do you have water supply to your institution all the time? ☐ Yes ☐ No

25. If your answer is No, on average, how often do you get water?____ hour(s) a day

☐ < Once a week ☐ About two days a week ☐ About three days a week

☐ About four days a week ☐ > Four days a week

26. What is the quantity of water used daily/monthly in your institution? (**check water bill**) ______ litres

27. What is your institution's opinion of the current water bill? ☐ Expensive ☐ Affordable Cheap ☐ Free

28. Where does wastewater from your institution drain to?

☐ Sewer ☐ into the street ☐ into the garden ☐ septic tank ☐ Recycled ☐ Others (specify_______)

Section C: Non Drinking Water Supply

29. Which of the following words best describes your first reaction to water recycling/reclamation?

☐ Disgusting ☐ Unhealthy & dangerous ☐ Good & OK ☐ Environmentally friendly

30. Has your institution considered using recycled wastewater for some non-drinking uses? ☐ Yes No

31. What would be your institution's primary reason(s) for using recycled/reclaimed water?

☐ To conserve drinking water

☐ To postpone the costly investment for a new water supply source or new wastewater treatment plant

☐ To provide a backup water source during drought

☐ To reduce effluent discharges into surface water

☐ To improve soil productivity as the non – drinking water serves as an additional source of fertilizer

☐ To save money on the water bill

☐ Other (Please specify ____)

32. Indicate the non drinking water sources that your institution would be comfortable to use:

☐ Wastewater/ Sewage ☐ Mine wastewater ☐ Raw water from river, lake or stream

☐ Stormwater/ Rainwater ☐ Salinewater (☐ seawater ☐ groundwater ☐ brackish water)

☐ Greywater (☐ kitchen water ☐ bath/ shower water ☐ laundry water ☐ wash basin water)

33. Indicate which uses your institution would be comfortable to use non – drinking water for:

☐ Cooling ☐ Boiler feed ☐ Process ☐ Construction ☐ Dust prevention

☐ Aquaculture ☐ Stock watering ☐ Power generation ☐ Mining

☐ Irrigating food crops ☐ Landscape irrigation ☐ Irrigating grass & flowers

☐ Other (Please specify ______________________) ☐ None of the above

34. Please rank in the tables below, in order of priority from **1** (most important) to **7** (least important) the critical issues you would consider:

When planning non-drinking water reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

When planning a dual pipe water reticulation system for drinking use and non-drinking reuse	**Rank**
Economics	
Technical/Engineering	
Public health and safety	
Legislation	
Organisational capacity	
Social/Cultural acceptance	
Public education	

Section D: Institutional perceptions

Statement	**Strongly Opposed**	**Opposed**	**Neutral**	**Supportive**	**Strongly Supportive**
The use of non – drinking water can reduce the amount of wastewater discharged to the environment					
Non - drinking water use can reduce the depletion of groundwater and surface water resources					
The use of non – drinking water can save many South African communities from drought					
This institution will use non – drinking water if the quality can be proven to be satisfactory					
This institution will use non - drinking water if it looks absolutely clear					
This institution will use non - drinking water if it is not disgusting					
This institution will use non - drinking water if it does not stains or cause corrosion					

This institution will use non - drinking water if it is odourless					
This institution trusts the municipality to provide non - drinking water that is safe and does not constitute a health risk					
This institution feels personally obligated to do whatever it can do to save water					
Water is a valuable resource that should be recycled					
There is considerable savings of fertilizer on farms irrigated with recycled wastewater					
This institution would rather not use non - drinking water					
This institution would never use non drinking water even in times of shortages					
This institution would only be prepared to use non - drinking water in times of water shortages					
The government is partly responsible for water shortages					
Every household should be free to choose their source of water supply (e.g. recycled wastewater, etc.)					
Fruits and vegetables irrigated with non – drinking water should be labelled in the supermarket					
This institution will use non – drinking water if other institutions are using it					
Many institutions affiliated with this institution support the use of non - drinking water					

Thank you for your time and information.