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A context based planning approach for comparative analysis of centralised and decentralised wastewater systems sustainability

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2012-01-31
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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

Wastewater management is traditionally viewed primarily as a technical and economic issue. However, it is now recognised that these are some of the criteria in an array of other factors that affect sustainability. Municipal authorities have traditionally used indicators in monitoring performance and reporting the state of the environment. However, they have neglected other critical aspects of the use of these indicators such as their input into the planning and decision making process. The overall objective of this study is to make use of Multi Criteria Decision Aid (MCDA) in a Decision Support System (DSS) for the comparative evaluation of wastewater systems technology with respect to technical, environmental and social criteria in one step and then carryout a detailed economic analysis on the finite solution set as a second step. The methodology consisted of comprehensive literature review, case study analysis and the development of the DSS for Gauteng Province in South Africa. One hundred and eighty three settlements and twenty wastewater treatment plants were visited. Sixteen wastewater technologies (land treatment, package plants, ecological systems, mechanical and pond systems) were incorporated into the DSS and evaluated on the basis of eleven indicators in order to measure their sustainability index. The normalised main criteria weights for the case study were technical (0.4), social (0.3) and environmental (0.3). The overall result shows that land treatment systems, ponds and ecological treatment systems pose the least economic and environmental impact with an average score above 85% of the sustainability index measure. These systems have low energy requirements and are more likely to create more employment per plant capacity than mechanical systems. The lessons learnt are that wastewater management is not a preserve for engineers and scientists but requires a multi-disciplinary approach. This MCDA tool will be used as a context-oriented planning tool and is useful in demystifying and communicating the decisions to a wider stakeholder base including users of the systems. The overall recommendation for the case study is that a differential wastewater management approach should be employed with tailor made solutions for each municipality and a proposal to set up a Capacity Building Centre as an indispensable prerequisite to empower the stakeholders.

DEDICATION

To my wife Rufaro and my sons Nyasha and Kuitakwashe.

ACKNOWLEDGEMENTS

This research would not have been successful without the help and encouragement of a number of people. Out of the many who believed in me when reason would have thought otherwise, I would like to extend my sincere gratitude to all I will mention herein and all the unsung heroes and heroines who in some way or other made this experience worthwhile:

- My Lord and Saviour, Jesus Christ in Him I live, move and I have my being;
- My supervisor, Professor Marjanovic for his guidance, supervision, commitment, encouragement and thoughtfulness.
- Professor Taigbenu, Professor Snaddon and Dr Ndiritu are acknowledged for their encouragement and sustained interest in my success;
- My parents, Mr. and Mrs. J.T Musiyarira, for forcing me to go to grade one, I will forever be grateful for the foundation they laid for me in life;
- Special thanks to my wife, Rufaro for the support and being there for the kids while I was away from home; and my sons, Nyasha and Kuitakwashe.
- My family, Shepstone & Sandra, Eileen & Samuel Muchemwa, Aggry & Lorettah, Rodgers & Farirai, Netsai & Show and Priscillar for their unwavering commitment to see me through my degree;
- Mr. Lovemore Machingura for his time and assistance in programming;
- My colleague-Chris Reynders and research fellows in the School of Civil and Environmental Engineering – through it all we encouraged and assisted each other.
- Water Managers in the 8 municipalities and Gauteng DPLG- Ojageer & team.
- My Primary and High School teachers;
- Polytechnic of Namibia, Harare Polytechnic & Clay Products staff and management.
- UZ UMYF members 1995- 2001, thank you for believing in me.
- Lastly, Allen & Jackie, Admire & Isabel, Bongai & Peggy, Chipo & Morgan, Joyce & Phillip & Tafadzwa Ndoro for their support.

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Musiyarira, H., Reynders, C. & Marjanovic, P. 'Multi-criteria use in Wastewater Planning' Presented at the 11th WaterNet/WARFSA/GWP Symposium 'Integrated water Resources Management: Where, Policy, Science and Practice meet' Victoria Falls, Zimbabwe, from 27-29 October 2010.

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LIST OF ACRONYMS

AI	Artificial Intelligence
BOD	Biological Oxygen Demand
CMAs	Catchment Management Agencies
CMU	Catchment Management Units
COD	Chemical Oxygen Demand
DPLG	Department of Provincial and Local Government
DSS	Decision Support Systems
DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
EPA	Environmental Protection Agency
ES	Expert System
FC	Faecal Coliforms
GWP	Global Water Partnership
IDP	Integrated Development Plans
LCA	Life cycle Analysis
LCC	Life cycle costs
MADM	Multi Attribute Decision Making
MCDA	Multi criteria Decision Aid
MCDA	Multi criteria Decision Analysis
MCDM	Multi criteria Decision Methods
MDG	Millennium Development Goals
mg/l	Milligrams per litre
MODM	Multi Objective Decision Making
MWTP	Municipal Wastewater Treatment Plant
N	Nitrogen
NGOs	Non Governmental Organisations
O & M	Operation and Maintenance
P	Phosphorus
SAT	Soil Aquifer Treatment
SS	Suspended solids

TSS	Total Suspended Solids
U.S. EPA	United States Environmental Protection Agency
UNEP	United Nations Environment Programme
UNPR	United Nations Progress Report
US$	United States Dollar
UWM	Urban Water Management
VM-MCDA	Value Measurement Multi criteria Decision Analysis
WHO	World Health Organisation
WRC	Water Research Commission
WRM	Water Resources Management
WSDP	Water Services Development Plan
WSM	Weighted Sum Model
WSP	Water Service Provider
WWTP	Wastewater Treatment Plant

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CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

In most developing countries, wastewater treatment is usually not adequate, whilst in those countries where municipal sewerage network is in place, the coverage is usually incomplete and the treatment level is insufficient (United Nations Environment Programme (UNEP), 2004). Ten to fifty percent of centralised wastewater systems in developing countries are failing annually and over sixty percent of them are over thirty years old (Gumbo & Marjanovic, 2003). According to UNEP (2004) publication, there are numerous factors which contribute to inefficient or failing wastewater management services and these include; low prestige and recognition, weak policies, a top down approach in planning and implementation, lack of adequate funding and political will, inappropriate technologies, low public awareness and neglect of consumer preferences.

Historically, wastewater management has been primary viewed as a technical and economic issue while other aspects of sustainable development criteria have been given minimal consideration. It is now accepted that economic and technical criteria are just a part of the elements in an array of other factors that make sustainable wastewater systems. Palme and Tillman (2008) reveal in their studies that water utilities have a general and long-standing tradition of using indicators in monitoring performance, reviewing progress and reporting the state of the environment as part of the regulatory enacted compliance but have neglected other critical aspects of use of these indicators such as their input into the planning and decision making process.

This research advocates for the use of sustainable indicators in a pro-active context based input to planning, utilising Multi Criteria Decision Aid (MCDA) for comparative analysis and assessment of the sustainability of wastewater systems. The overall objective was to develop a methodology for wastewater systems selection and to produce a practical planning tool to aid in decision making for municipalities in South Africa and other developing countries. This tool would be context oriented and enables a number of alternatives to be evaluated and considered in a 2-step approach of assessment. The context is important since the need for reliable and appropriate wastewater management as well as the performance of the technologies is a function of the local conditions.

1.2 Background

The development of the centralised wastewater management concept originates from the 19th century with the prime objective of preventing the outbreak and spread of water borne diseases (Esrey, 1998). Since the large-scale introduction of centralised water supply and sewerage infrastructure, cities in developed countries have been essentially free of water borne diseases. Despite this evident success, the present day concept of urban water management needs to be seriously reconsidered from a sustainability point of view.

Centralised wastewater systems were adopted as a means of pollution control, when energy and environmental impacts were not of major concern as in present times. In the 19th century population growth and density as well as environmental impacts were not as serious as they currently are. Centralised solutions are now contributing, either directly or indirectly to many of the problems faced by society (Esrey, 1998). The pollution loads generated nowadays have become too big to be remediated naturally. Within the last three decades alone, the world population has doubled to six billion people, the level of urbanisation has increased and wastewater discharged into the

environment has increased concurrently especially in developing countries (UNEP, 2004). Thus urbanisation will result in more damage unless appropriate action is taken in wastewater management.

Varis and Somlyody (1997) reveal that that urbanisation in the present and prospected form is one of the most drastic global changes that mankind has ever faced. It is a fact that Sub-Saharan Africa is the world's most rapidly urbanising region, and most of all this growth has been in slums. UN Millennium Report (2010) states that in the slums, the new city residents' face overcrowding, inadequate housing, and a lack of water and sanitation. Jackson (2002) expands this by pointing out that the mushrooming of informal settlements in major cities usually precedes installation of basic services provision thus leading to exacerbation of the problem of waste management. Other researchers such as Gumbo & Marjanovic (2003) have confirmed that this approach will continue to put severe strains on the water supply and sanitation services resulting in many African cities having an increasing number of overcrowded, informal settlements or 'shanty towns', characterised by inadequate sheltered housing and poor provision of infrastructure services. According to Tayler *et al.* (2003) the informal sector is now the main provider of urban housing, but informal developers seldom provide their schemes with anything more than the most basic services. The existing frustration of inadequate service provision is exacerbated by the fact that population growth and the mounting pressures of increasing urbanisation have offset much of the gains in service coverage (Gentry *et al.* 1997).

From the 1960s to the late 1980s, massive centralised investments in water supply infrastructure succeeded, at best, in keeping pace with population growth in most underserved regions but the same did not occur with wastewater management infrastructure. Currently, however, the number of people without adequate water services remains as large as it was a decade ago. Urban areas are therefore destined to become demand nodes that would require ever increasing investment into services

and infrastructure. In the South African setting the historical and conventional wisdom approach used and continues to be, centralised provision of water supply and sanitation services.

Centralised wastewater solutions have been slow in response to rapid urbanisation growth. The design and implementation of centralised wastewater management solution is usually slow, with a minimum of five to twenty years being required from the conception of the centralised wastewater system project to full utilisation of the system. Furthermore the 20 year planning horizon typically associated with the centralised wastewater management systems is associated with significant uncertainties regarding the forecasted volumes of wastewater to be treated and as a result the plant may end up being either undersized or oversized at the time of commissioning. This leads to inadequate plant operation right from the very beginning of the plant's commission. Centralised systems therefore, often end up not meeting the requirements or lagging behind the demand. According to Balkema *et al.* (2002) centralised wastewater systems deliver the services they were meant to but they are not necessarily sustainable.

1.2.1 Sustainable Wastewater Management

Fricker (1998) states that sustainability concept has captured many people's imaginations and aspirations but it has also eluded many as a tangible and identifiable goal. Mihelcic *et al.* (2003) stress that despite the lack of a common understanding of what sustainability is and the variable interpretations among different disciplines, there is a general agreement that it strives for the maintenance of economic well being, protection of the environment, prudent use of natural resources, and equitable social progress which recognises the just needs of all individuals, communities, and the environment. Millennium Development Goal (MDG) number 7's principle is

environmental sustainability and how this can be achieved remains a challenge in most developing countries.

1.2.2 Millennium Development Goals

Millennium Development Goal number 7 calls for a 50% reduction in the number of people living without access to reliable and safe water supply by the year 2015 as well as a 50% reduction in the number of people without access to appropriate sanitation services. MDG Target 11 at the same time calls for a significant improvement in the lives of at least 100 million slum dwellers by providing jobs and alternative sources of income besides other things. Estimates indicate that some reasonable progress was made in most of the developing regions between 1990 and 2002 but sanitation coverage still remains very low. Over the period 1990-2002, about 1 billion people globally gained access to improved sanitation (UN Report, 2004).

From a global perspective, the world is on track to meet the water target, however sub-Saharan Africa, despite impressive programs, still lags behind. Obstacles to achieving the target in the region include political instability and conflict, high population growth rates and low priority given to water and sanitation (UN Progress Report, 2004). If the 1990-2002 trends holds, the world will miss the sanitation target by more than half a billion people. With a business as usual investment scenario, the population without adequate facilities would increase to 3.2 billion by 2030. The situation is most serious in sub-Saharan Africa and Southern Asia. Research findings by Gumbo & Marjanovic (2003) reveal that;

- Connection levels for all services in Africa are lower than in all other world regions
- Approximately 40% of residential accommodation in Africa is non-permanent, over 148 million people live in urban slums

- House price-to-income ratios in Africa are the highest in the world at 12.5% which is double that of cities in highly industrialised countries.

The United Nations Millennium Development Goals Report (2004) showed the global urban and rural population without adequate sanitation was 1.7 billion in 1990 and 2.6 billion in 2002. The projected estimates reveal that even with accelerated investment and improved process and operation efficiency of centralised systems, this number would not reduce before the year 2030 because of population growth (Gumbo & Marjanovic, 2003). The world can meet the sanitation target by rapid acceleration in the provision of services by implementing decentralised systems rather than centralised systems. Based on literature studies, the likelihood of achieving MDGs therefore increases with decentralisation of wastewater management and innovative approaches to water management rather than with centralised wastewater management systems but the most important question is how sustainable are the technologies employed within the decentralised systems.

1.2.3 Questioning the Old Premises

According to the Rocky Mountain Institute studies (2004), the conventional wisdom in the general population and among many experts in the wastewater field is that centralising treatment is the best wastewater management strategy for most communities—the most reliable, easiest to manage, and least costly per capita. New knowledge has led to the questioning of the old premises. Since late 1960s, a major effort has been undertaken by research institutes and agencies to achieve more effective and widespread treatment of wastewater (Metcalf & Eddy, 2004). This research has been due to:

- increased understanding of the adverse environmental effects of wastewater discharges;

- developing knowledge of the adverse long term effects caused by wastewater discharge into surface water bodies;
- the development of a culture of national concern for environmental protection;
- increased scientific knowledge;
- the need to conserve natural resources and in many locations to reuse wastewater;
- ever expanding fields of knowledge of the basic principles and capabilities of the various methods for wastewater treatment i.e. knowledge of the soil rather than stream as an avenue for effluent disposal.

This wisdom has now been questioned in the sense that the environment has become a major concern all over the world today, energy is no longer cheap and other resources are now recognised as being limited. All the above listed factors are increasing the pressure for society to come to grip with these problems and work towards the sustainability of urban water systems. The historical approach does not seem to be able to cope with the problems as there continues to be an ever increasing deterioration of water quality and especially so in developing countries. In the context of urban water management (UWM) water quality seems to be the major problem in almost all developing countries (Moyo, 1997; Gijzen, 2001). The historical approach to urban wastewater management remains fundamentally flawed as it fails to take into cognisance the global trend of rapid urbanisation.

The main objective of this research is to develop a context based planning approach methodology which can facilitate the comparative analysis and assessment of centralised and decentralised wastewater systems technologies. The research also considers decentralisation of wastewater management in urban settlements in the South African context – its advantages and disadvantages and its role in contributing

to the achievement of Millennium Development Goals (MDGs) – specifically Goal number 7: Environmental Sustainability.

1.3 Problem Statement

The decision making process within wastewater planning has not been clear in terms of the choices considered and the reasons for the selection of a particular system solution. Zeng *et al*. (2006) have pointed out that traditionally, many wastewater systems and technologies have been selected on an ad-hoc basis with more attention being paid to the economic data provided in the feasibility report of the wastewater treatment plant project and the political and economic strength of the recipient communities. This resulted in the selection of the alternatives with minimum capital and operation costs being lauded as 'the most economical' means of meeting the applicable water quality and public health requirements without consideration of the long term sustainability. This approach does not meet the triple bottom line requirements for sustainable development and overlooks the importance of the local context, which has to be taken into consideration in assessing the sustainability of specific wastewater solutions since technologies are not inherently sustainable but are rule function of the local context specifics.

The root cause of many of the factors that have contributed to this unfortunate situation can be traced to a traditional top-down; supply led, technically based and sectoral approaches to wastewater management which neglects environmental, social and public health considerations that should collectively form the core criteria for the decision making. This has resulted in the provision of inappropriate and unsustainable solutions with high economic, social and ecological costs on human societies and natural environment (Massoud, 2007).

The supply driven approach is characterised by serious flaws where planners and engineers assess needs and decide what type of service to provide without extensive and meaningful consultation with the primary stakeholders. There has been a tendency by policy makers to construe the needs of the stakeholders without adequately engaging them. This approach and the lack of research and development activities in developing countries led to the selection of inappropriate and unsustainable technology (Ilemobade, 2003; Massoud *et al.,* 2007).

1.4 Objectives of the Research

The use of sustainable indicators in a multi criteria decision aid can improve the current planning approaches whilst leading to attainment of sustainable development in the wastewater management sector. The overall objective of this study is to make use of Multi Criteria Decision Aid (MCDA) in a Decision Support System (DSS) for the comparative evaluation and selection of wastewater systems technology with respect to technical, environmental and social criteria in one step and then carryout a detailed economic analysis on the finite solution set as a second step. This multi criteria decision aid tool is to be used as a context-oriented planning tool by local governments and wastewater and water service authorities and/or providers. The specific objectives of the research were defined as follows;

- To improve or restructure the current planning and decision-making process so that consideration of socio-economic, technical and environmental issues is fully integrated in the process and ensures a broader range of public participation.
- To develop a decision support system incorporating multi criteria based on the use of sustainability indicators for wastewater system and technology selection in South Africa.

- To undertake and catalogue review of the economic advantages and disadvantages of decentralised wastewater systems relative to larger scale centralised systems.
- To provide the appropriate technical information necessary for informed decision-making on wastewater management.
- To provide recommendations on wastewater management for the case study areas.

The application of multi-criteria assessment across the technical, environmental, social and economic indicators through a user friendly decision support system forms the fulcrum of this research. The basis is to develop a methodology which is simple and assists experienced personnel to ensure the integration of economic, social and environmental considerations in decision-making at all levels in the wastewater sector. The MCDA use shows that wastewater management is not a preserve for engineers and scientists but requires a multi-disciplinary approach that encompasses social scientists, economists, human resources, scientists and engineers.

In order to fulfil the objectives of the research and achieve the desired research output, a rather unique methodological approach had to be followed. This approach poses a set of fundamental research questions with reference to a particular real life situation (Case study approach) and tries to answer them by the analysis of the existing situation for particular case (study area) and then uses the findings of this process to identify the problems in current decision making processes in order to develop and propose a new approach to decision making and offer a useful decision making support tool in the form of a user friendly decision support system.

1.5 Research Questions

The major significant question posed in this context was in relation to current approaches to wastewater management based on the conventional centralised approach:

Do conventional centralised wastewater management systems have the ability to attain sustainable wastewater management through improving the existing centralised systems or is a completely radical switch to new decentralised systems or a somewhat less radical switch to a hybrid of the two required and appropriate in order to achieve wastewater management sustainability?

The refinement of the above question formed an integral fundamental basis of the research and leads to the following derived questions:

- Is decentralisation the sustainable way to go?
- How is sustainable development currently understood and defined and how are sustainability criteria used by municipal and private authorities in South Africa?
- Based on the above, how could sustainable indicators be applied within the study areas?

1.6 Research Methodology

The research methodology employed is summarised in the figure 1.1. The first step in the methodology was to establish a clear understanding of sustainable wastewater management and the concepts involved. This understanding formed the foundation for step 2 which was the status quo analysis in study area (eight municipalities in Gauteng). The expected findings of step 2 were formulated as the primary drivers of this research. The status quo analysis identified a deficient decision making framework in wastewater management in the municipalities and this established the justification for step 3 which was the establishment of a clear understanding of

Decision Making in Wastewater Management. Literature review and synthesis were the main approach in completing step 3 of the research. With clear understanding of the problem of Sustainable Wastewater Management and the associated decision making framework it was then possible to engage in steps 4 and 5 and develop decision making methodology and the associated decision support tool to enable better decision making in practice. Finally, in step 6, the conclusions were formulated and recommendations were made.

The main contribution to new knowledge is made in the development of the methodology used in this research and includes the decision support system utilising MCDA. Chapters 4, 5 and 6 contain the new knowledge component of this research as shown in Figure 1.1 which is highlighted in light blue colour.

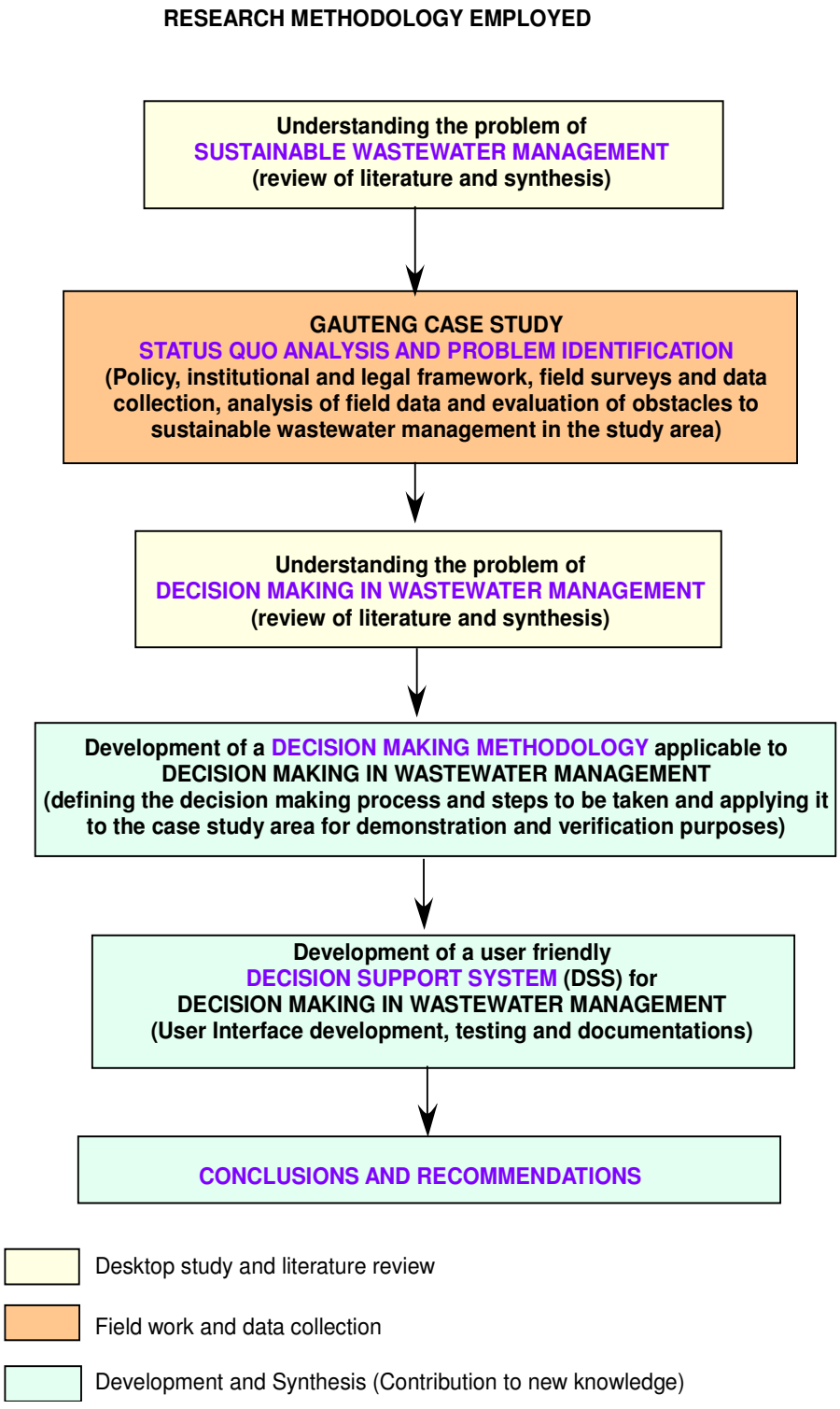


Figure 1.1 Research Methodology

1.7 Justification of the Study

Literature studies reveal that, up to now, no in-depth studies have been done to determine if it is possible to attain sustainable urban water management through improving the existing centralised systems, or radically switching to new decentralised systems or implementing a mixed architecture that includes the two systems. Balkema *et al.* (2001) reinforce the fact that in as much as several researchers name decisive indicators, none of them give a clear analysis of the trade off made, and as such there is still limited insight as to which systems are most sustainable in different situations.

In most developing countries, municipal managers are continually faced with difficult task of making decisions in the absence of well structured context oriented decision making tools which facilitate generation of appropriate solutions. Many of the tasks are tedious and require massive financial resources and in-depth knowledge of the science involved. Ilemobade (2003) points out that commercial software packages are either too expensive to be purchased by the municipalities or only perform a limited number of tasks among the many which have to be done. Generally there is evidence from practice that one of the primary obstacles to achievement of sustainable wastewater management is actually the lack of a structured and adequate decision making framework and especially so at the level of system level decisions and technology selection. The findings of this research will assist in improving and strengthening planning and decision making in the municipalities.

1.8 Report Layout

This thesis consists of six major parts as summarised in the following sections below;

Chapter 1 introduces the topic of research and outlines the background to the study, followed by succinct statements of research problem. The research problem is stated

with supporting research questions. Subsequently, research propositions are formulated with the aims and objectives of the study. In addition, a brief description of the research methodology is provided.

Chapter 2 discusses the literature review that is relevant to wastewater systems management. This chapter highlights the merits, demerits and limitations that come with adoption of the centralised and decentralised systems.

Chapter 3 presents the current/status quo findings of wastewater management in the Case Study area and discusses the legislature framework in South Africa and the policies put in place by the provincial government. Comparison is made in relation to international practices, norms and standards for policy making.

Chapter 4 presents the tools, techniques and the methodologies used in the analysis. It also describes the methodologies for the formulation of the Decision Support System.

Chapter 5 presents the assessment framework employed in evaluating the chosen technology in pursuit of sustainable goals. It also discusses the development and output of the DSS and possible applications to the Gauteng Provincial Government. A systematic computation procedure for the model is presented in this chapter.

Chapter 6 presents the recommendations and conclusions of the study. The usefulness of the developed methodology is discussed based on both the theoretical principles of the generic criterion and the results obtained through the case study. Finally, unresolved issues and ideas for further research are listed.

CHAPTER 2

UNDERSTANDING THE PROBLEM OF WASTEWATER MANAGEMENT

2.1 Background Information

In most developing countries, wastewater treatment is usually not adequate. A World Bank Report (1991) reveals that even where treatment facilities exist, poor maintenance and operation often results in failing treatment processes which may cause detrimental health impacts and the pollution of the surface waters. In South Africa over 80% of the treatment works do not meet the Department of Water Affairs (DWA) standards requirements and most of them are overloaded (Manus & van der Merwe-Botha, 2010). The adoption of a centralised sewerage scheme may actually increase the risk of water-borne disease outbreaks in developing countries since it is usually not accompanied by effective end of pipe treatment. This conventional approach is associated with relatively high risk of failure and potential health and environmental hazards.

2.2 Health and Sanitation

Urban health in all countries is closely linked to high levels of water supply, sanitation, personal and domestic hygiene. Similarly, peri urban ill health in developing countries is a direct result of inadequate (water supplies, sanitation facilities and solid waste collection) and consequently low levels of personal and domestic hygiene (Mara, 1994). The World Health Organization (WHO) estimates that as much as 80% of all morbidity in developing countries is due to water and excreta related diseases, i.e. a result of inadequate water supplies and inadequate sanitation. If the peri-urban environment in developing countries is not changed,

people will continue to be ill and in the words of the late Barbara Ward, will "continue to defecate themselves to death".

There are many reasons why good wastewater management is important such as human dignity, safety and a safe healthy environment. However the most important reason is health. Poor sanitation has serious consequences for health (WHO/UNICEF, 2000). It has been estimated that 2.2 million children, mostly under the age of five, die each year from diarrhoeal diseases which are associated with polluted drinking water, poor sanitation and poor domestic hygiene (Murray & Lopez, 1996). Good community health is dependent on three factors, namely enough clean water, appropriate and adequate toilet and washing facilities and good personal and domestic hygiene. In order to achieve a good standard of public health in communities that have little or no sanitation facilities it is important that the programmes encouraging adequate affordable and sustainable sanitation are implemented.

Poor sanitation cripples national development i.e. workers produce less, live shorter lives, save and invest less and are less able to send their children to school. Thousands of people in sub-Saharan Africa suffer from waterborne diseases every day, caused in part by improper or non-existent removal and treatment of human excreta. Many children, especially girls, are unable to attend school for lack of sanitation facilities. The impact of lack of sanitation services on human health and economic development is staggering. According to a UN Report (2006), 443 million school days are lost annually worldwide due to diarrhoeal diseases caused by inadequate sanitation. In sub Saharan Africa, treating diarrhoea consumes an estimated 12% of national health budgets, and half the hospital beds are occupied by people with sanitation related diseases. The health implication of poor housing and living conditions in urban areas of the developing countries are described in detail by Cairncross *et al.* (1998). The relation between lack of water supply and sanitation and child mortality is presented in Figure 2.1

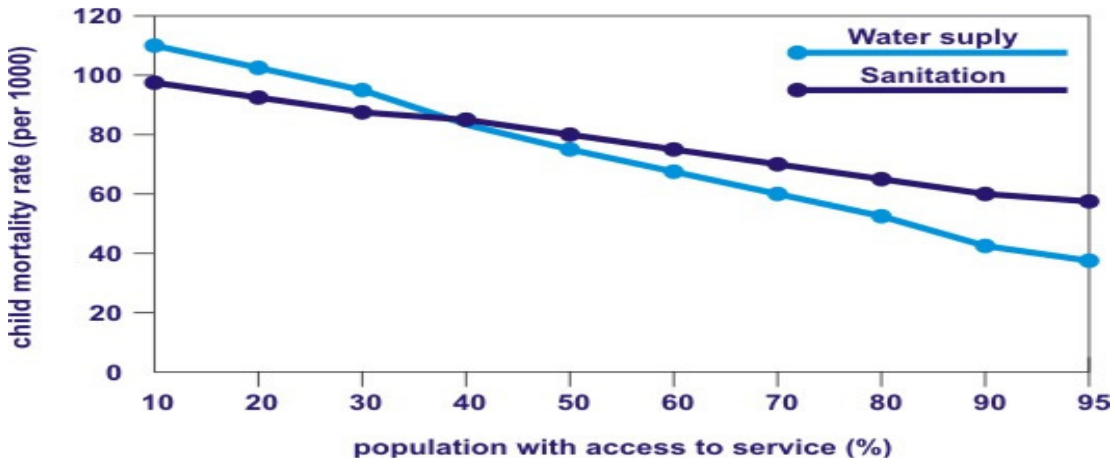


Figure 2.1- Predicted Child Mortality by Percent of Access to Drinking Water and Household Connections to Sewerage Systems in 1993 (after Shi, 2000).

2.3 Wastewater Systems

Sustainable water management is especially dependent on the system employed for wastewater management. In this context there are two distinct types of wastewater management systems, namely centralised and decentralised wastewater management systems. Wastewater systems have sub systems or processes such as generation (household & industry), collection, conveyance, storage, treatment, reuse and disposal systems. This research focuses on the treatment process which is only but a part of the whole wastewater system. According to the Rocky Mountain Institute studies (2004), centralised systems for wastewater treatment are considered by many in the water sector as the best practice for most communities because of the high level of reliability, established management framework and economies of scale giving an apparent (but not necessarily real) advantage of least cost per capita. This has been shown not be the case by recent research carried out in the developed countries and is definitely not the rule in the developing countries where affordability becomes important in determining the effectiveness of the centralised wastewater management systems.

This common view in the developed world has been under scrutiny for many years. In a report on sanitation and disease in the developing world to the World Bank by Feachem *et al.* (1983), it is pointed out that centralised systems of developed countries are not the result of a logical and rational design process, but rather a product of history that started about 100 years ago when the related fundamental physics and chemistry knowledge base were limited and microbiology virtually undiscovered. According to Feachem *et al.* (1983), "These practices are not especially clever, nor logical, nor completely effective—and it is not necessarily what would be done today if these same countries had the chance to start again." Morrissey and Harleman (1992) argue that enormous water pollution problems related to inadequately treated wastewater in the large cities of the developing world requires innovative, revolutionary thinking, not the complacency of 'evolutionary' solutions.

2.4 Centralised Systems Approach to Wastewater Management

In the developed world, wastewater treatment is mainly based on centralised systems connecting a multitude of households to one main sewage treatment plant. This centralised system developed over several decades has regularly been adapted to increasing demands. Most developing countries have also adopted centralised wastewater collection and treatment systems and such is the case in most cities of South Africa. The Gauteng Sanitation policy recommends centralised wastewater systems as the only solution for wet sanitation. The basis for such a stance on the policy reveals a bias towards centralised systems without considering other options or taking a holistic view which evaluates the pros and cons of centralised and decentralised systems. Balkema *et al.* (1998) summed it up by clearly pointing out that central sewage systems have been able to solve many hygienic problems and have made tremendous progress in ecological improvements, but centralised systems also have weaknesses that should be critically examined. From a cleaner production

perspective, it is senseless to mix wastewaters of different qualities and discharge into one facility for treatment and thus making it difficult to treat and reuse. Central collection and treatment systems can also be questioned from an economic point of view since high investments are needed for building and maintaining their infrastructure. The greater chunk of these expenditures is needed for transporting the wastewater in the sewers, and not for the purification process itself. Centralised wastewater systems are capital, skill and energy intensive and are based on the use of large amounts of high quality potable water to flush away and dilute wastes (Balkema *et al.*, 2001). A summary of the main points in questioning the wisdom of centralising wastewater treatment is set as shown in sections 2.4.1 to 2.4.8.

2.4.1 Affordability

Centralised systems are simply often too expensive for small communities to construct since small communities have fewer people to support a large wastewater investment. Kreissl and Otis (2000) highlight that even if small communities are able to obtain funds and build Centralised systems, often the technologies prove to be difficult and costly to maintain, given the limited technical and financial capacity of most small communities. In addition, both the construction, and operation and maintenance of the necessary hardware for the flush and discharge options are a heavy financial burden as evidenced in Fig 2.2. Hauff and Lens (2001) argue that centralised systems are directly cross subsidised and even in developed countries the chance for them ever becoming financially sustainable is low.

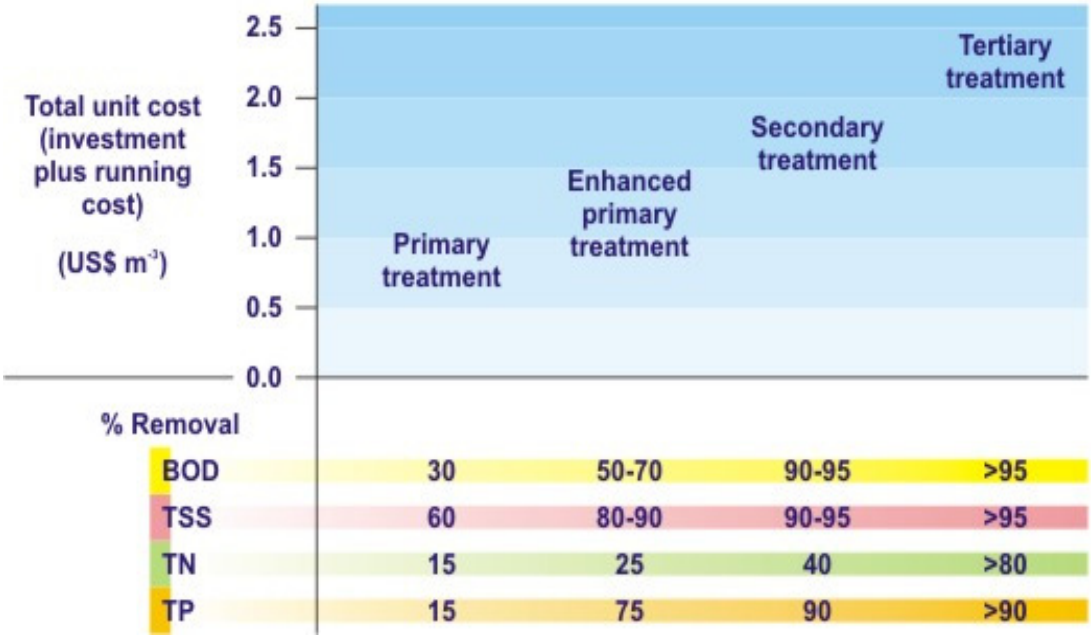


Figure 2.2 Typical Total Unit Costs for Wastewater Treatment (Data from Western Europe and the United States, Veenstra *et al*., 1997)

2.4.2 Water Pricing

Many past failures in water resources management are attributable to the fact that water pricing is not reflective of total system costs and that water has been – and still is – viewed as a free good. It is known that prices for wastewater treatment in many countries are well below the full cost of the infrastructure and personnel needed to treat the wastewater. The overall cost comprises the capital charges, the operation and maintenance (O & M) costs, the opportunity cost, economic externalities and environmental externalities. Cost recovery of O & M costs is a minimum condition for a sustainable project. Without cost recovery, it is likely that the performance of the project will deteriorate seriously over time.

Charging for water at less than full cost means that the government, society and/or environment 'subsidises' water use and leads to sub-optimal use of the resource. In

most Water Resources Management (WRM) studies, financial viability is viewed as a constraint that must be satisfied. It is not viewed as an objective whose maximisation could result in a reduction in economic efficiency, equity or other non-monetary objectives. The Dublin Water Conference addressed the need to extract the maximum benefits from a limited resource as well as the need to generate funds to recover the costs of the investments and of the operation and maintenance of the system.

2.4.3 Financial Resources

A study carried out by Grau (1994) and Gijzen (1997) estimated the period of time needed to meet the European effluent standards by a number of low and middle income countries, assuming that 1.5% of the GNP could be invested in sewers and treatment facilities as shown in Table 2.1. This period exceeds by far the economic life-time of the treatment plant (20–30 years) and in many cases even that of sewers (50-60 years). The implementation of centralised wastewater collection and treatment in developing countries to reach EU standards is therefore unrealistic, except maybe in densely populated urban centres where the average income is much higher.

Table 2.1- Estimated Period of Time needed to meet EU Effluent Standards at an Investment Level of 1.5% of the GNP

Country	Population (Million)	GNP c^{-1} (US $ c)	Cost to meet EU standards (US $ c^{-1})	Time needed at 1.5% GNP y^{-1})
Bulgaria	8.5	2210	3755	113
Egypt	60	1030	4000	259
India	935	335	3750	746
Kenya	29.2	290	4500	1034
Mexico	92.1	2705	3750	92
Poland	38.3	1700	1230	48

(Adapted from Gijzen, 1997)

2.4.4 Wastewater Investments

Population growth, coupled with insufficient investment, makes the goal of adequate water and sanitation for all by 2015 an uphill struggle. In most developing countries the demand for sewerage greatly exceeds the resources available to provide its treatment and this is exacerbated by uncoupling of water supply provision from the provision of sanitation services simultaneously. The cost of centralised systems infrastructure is prohibitive in the majority of the developing countries. The World Water Vision and the associated Framework for Action developed during the second World Water Forum in 2000, estimates the cost of required water services for developing countries in the period between 2000 and 2025 at around $180 billion per year. This estimate is only for new works. It did not account for the costs of maintenance, rehabilitation and replacement. The sectoral breakdown is about $30 billion for agriculture, $75 billion for environment and industry, and $75 billion for water supply and sanitation (Marjanovic, 2008). At present, the largest investor in water services in developing countries is government (the traditional public sector), which contributes about $50 billion. The domestic private sector contributes $15 billion. International donors contribute a further $9 billion (the World Bank, for example, accounts for about $3 billion), and the international private sector contributes around $4 billion. The total is therefore only $78 billion per annum. The annual shortfall between demand and present resources is unimaginably huge: $102 billion per year for new works alone (Marjanovic, 2008).

2.4.5 Maintenance Backlog

Centralised systems have a huge backlog of deferred maintenance. The gap between what urban communities are spending on maintenance and upgrades of collection and treatment systems (as well as drinking water infrastructure) and what is actually needed amounts to many billions of dollars a year. According to Rocky Mountain Research (2004) about US$100 billion/year is needed globally for operation and

maintenance of centralised systems whilst only US$32 billion/year is made available. This is a common situation in the developing world but is not unique to it. It is not clear how this deficit will be narrowed as the need for new connections grows due to rapid urbanisation in the face of declining resources.

2.4.6 Loss of Valuable Resources

Centralised sanitation systems have other fundamental shortcomings apart from their high economic costs. They are responsible for soil and groundwater pollution, over-exploitation of limited renewable water sources, waste of valuable components in wastewater and the complicatedness of effective removal of pollutants (GTZ, 2003; Langergraber, 2005; Wilderer & Schreff, 2000). The traditional urban water management systems approach does not take into account the reuse of water in the local watershed and the recovery of useful wastewater ingredients (energy, nutrients, water and metals). Water is usually pumped out of the local watershed and this can create an imbalance in water and nutrient fluxes and therefore distort natural hydrological and ecological regimes (Mihelcic, 2007). Wastewater is the only water resource that is increasing with increase in population is but as its name suggests, wastewater is wasted and rarely used as a resource in the developing countries.

Vinneras (2002) argues that the practice by modern sewage treatment systems of applying tertiary treatment for the removal of nitrogen and phosphorus via physical-chemical or biological processes is irrational when analysed as part of the overall food production and consumption cycle. Vinneras further strengthens his argument by highlighting that intensive agriculture requires the use of substantial amounts of inorganic fertiliser, which is obtained through energy intensive industrial fixation of atmospheric nitrogen. This approach is inefficient from a radical resource (Nitrogen & Energy) productivity point of view.

2.4.7 Groundwater Pollution

Gerba (1998) reveals that there is evidence that leaking sewer pipes are a substantial water quality problem in many parts of the world. In some areas, leaking sewers may be a greater source of ground and surface water contamination across the country than are septic systems. This nullifies the misconceptions that onsite systems are the only culprits in groundwater pollution.

2.4.8 Linear Solutions to Wastewater Management

Within the context of material flows, centralised wastewater management system is an open ended loop system and is nowadays considered as being unsustainable in light of the high resource intensity (energy, inefficient use of fresh water) and very little if any useful by-products recovery contained in wastewaters (Lettinga *et al.,* 2001). This linear approach to management of wastewater causes multiple problems as shown in Figure 2.3. Locally produced waste can cause effects as far as 100 kilometres downstream, while accumulated effects sometimes are only observed after many years. Cause-effect relations are often obscured and this makes proper management more cumbersome. Centralised systems have remained the dominant design despite growing evidence from new and established research groups proving that centralised systems are not the standard to aim for. Centralised systems are also inundated with numerous problems highlighted in the prior section but there are also so many factors favouring the continuation of centralised systems as a basis for wastewater management.

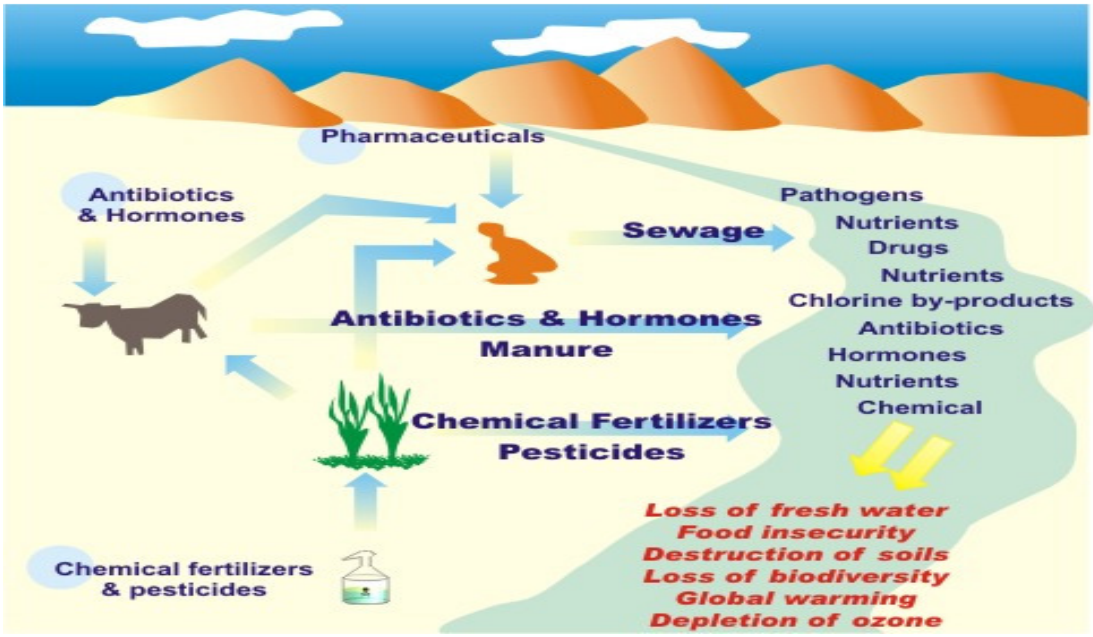


Figure 2.3 Linear Sanitation Solutions Cause Multiple Problems (Modified from: Esrey *et al*., 2000)

2.5 Factors Favouring Centralised Systems

Wilderer (2005) states that a key reason why the developed world still clings to centralised systems is that the industrialised cities have inherited infrastructure which heavily favours the continuation of centralised management of water in urban areas.

2.5.1 Lock in Effects

Panebianco and Pahl-Wostl (2006) argue that most countries cling to Centralised systems because of the existence of lock-in effects, which are particularly relevant in large technical systems. In principle there are a number of alternative technical solutions that are rarely taken into consideration because centralised treatment has been the traditional solution (Hoffmann *et al*., 2000). Since Centralised technologies are deeply entrenched, the adoption of innovative substitutes may be met with a lot of resistance. “This technological “lock in” may occur for any number of reasons,

including institutional, political, and economic commitments or behavioural, learning, and cultural habits" (Borsuk *et al.*, 2008). It may also be that those stakeholders in the best position to effect adoption of the new technology may not have a view of the long-term advantages nor a clear path for implementation.

2.5.2 Security and Safety of Selecting Familiar Solutions

According to Wilderer (2005) the first reason is that it is unwise to change a well established practice without making an effort to understand the basis of the heritage. Second, there is always a significant inherent inertia against change among wastewater management professionals. There is a need for a deeper appreciation and a detailed understanding of the heritage solution if any arguments for the suggested changes are to be accepted. Morrissey and Harleman (1992) reveal that private engineering design firms are reluctant to use what they consider to be new approaches and furthermore they claim that a study by the American Consulting Engineers Council reported that three-fourths of their respondents avoid using innovative technology because they were afraid they could be sued if something went wrong.

2.5.3 Standard Designs

Standard designs persist; meaning developers and construction firms do not have to put extra effort since the design for such systems are standard (Harremoes *et al.,* 1996). In most countries wastewater management agencies and the consulting firms usually advise local authorities to choose or select Centralised systems. These agencies already have a bias towards centralised systems because of their established design standards and operating procedures. Generally non-conventional systems are relatively unknown; therefore there is a general lack of knowledge on these systems, by planners, engineers and the public. There is a general perception that decentralised systems offer substandard service (Bakir, 2001).

2.5.4 Standard Practices

The standard practice in some parts of the U.S.A is for a municipality to engage a firm on a non competitive basis to design a plant requires contract bids for construction and then operate the plant with city employees or ask a private partner to run it (Harleman & Murcott, 1998). South Africa uses a similar practice and this approach discourages innovation because the only competition is in the construction. In contrast, the European practice of bidding on a design/build/operate package encourages competition through using cost-effective, innovative treatment processes. European design firms that engage in this type of bidding have their own research laboratories to ensure that they understand and advance the treatment processes they propose.

2.5.5 General Perceptions

There is a general public misconception that centralised sewage treatment plants perform better, protect property values and are more acceptable than decentralised systems. As stated previously, earlier trends have shown that most municipalities use centralised systems and have grown accustomed to them. It is human nature to cling on to things that are known and trusted to work and provide the expected results but this trust comes at a cost. It is due to the fear of the unknown or of change or just the misunderstanding of what decentralised systems are; that people would rather use centralised systems over decentralised systems.

2.5.6 Policies and Regulatory Constraints

There is a well established government policy and regulatory framework, government agencies or corporation responsible for the centralised systems management. Harremoes *et al.* (1997) reveal that there is a place in government policy to ensure proper operation of the system with accompanying government agencies and

structures to collect the rates and taxes. There are prohibitive statutes that discourage local authorities from developing or implementing effective management and oversight functions. Some liability laws and policies discourage innovation and a case in point is the Gauteng sanitation policy which discourages the use of intermediate sanitation options. The Gauteng sanitation policy only allows for full waterborne sanitation and Ventilated improved pits (VIPs).

2.5.7 Investments

The challenges of the centralised systems suggest that the current conventional approach to water supply and sanitation should be reconsidered. Changes in the industrialised world will be slow partly due to the massive investments made in the existing infrastructure for water supply, collection and treatment and also because of the considerable commercial interests of established companies which supply the technology (Wilderer, 2005). Most low- and middle- income countries have not yet invested heavily in the physical infrastructure for urban water supply and sanitation, and may benefit in the short term from such new approaches to sanitation.

2.5.8 Economies of Scale

There are economies of scale to be realised with centralised systems particularly with reference to treatment systems. The investment, operation and maintenance costs are largely tied to the sewerage system (Bakir, 2001). There can be diseconomies of scale in collection and transportation of the sewage to the treatment works. Smaller systems loose the advantages of economies of scale that are possible in wastewater treatment capital costs and O&M costs. However, smaller systems also avoid diseconomies of scale that are inherent in sewer systems. Given that collection system costs are roughly 80-90 percent or more of total systems cost, collection diseconomies of scale can overwhelm treatment economies of scale, resulting in decentralised systems being the more economical choice (Marjanovic *et al.,* 2009).

2.5.9 Ease of Institutionalisation

Centralised systems have the advantage of ease of institutionalisation of the operations and maintenance function. This is because centralised systems emerged as a successful solution when the motivation for water engineering was the cholera outbreaks in European cities (Harremoes, 1997). These reactive approaches made centralised systems lock the market and become a dominant design but this did not necessarily make them the best design or solution. The dominance of the centralised systems is such that when sewerage passes through a property the sewerage rate is charged regardless of whether the connection is made and there is a normal a mandatory period required for connection.

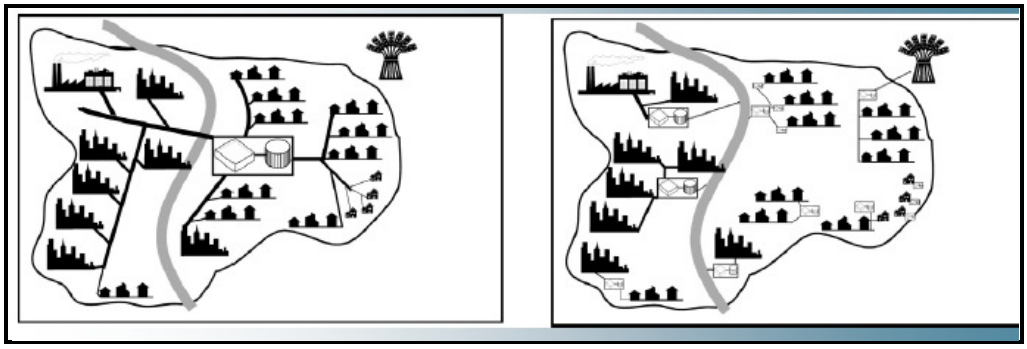
2.6 Decentralised Systems for Wastewater Management

The ever growing and unending limitations of central wastewater disposal systems have triggered a search for technological alternatives. Decentralised systems are an alternative to centralised systems. They may help communities avoid or resolve the problems noted above or address many other issues inherent in centralisation of wastewater services. Panebianco and Wostl (2006) argue that in contrast to the Centralised end-of-pipe concept, decentralised technologies aim at minimising the required resources and treat and reuse the different substance flows in an adaptive way at an early stage in the purification process. Other advantages of decentralised technologies are their flexibility in responding to technological and socio-economic developments, their adaptability to specific demands on water quality, their compliance with the polluter-pays-principle and to some extent, their relatively lower vulnerability, e.g. to terrorism or to a total breakdown of the system.

An often quoted definition of decentralised wastewater systems comes from Crites and Tchobanoglous (1998). *"Decentralised wastewater systems collect, treat and reuse or dispose of wastewater at or near its point of generation.*" Decentralised

systems include *onsite systems* that treat wastewater from individual homes or buildings, and *cluster systems* that treat wastewater from groups of two or more homes. In the context of this research decentralised is defined as wastewater management systems that manage wastewaters ranging from that generated from individual households and to wastewater generated from relatively small part of an urban community.

Figure 2.4 provides a graphical depiction of centralised and decentralised approaches to wastewater management serving a given area. In principle there is a continuum from full decentralisation (individual systems for each household) to fully centralised system (all households in a community connected to a single wastewater treatment facility (Figure 2.5)). To elaborate further on the relative scale notion, it is often useful to talk in terms of *centralisation* or *decentralisation.* For instance, a cluster system reflects centralisation relative to onsite systems. A regional wastewater treatment plant (WWTP) serving multiple municipalities reflects a higher degree of centralisation than a number of "centralised" but smaller municipal or community-scale WWTPs.



Centralised **Decentralised**

Figure 2.4 Centralised and Decentralised Approaches to Wastewater Management (EPA, 2004).

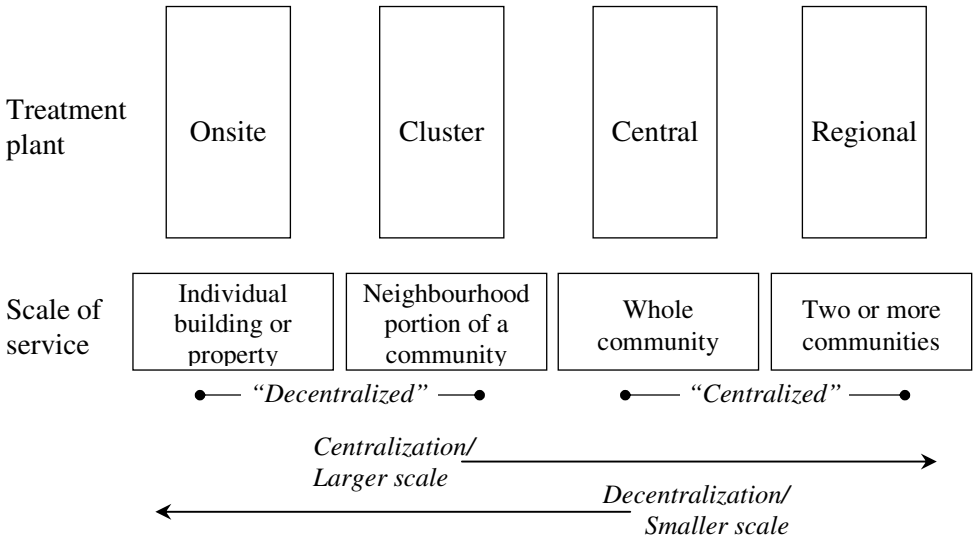


Figure 2.5 Continuum of Centralisation and Decentralisation in Wastewater Management in urban context (Rocky Mountain Institute, 2004)

It is important to note that the differentiation between decentralised and centralised systems as discussed in this research refers purely to physical characteristics of the system. Physical decentralisation does not necessarily imply anything about institutional structures for managing wastewater systems. Nhapi (2005) reveals that assuring appropriate management is a "hot topic" in decentralised systems and for small central treatment plants. Indeed, poor management of small treatment plants has been a key driver for centralising or regionalising physical wastewater infrastructure. The problems often seen with decentralised and small treatment plants are not necessarily intrinsic to their physical scale; rather they may reflect inadequate technical, financial, and managerial capabilities of their owners or managers, problems that can be addressed with appropriate institutional mechanisms.

2.6.1 Management of Decentralised Wastewater Systems

As Nhapi (2005) stated, the decentralisation of wastewater management in urban communities in Africa will have serious implications on the current institutional

arrangements. It would necessitate well-organised and responsive institutions capacitated to deliver the needed services. Political commitment and support are required on the part of government in order to develop an enabling environment for private sector investment. The initiative would involve government, town councils, and private sector participation. A clear structure of roles and responsibilities would need to be defined so that efforts are not duplicated. While technology selection, with an emphasis on costs, recovery, and profitable reuse of nutrients, is very important in the formulation of strategies, it should not be made at the expense of environmental and social factors which are as a rule, more dominant constraints than are the economic factors. Preferably, technologies that could achieve the above criteria whilst being backed by local expertise could be used as a starting point. Different approaches and technologies would apply to different areas. With decentralised systems the opportunities for urban agriculture integration with innovative urban planning and water/nutrient management and the potential for other innovative approaches increase significantly.

2.6.2 Factors Favouring Decentralised Systems

Research carried out by the Rocky Mountain Institute (2004) showed that conventional onsite wastewater treatment systems, when properly installed and operated, can meet the required standards and provide greater than 99 percent removal of faecal coli forms. Anderson and Otis (2000) reveal that various onsite and cluster wastewater technologies can remove substantial amounts of nitrogen (N) and phosphorus (P), even to levels approaching “advanced wastewater treatment” standards of 90 percent N and P removal. In addition, and of special importance for Africa, natural wastewater treatment systems and eco-technologies can achieve similar removal efficiencies if designed and implemented properly.

Rocky Mountain Institute (2004) studies reveal that there is an additional benefit of higher potential for water reuse and nutrient recovery. Decentralised systems may create more jobs in a community than conventional centralised systems (Bakir, 2001; & Muga, 2006). In essence decentralised systems are often much more affordable for communities and their effective management can maintain system reliability at a low cost. Often in considering various technical options for implementation, the costs of decentralised systems have been unfairly highlighted, disregarding their other potential benefits. As such decentralised systems have been marginalised. Water pollution and possible future water scarcity problems could be feasibly solved by an integrated decentralised wastewater management approach. In summary, the opportunities for improved decision making and wastewater management that decentralisation offers are vast. However, many factors still remain either poorly understood or controversial and require urgent attention and further research.

2.6.3 Decentralised Systems Challenges

Radically switching to decentralised systems is a mammoth task and coupled to this, one has to add the need for a serious transformation in wastewater management in order to achieve Millennium development Goals (MDGs) – specifically Goal number 7: that of Environmental Sustainability. It should be noted that despite literature studies alluding to the fact that decentralised systems are more sustainable, they are not a panacea, they have their weaknesses which should be critically analysed and addressed before radically switching to them. The factors highlighted in sections 2.6.3.1 to 2.6.3.4 need to be addressed before decentralised systems can be fully embraced in the same realm as the centralised systems.

2.6.3.1 Failure of Onsite Systems

If onsite systems are not managed properly, they can lead to overflow of wastewater into the surrounding areas, causing detrimental health impacts. Historically, the lack

of proper management and design made decentralised systems unacceptable rather than their inherent technological inability to meet the required performance levels. This has in turn created perceptions that there are technical inferior to centralised systems which have a history of a high effective management system (Rocky Mountain Institute, 2004).

2.6.3.2 High Capital Costs

Most of the decentralised systems on the market are quite expensive and have out-priced themselves from implementation in developing countries. Bakir (2001) points out that the cost of a few smaller treatment plants will be significantly higher than the cost of one centralised treatment plant. The major aspect has been that decentralised technologies on the market have not made significant inroads into acceptance by the general public and hence the cost of production of such technologies is high until such a time the technologies can be mass produced.

2.6.3.3 Life Styles Changes

Acceptance of decentralised systems will largely depend on the impact imposed on the communities on their life styles. The conventional approach has been invisible to many but decentralised technologies call for more visibility and interactions with the users (Marjanovic, 2008).

2.6.3.4 High Requirements

The operation and maintenance requirements of numerous small treatment plants are usually more than those of one centralised treatment plant. Decentralised technologies are still in their infancy stages of development and there is still high uncertainty in their ability to deliver the requirements for sustainable development (Wilderer, 2005).

The consideration of the disadvantages of both centralised and decentralised systems leads to only one conclusion*:* the dominant approaches of the past need to be re-examined and better ways must be found in the search for sustainable wastewater management. The fundamental question remaining is whether it is possible to attain sustainable urban water management through improving the existing centralised systems or whether a radically switch to new decentralised systems is required. A brief summary extracted from the Rocky Mountain Institute research (2004) in the United States of America on the decentralised and centralised wastewater systems advantages and disadvantages is highlighted in Appendix F.

2.7 Main Drivers for Wastewater Management Systems

A general framework on wastewater management that emerges from the above review is that a set of two categories of drivers exist for wastewater management: drivers which are socially induced and those that are a consequence of a physical world and policy constraints that one operates within. This is summarised in Figure 2.6. The primary set of drivers falls within the inner circle in Figure 2.6 and consists of the following drivers:

- Environmental Sensitivity
- Capacity of the receiving environment
- Water Supply level (link to resource availability)
- Demographics and the resulting demand for water
- Regulatory requirements (a link to socio economic system and associated secondary drivers)

The secondary set of drivers is within the social domain and consists of the following:

- User requirements
- Economic Feasibility
- Political feasibility
- Adopted management model (institutional feasibility)



Figure 2.6 Drivers of Wastewater Management (Adapted from Marjanovic *et al.*, 2010)

It is obvious from the above, that the end point of a decision making turns out to be a choice of a particular system type (centralised or decentralised framework) and appropriate technologies (***technologies for wastewater treatment***) to fit into the chosen system type. This endpoint however occurs within the constraints imposed on the choices by the socio economic, administrative and legal and physical constraints that exist in any given situation (Figure 2.7).

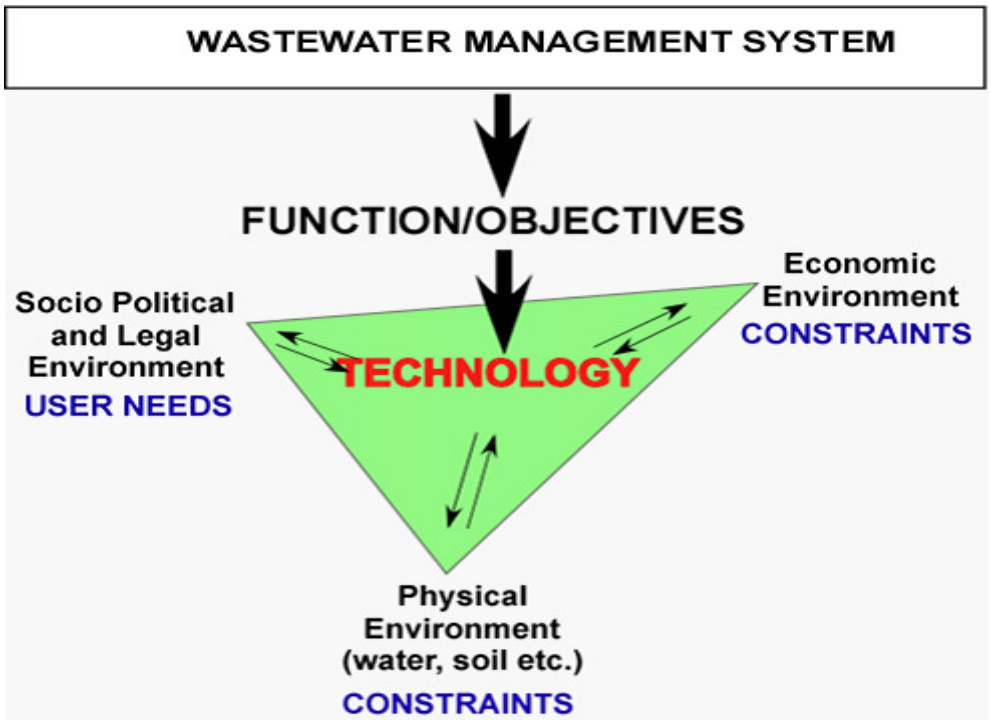


Figure 2.7 Wastewater Management System Level Constraints (After Balkema, 2002)

This then brings to the forefront the problem of appropriate technology choice and essentially establishes a need for a **multi criteria (constrained) decision making** process to select the best appropriate system level and/or a technology for a particular situation as a prerequisite to achieving sustainable wastewater management.

2.8 Available Technologies

According to Henze *et al.* (1997) there is a whole spectrum of technologies for wastewater management both within the context of centralised wastewater management system or within the context of a decentralised wastewater management framework. The actual analysis of all the technology options available is beyond the scope of this thesis but for the purpose of completeness typical options are summarised and presented in Appendix G as fact sheets that may be consulted. The

DSS contains a database of these technologies and allows addition of new or any required technologies. There is a prescribed way of entering new technologies so that the comparative analysis is well captured. It suffices here to say that the analysis carried out within this research included the technology aspects also and the findings thereof are presented elsewhere in this thesis and integrated into the decision making methodology and the decision support tool discussed in Chapter four and five. The ultimate goal of wastewater management is public health and the technologies chosen have a role to play in minimising and eliminating water related diseases.

2.9 Summary

The sustainability and limitations of the centralised and decentralised approaches to wastewater management in meeting the Millennium Development Goals were analysed in this chapter. Major findings from the literature review are that the problems and limitations of the centralised approaches to wastewater management are being encountered more and more. It has been shown that central disposal systems have inefficient economic structure (inefficient financing) and high economic requirements i.e. high investments are needed for building and maintaining their infrastructure. The major share of their operating costs is covers financing costs and the cost of transporting the wastewater in the sewers, and not for the purification process itself. One major fundamental shortcoming of centralised systems is their slow response to rapid urbanisation. Despite these shortfalls centralised systems remain the dominant mode of operation. This is mainly due to 'lock' in effects since much capital investments and researches have been made into these systems.

Contemporary research and literature studies appear to be favouring the development of decentralised systems. Many questions have been raised on whether these systems are more sustainable than centralised wastewater treatment system. Another area of discussion has been on determining the aspects that leads to sustainability. These

unanswered questions form the basis of this research. The objective of this research is to present elements for comparison among the systems using a holistic approach based on sustainability indicators; environmental, economic, technical and social criteria. In an era where there is growing concern of the local and global impact of our current environmental management strategies, and the need to reduce sanitation problems, disease, and poverty, there is a greater need to develop more environmentally responsible, appropriate wastewater treatment technologies whose performance is balanced by environmental, economic, and societal sustainability.

CHAPTER 3

WASTEWATER MANAGEMENT IN PERI URBAN MUNICIPALITIES OF GAUTENG - CASE STUDY

3.1 Introduction

This chapter covers the case study areas and policy, legal, planning and institutional framework for water wastewater management in South Africa. Sections 3.2 to 3.3 cover the case study areas and highlight the status quo of water and wastewater management in eight municipalities in Gauteng province. Section 3.4 to 3.4.7 cover the policy, legal and institutional framework while sections 3.5 to 3.6 cover the planning and decision making framework. Comparisons with international norms and standards are made within section 3.4.5.

3.2 Background

The study area covered eight Municipalities and one district management area shown in Figure 3.1. The research covered the following municipalities in three phases; phase 1 (Lesedi, Midvaal, and Emfuleni), phase 2 (Kungwini and Nokeng Tsa Taeman) and phase 3 (Westonaria, Randfontein and Mogale). It was all municipalities in Gauteng Province minus the Metros. These municipalities were chosen because unlike the Metros they have high human resource capacity challenges and these municipalities are more likely to have decentralised systems in poly-culture with the centralised systems. These local municipalities were more likely to benefit much out of the research and are virgin areas for promoting new concepts to wastewater management.

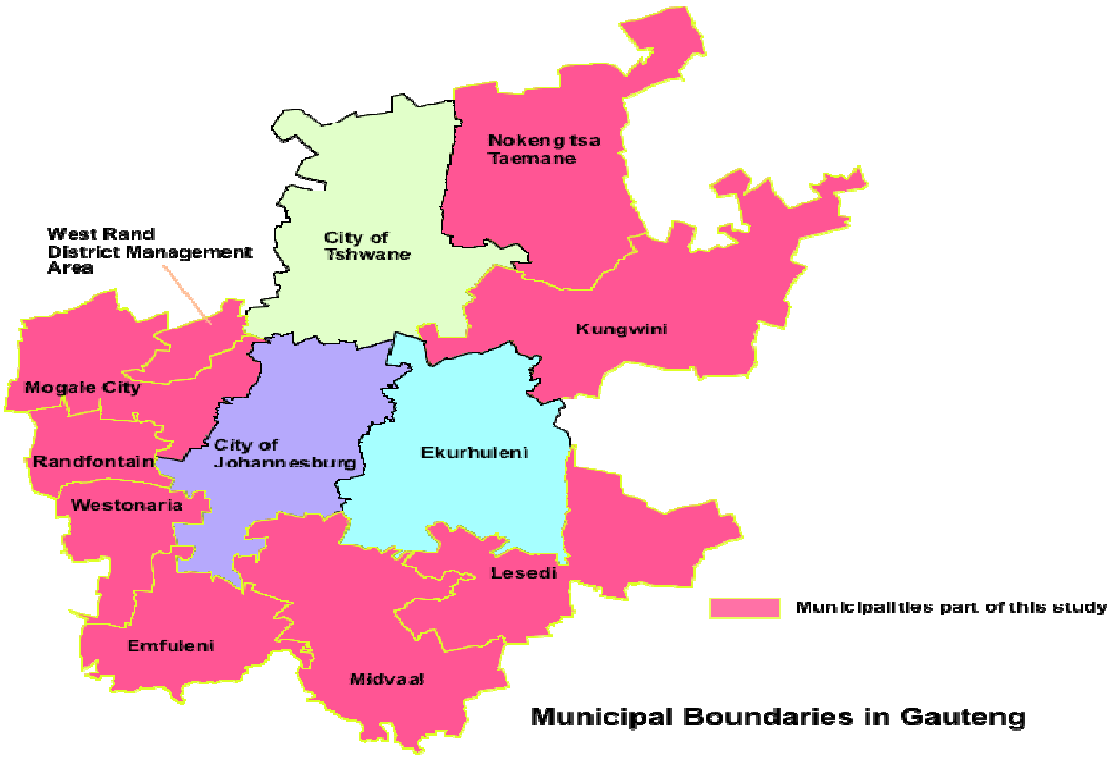


Figure 3.1 Municipalities in the Study Area

Both formal and informal settlements/communities are present in each of the municipalities studied. In formal communities, most of the houses are connected to public water supply and sewerage systems. Table 3.1 summarises the current situation with respect to the status of water supply and sanitation/wastewater management in the studied municipalities. It should be noted that with exception of the Midvaal Municipality, more than 80 % of houses are connected to a formalised sewer system and a wastewater treatment plant. In such cases specific water consumption, is in excess of 100 l/cap/day as a rule. Houses that are not connected to the sewer system and a wastewater treatment plant mostly have on site sanitation systems installed (these are typically septic tanks). In few exceptions in formal communities with water supply connections, dry sanitation systems are used (Ventilated Improved Pit (VIP)).

Table 3.1 Wastewater Management Indicators for Formal Settlements/Communities

Municipality	% of houses by Municipal water supply-house connection	% of houses with onsite sanitation	% of houses connected to WWTP
Mogale City	100%	<20%	>80%
Westonaria	100%	<20%	>80%
Nokeng	100%	<5%	>95%
Kungwini	100%	<15%	>85%
Lesedi	100%	<7%	>93%
Emfuleni	100%	<3%	>97%
Midvaal	100%	<35%	>65%

In informal settlements/communities the situation is very different. Many of those communities either have inadequate services provision with respect to water supply and sanitation or in some case no service provision at all.

3.2.1 Wastewater Treatment Plants

According to the research carried out by Manus and Van der Merwe-Both (2010), South Africa has a substantial wastewater management industry that comprises approximately 970 treatment plants, extensive pipe networks, pump stations. Gauteng province has the highest number of medium to large WWTW's, with a smaller number of micro size plants. Smith (2009) highlights that wastewater treatment plants can be categorised according to the following sizes (flow/time related):

Table 3.2 Wastewater Treatment Plants Categories

Category	(Flow/time related) Mℓ/day
Micro size plants	<0. 5
Small size plants	0.5-2
Medium size plants	2-10
Large size plants	10-25
Macro size plants	>25

(After Smith, 2009)

A summary of the research by Manus and van der Merwe-Botha (2010) on the size distribution of wastewater treatment plants in South Africa during November 2008 to August 2009 is shown in Fig 3.2. Both pie charts (Fig 3.2 and Fig 3.3) show the categories proportionate to the number of the treatment works.

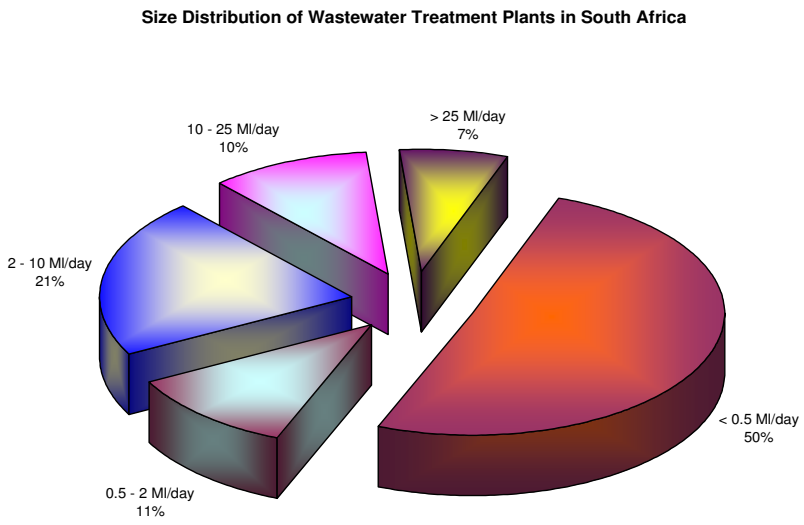


Fig 3.2 Size Distribution of Wastewater Treatment Plants in South Africa (After Manus and Van der Merwe-Botha, 2010)

The spread in Gauteng shows that 58.2% of all the WWTW's fall in the Macro Size Category, with 23.3% of the treatment plants being large size WWTW's as shown Fig 3.3.

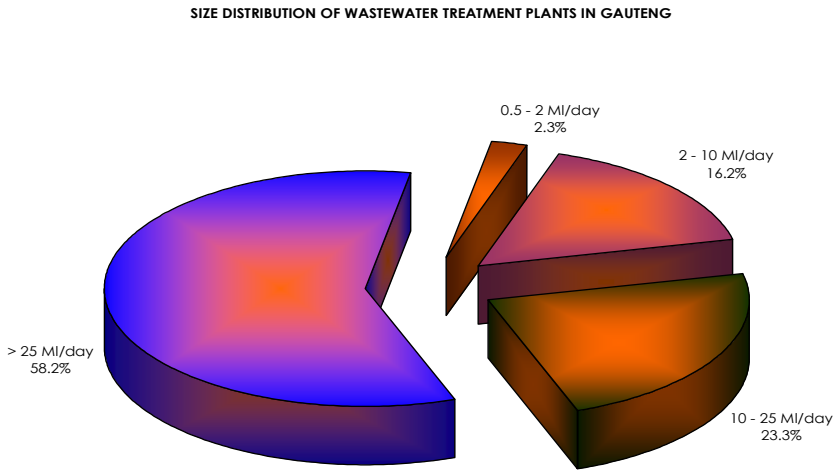


Fig 3.3 Size Distribution of Wastewater Treatment Plants in Gauteng (After Manus and Van der Merwe-Botha, 2010)

In view of the current situation in South Africa the most relevant question seems not to be between Centralisation or Decentralisation but rather to what degree a decentralisation approach needs to be introduced to ensure the most appropriate and effective wastewater management. A general answer to this question is actually not possible as each particular situation will have its own optimal solution. A different level of decentralisation will be possible and desirable for each individual Water Services Authority as the ultimate level of responsibility for water services provision is located with these authorities.

3.3 Key Findings and Lessons Learnt - South Africa

Tables 3.3 and 3.4 summarise the status quo findings of the study for Informal settlements with respect to water supply and sanitation respectively. The Guidelines for Human Settlement Planning and Design, CSIR 2000 (Red Book) water supply classification system was used to summarise the data. The Housing department plans for informal settlements were of paramount importance in this study. This information was collected and captured from the relevant Housing Departments in different Municipalities. Table 3.5 summarises the current status of planning for the informal settlements with respect to housing.

Table 3.3 Water Supply Indicators for Informal Settlements/Communities

Status of Water Supply as per Red Book categories	Municipality	Settlement	No. of people
No formal supply	Randfontein	Middelvlei Station	195
	West Rand District	Swartkrans 172 IQ Ptn 55, Kroomdraai 520IQ Ptn 55	335
		Kromdraai 520 IQ Ptn 6	
	Nokeng	Roodeplaat (Derdepoort 65)	180
	Mogale City	Rietfontein Plot 81	660
	Iesedi	Ratanda ext 4b	100
	Midvaal	Cross str, De Deur, Portion 51 De Deur	100
	Emfuleni	Magusheng, Mapolankeng	195
Carted in	Westonarea	Thusanang 'B', Glenharvey-steruteru	100
	Randfontein	Jabulani-Drowell, Boipei, Groenplaas Withuise, Bosswinkel	2555
		Elandsvlei Ptn 136	
	Nokeng	Donkerhoek, Roodeplaat (Leeufontein)	660
	Mogale City	Nooitgedaght Plot 77, Nooitgedaght Plot 42, Nooitgedaght Plot 91	25651
		Nooitgedaght Plot 89, Swartkops Plot 55, Driefontein Plot 71	
		Joe Slovo, Lindley Plot 63, Swartkops Plot 525, Buya Africa, Rietpoort	
		Toad Tree Farm, Kombi, Hekpoort, Tsakane, Smoke Down,	
		Tshama Hantse, Van Wyks Restant Ptn 2, Driefontein Ptn 47	
		Zwartkops Ptn 54, Lindley Ptn 31, Tswelopele	
		Kudung (Bloekomspruit), Kudung (Soetvelde), Makakong, Sporong	4545
	Midvaal	Lekakeng, Nelsonia, Haroldsfarm, Kroomdraai farm, Waterval farm	
		Keyalitsha, Dusting, Brakfontein, Skansdam, Biotomelo,	
		Aloe ridge Quarry,	
	Kungwini	Sterkfontein, Swavelpoort, Kanana Kameelzynkraal, Kleinzonderhout	12735
		Witpoort, Blesbokfontein, Roodepoort, Sokhulumi, Zusterstroom	
		Sehlkwane	
Boreholes	Randfontein	Siyahlala '2', Siyahlala '1'	830
	West Rand District	Sterkfontein 173 IQ Ptn 19, Kromdraai 52 IQ Ptn 26	730
		Mooiplaats 524 IQ Ptn 2, Renosterspruit 495 IQ Ptn 72	
		Rietfontein 189 IQ Ptn 318	
	Nokeng	Rust De Winter, Dewagensdrift, Onverwacght	1835
	Mogale City	Nooitgedaght Plot 38, Rietfontein Plot 163 (10%), Orient Hills	3961
		Hapers Café, Boikarabelo	
	Kungwini	Donkerhoek, Nooitgedaght, Blesbokfontein, Wagenbietjieskop	1615
		Rietfontein 1, Rietfontein 1, Valchspruit, Rietfontein 2, Rietfontein 3	
		Rietfontein 4, Wolvekop 1, Wolvekop 2, Zorgvleit 1, Zorgvleit 2	
Municipal standpipes < 200 m	Westonarea	Bekkersdal, WaterworksWaterworks, Thusanang 'A'	72500
	Randfontein	Fourways, Scrapyard, Dumping Site	1615
	Nokeng	Refilwe - Cemetry, Refilwe - Municipal Offices, Refilwe - Municipal Park	7075
		Roodeplaat - RDP Offices, Phumzile (Old waste dump)	
	Iesedi	Ratanda ext 4a, Impumelelo	5650
	Midvaal	Mamelo (Vaal Merina), Sicelo Ext 5	10715
	Emfuleni	Sharpville, Sebokeng zone 24 , Sebokeng zone 17	6730
	Kungwini	Rehabiseng, Schietpoort	2625
Municipal standpipes > 200 m	Randfontein	Manganese, Zanzele	9100
	Nokeng	Refilwe - Treatment Works, Roodeplaat Plot 175	11270
	Mogale City	Rietfontein Village, Rietfontein Plot 63, Rietfontein Plot 163 (10%)	57374
		Van Wyk Restant Plot 59, Pongoville, Tudor & Soul City, Radikgmo	
		Vlakplaats Plot 6, West Village	
	Iesedi	Ratanda ext 4c, Ratanda ext 4d, Ratanda ext 4e, kwazenzele settlement	5750
	Midvaal	Driefontein farm	1250
	Emfuleni	Thepisong Taxi Rank, Soul CitySoul City, Quaggafontein (Bioketlong)	26800
		Sonderwater, Iron side industrial, Sebokeng zone 7 Ext 1, Sebokeng zone 7	
		Marakong, Capegate, Polomiet, Winnies Park, Butchery Vaal Oewer	
		Barrage, New village	
Municipal yard taps	Iesedi	Sepiwe/Floracadia, Kwazenzele	1475
	Emfuleni	Sebokeng zone 21, Garage	3175
	Kungwini	Zithobeni	27825
Municipal stand connections	Westonarea	Zuurbekom	50
	Randfontein	Elandsvlei Ptn 74	500
	Midvaal	Bantubonke	950
	Emfuleni	Olg Vereeniging	1500
	TOTAL		**310911**

Table 3.4 Wastewater Management/Sanitation Indicators for Informal Settlements/Communities

CLASSIFICATION	MUNICIPALITY	SETTLEMENTS	POPULATION
No formal facility	Randfontein	Manganese, Middelvlei Station, Groenplaas Withuise, Bosswinkel	725
	West Rand District	Swartkrans 172 IQ Ptn 55	180
	Mogale City	Nooitgedaght Plot 42, Nooitgedaght Plot 91, Swartkops Plot 55, Van Wyks Restant Ptn 2, Lindley Ptn 31	823
	Lesedi	Ratanda ext 4b, ext 4d, ext 4e	950
	Midvaal	Aloe Ridge Quarry, Portion 51 De Deur	120
	Emfuleni	Mapolankeng, Marakong	225
	Kungwini	Wolvekop '2'	5
Pitlatrines	Westonarea	Thusanang 'B', Zuurbekom (90%), Glenharvey-Steruteru, Waterworks (80%)	3745
	Randfontein	Fourways, Scrapyard, Zanzele, Boipei, Siyahlala '2', Elandsvlei Ptn 136, Dumping Site	12645
	West Rand District	Sterkfontein 173 IQ Ptn 19, Kromdraai 520 IQ Ptn 5, Kromdraai 520 IQ Ptn 6, Kromdraai 52 IQ Ptn 26, Rietfontein 189 IQ Ptn 318	620
	Nokeng	Refilwe - Treatment Works, Refilwe - Cemetry, Refilwe - Municipal Offices, Refilwe - Municipal Park, Dewagensdrift (80%), Onverwacght (80%), Roodeplaat (Leeufontein) (90%), Rust De Winter	13461
	Mogale City	Nooitgedaght Plot 77, Rietfontein Village, Joe Slovo, Lindley Plot 63, Zwartkops Plot 525, Rietfontein Plot 163, Driefontein Plot 71, Pongoville, Van Wyk Restant Plot 59, Radikgmo, Tsakane, Smoke Down, Tshama Hantse, Driefontein Ptn 47, Zwartkops Ptn 54, Buya Africa (80%), Nooitgedaght Plot 89 (80%), Rietpoort (80%)	64243
Pitlatrines	Lesedi	Kwazenzele informal, Ratanda ext 4a & ext 4c, Impumelelo (90%), Kwazenzele settlement (90%)	10200
	Midvaal	Kudung (Soetvelde), Mamelo (Vaal Merina), Kudung (Bloekomspruit), Bantubonke, Makakong, Sporong, Lekakeng, Nelsonia, Haroldsfarm, Kromdraai farm, Driefontein farm, Waterval farm, Keyalitsha, Brakfontein (80%), Biotomelo (80%), Cross str De Deur, Sicelo Ext 5	17097
	Emfuleni	Sharpville, Thepisong Taxi Rank, Soul City, Quaggafontein (Bioketlong), Sonderwater, Sebokeng zone 24; Sebokeng zone 21, Sebokeng zone 7, Sebokeng zone 7 Ext 1, Sebokeng zone 17, Garage, Iron Side industrial, Magusheng, Capegate, Polomiet, Winnies Park, Barrage, Butchery New village	36675
	Kungwini	Rehabiseng, Zithobeni ext 8; behind stadium; behind hostel & ext 3, Nooitgedaght, Witpoort, Blesbokfontein, Sokhulumi, Schietpoort, Rietfontein '1'; '2', '3', Rietfontein '4', Zusterstroom, Valchspruit, Sehlkwane, Wolvekop '1', Zorgvleit '1', Zorgvleit '2'	36270
Chemical toilets	Nokeng	Roodeplaat Plot 175, Dewagensdrift (20%), Onverwacght (20%), Donkerhoek, Roodeplaat - RDP Offices, Roodeplaat (Derdepoort 65), Roodeplaat (Leeufontein) (10%), Phumzile (Old waste dump)	7559
	Mogale City	Rietfontein Plot 81, West Village	2160
	Kungwini	Sterkfontein, Swavelpoort, Donkerhoek, Kanana (Kameelzynkraal), Kleinzonderhout, Schietpoort	8510
VIP's	Westonarea	Bekkersdal, Thusanang 'A', Waterworks (20%)	68900
	West Rand District	Renosterspruit 495 IQ Ptn 72, Mooiplaats 524 IQ Ptn 2	265
	Mogale City	Rietfontein Plot 63, Nooitgedaght Plot 38, Orient Hills, Toad Tree Farm, Kombi, Hapers Café, Hekpoort, Mpandiene, Boikarabelo, Vlakplaats Plot 6, Nooitgedaght Plot 89 (20%), Buya Africa (20%), Rietpoort (20%)	9420
	Lesedi	Sepiwe (Floracadia), Impumelelo (10%), Kwazenzele settlement (10%)	1825
	Midvaal	Dusting, Brakfontein, Skansdam, Biotomelo (10%)	343
Composting toilets	Mogale City	Tswelopele	1000
	Kungwini	Kleinzonderhout	15
Aqua privies & variantions	Westonarea	Zuurbekom (10%)	5
Septic tanks			
	Randfontein	Jabulani-Drowell, Siyahlala '1', Elandsvlei Ptn 74	1425
Full Waterborne	Mogale City	Tudor & Soul City (Toilet ablusions blocks)	10000
	Emfuleni	Old Vereeniging Hospital	1500
		TOTAL	**310911**

Table 3.5 Summary of the Housing Department Plans with Respect to Informal Settlements

MUNICIPALITY	SETTLEMENTS	POPULATION	HOUSING STRATEGY
Westonarea	Thusanang 'A'	3500	**FORMALIZATION**
West Rand District	Kromdraai 52 IQ Ptn 26	230	
Nokeng	Roodeplaat Plot 175, Dewagensdrift, Onverwacght	7220	
Mogale City	Pongoville, Tudor & Soul City, Orient Hills, Toad Tree Farm, Vlakplaats Plot 6	30725	
Lesedi	Kwazenzele formal	1200	
Emfuleni	Sonderwater, Quaggafontein (Bioketlong), Sebokeng zone 21, Garage, Sebokeng zone 7 Ext 1, New village	18930	
Kungwini	Rehabiseng, Zithobeni ext 8; behind stadium, behind hostel & ext 3, Roodepoort, Sohulumi	35275	
Westonarea	Bekkersdal, Waterworks, Thusanang 'B', Zuurbekom, Glenharvey-Steruteru	69150	**RELOCATION**
Randfontein	Fourways, Manganese, Scrapyard, Zanzele, MiddelMei Station, Jabulani-Drowell, Boipei, Siyahlala '2', Siyahlala '1', Groenplaas Withuise, Bosswinkel, Elandsvlei Ptn 136, Elandsvlei Ptn 74, Dumping Site	14795	
West Rand District	Swartkrans 172 IQ Ptn 55, Kromdraai 520 IQ Ptn 5, Kromdraai 520 IQ Ptn 6, Rietfontein 189 IQ Ptn 318, Renosterspruit 495 IQ Ptn 72, Mooiplaats IQ Ptn 2	750	
Nokeng	Refilwe - Treatment Works, Refilwe - Cemetry, Refilwe - Municipal Offices, Refilwe - Municipal Park, Roodeplaat - RDP Offices, Donkerhoek, Roodeplaat (Derdepoort 65), Phumzile (Old waste dump)	13425	
Mogale City	Nooitgedaght Plot 77, Nooitgedaght Plot 42, Nooitgedaght Plot 91, Rietfontein Village, Joe Slovo, Lindley Plot 63, Swartkops Plot 525, Rietfontein Plot 163, Swartkops Plot 55, Driefontein Plot 71, Buya Africa, Van Wyk Restant Plot 59, Rietpoort, Kombi, Hekpoort, Mpandiene, Boikarabelo, Tsakane, Smoke Down, Tshama Hantse, West Village, Van Wyks Restant Ptn 2, Driefontein Ptn 47, Zwartkops Ptn 54, Lindley Ptn 31, Tswelopele	39636	
Lesedi	Sepiwe/Floracadia, Ratanda ext 4a, ext 4b, ext 4c, ext 4d, ext 4e; Impumelelo, Kwazenzele settlement	11775	
Midvaal	Mamelo (Vaal Merina), Kudung (Bloekomspruit), Kudung (Soetvelde), Bantubonke, Makakong, Sporong, Lekakeng, Nelsonia, Haroldsfarm, Kromdraai farm, Driefontein farm, Waterval farm, Keyalitsha, Dusting, Brakfontein, Skansdam, Biotomelo, Aloe Ridge Quarry, Portion 51 De Deur, Cross str De Deur, Sicelo Ext 5	17560	
Emfuleni	Old Vereeniging Hospital, Sharpville, Thepisong Taxi Rank, Soul City, Sebokeng zone 24, Iron side industrial, Sebokeng zone 7, Sebokeng Zone 17, Magusheng, Mapolankeng, Marakong, Cape Gate, Polomiet, Winnies Park, Barrage, Butchery (Vaal Oewer)	19470	
Kungwini	Sterkfontein, Swavelpoort, Donkerhoek, Kanana (Kameelzynkraal), Kleinzonderhout, Nooitgedaght, Witpoort, Blesbokfontein,	8200	
West Rand District	Sterkfontein 173 IQ Ptn 19	85	**NOT CLASSIFIED**
Nokeng	Rust De Winter, Roodeplaat (Leeufontein)	375	
Mogale City	Nooitgedaght Plot 89, Rietfontein Plot 81, Rietfontein Plot 63, Radikgmo, Nooitgedaght Plot 38, Hapers Café	17285	
Kungwini	Wagenbietjieskop, Schietpoort, Rietfontein '1', Rietfontein '2', Rietfontein '3', Rietfontein '4', Zusterstroom, Valchspruit, Sehlkwane, Wolvekop '1', Wolvekop '2', Zorgvleit '1', Zorgvleit '2'	1325	
	TOTAL	**310911**	

3.3.1 Summary of the Status Quo Analysis of the Study Area

Two distinct situations characterise wastewater management/sanitation services in the study area:

1. Formal settlements generally serviced full water supply and house connections accompanied by centralised sewerage collection and wastewater treatment facilities. The wastewater treatment facilities are based on secondary or advanced secondary biological wastewater treatment technologies and discharge their effluents to local recipients.

2. Informal settlements characterised with typically inadequate water supply services and rudimentary sanitation services, with the few exceptions, not connected to any wastewater treatment facilities as shown in the typical pictures in Appendix A.

For the first group of settlements, respective municipalities own and operate multiple wastewater treatment plants. The relevant information collected as a part of this project for each of these treatment plants is summarised in Tables 3.6 to 3.13 for each municipality in which wastewater treatment plants exist and are operational.

Table 3.6 Wastewater Treatment Plant Indicators for Emfuleni

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed							Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge		
			Function	C or NC								Parameter	C or NC	
Rietspruit												pH	C	
	(Plant office)	Class A	Supervision	NC	25 ML/d	43 ML/d	Screening	No	Sedimentation	Activated sludge/	Drying beds	SS	NC	None
	26° 41' 37" S		Operators	NC		(overloaded)	Grit removal			clarification	Stockpile to	NO2 & NO3	C	
	27° 45' 41" E		O & M	C						Biofilters/	landfill	COD	NC	
			OH & S	2/10						humus tanks		NH4	C	
										Cholorination		PO4	no record	Rietspruit &
												FC's	NC	Vaal dam (pipeline)
Leeuwkuil												pH	C	
	(Chlorination	Class A	Supervision	NC	24 ML/d	13 ML/d	Screening	No	Sedimentation	Activated sludge/	Wet sludge	SS	NC	None
	contact tank)		Operators	NC		(spare cap)	Grit removal			clarification	to land	NO2 & NO3	C	
	26° 40' 27" S		O & M	C						Biofilters/		COD	NC	
	27° 50' 46" E		OH & S	2/10						humus tanks		NH4	C	
										Cholorination		PO4	NC	Vaal river
										Maturation pond		FC's	C	
Sebokeng												pH	C	
	(Chlorination	Class A	Supervision	NC	100 ML/d	110-150 ML/d	Screening	Balancing tank	No	Activated sludge/	Anaerobic	SS	C	None
	contact tank)		Operators	NC		(overloaded)	Grit removal	(not operational)		clarification	digestors	NO2 & NO3	NC	(equipment avail)
	26° 40' 27" S		O & M	C						Chlorination	Wet sludge	COD	C	
	27° 50' 46" E		OH & S	2/10							to land	NH4	C	
											(Biogas capture	PO4	C	
											& power	FC's	NC	Rietspruit
											generation -			
											not operational)			

Table 3.7 Wastewater Treatment Plant Indicators for Westonarea

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed							Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge		
			Function	C or NC								Parameter	C or NC	
Hennie v Niekerk										**Module1:**		pH	no record	
	(Inletworks-	Class B	Supervision	C	26,5 ML/d	17 ML/d	Screening	No	Sedimentation	Activated sludge	Anaerobic	SS	no record	Partial
(Westonarea)	Module 1)		Operators	NC		(spare cap)	Grit removal		(Module 1)	(orbal ditch)/	digesters x 3	NO2 & NO3	C	Irrigation of
	26° 18' 43" S		O & M	C						clarification	Humus tanks	COD	C	golf course
	27° 36' 44" E		OH & S	4/10						**Module 2:**	Sludge dams	NH4	no record	
										Activated sludge/	Sludge drying	PO4	no record	Wonderfontein
										clarification	pans	FC's	C	spruit (via
										Chlorination	Sludge disposal			pipeline)
										Maturation pond	to landfill			

Note: NC and C indicates non compliance and compliance respectively with the requirements and or operation of the treatment facility

Table 3.8 Wastewater Treatment Plant Indicators for Kungwini

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed						Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification & polishing	Sludge treatment & disposal	Final effluent discharge	
			Function	C or NC								Parameter / C or NC	
Godrich												pH C	
	(Inletworks)	Class C	Supervision	NC	5 ML/d	4 ML/d	Screening	No	No	Activated	Waste sludge	SS C	None
	25° 47' 53" S		Operators	NC			Grit channels			sludge /	to land	NO2 & NO3 C	
	28° 46' 54" E		O & M	C						clarification		COD C	Bronkhorst-
			OH & S	3/10								NH4 C	spruit
										maturation pond		PO4 NC	
												FC's no record	
Rethabiseng												pH C	
	(Inletworks)	Class E	Supervision	NC	1,5 ML/d	1,0 ML/d	Screening	No	Storage tank	Stabilization	Anaerobic pond	SS C	None
	25° 43' 12" S		Operators	NC			Grit channels			ponds (AN & Fac)	periodic	NO2 & NO3 NC	
	28° 43' 49" E		O & M	C						Maturation pond	clean-out	COD C	
2			OH & S	3/10								NH4 NC	Spruit
												PO4 C	
												FC's no record	
Ekangala												pH C	
	(Inletworks)	Class C	Supervision	NC	2 ML/d	2,5 ML/d	Screening	No	No	Stabilization	Anaerobic pond	SS no record	Some
	25° 40' 53" S		Operators	NC			Grit channels			ponds (AN & Fac)	periodic	NO2 & NO3 no record	channel irrigation
	28° 44' 53" E		O & M	C						Maturation pond	clean-out	COD C	
			OH & S	3/10								NH4 no record	Bronkhorst-
												PO4 no record	spruit
												FC's C	

Table 3.9 Wastewater Treatment Plant Indicators for Lesedi

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed						Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge	
			Function	C or NC								Parameter / C or NC	
Devon												pH C	
	(Inlet works)	Class C	Supervision		1,43 ML/d	1,5 ML/d	Screening	No	No	Activated	Drying beds	SS C	None
(ERWAT)	26° 20' 44" S		Operators	No		(at capacity)	Grit channels			sludge /	Stockpile &	NO2 & NO3 no record	
	28° 44' 40" E		O & M	info						clarification	dispose to	COD C	Spruit
			OH & S							Chlorination	landfill	NH4 C	
												PO4 C	
												FC's no record	
Heidelberg												pH C	
	(Inlet works)	Class A	Supervision	C	5 ML/d	7 ML/d	Pumped outfall	No	Sedimentat	Activated	Drying beds	SS C	None
(Lesedi - ERWAT)	26° 32' 21" S		Operators	NC		(overloaded)	Screening			sludge /	Stockpile &	NO2 & NO3 C	
	28° 19' 48" E		O & M	C			Grit removal			clarification	dispose to	COD C	
			OH & S	10/10						Chlorination	landfill	NH4 NC	
												PO4 C	Suikerbosrant
												FC's C	spruit
Ratanda												pH C	
	(Inlet works)	Class A	Supervision	C	5 ML/d	2,3 ML/d	Screening	No	Sedimentat	Activated	Drying beds	SS C	None
(ERWAT)	26° 34' 55" S		Operators	NC		(spare cap)	Grit removal			sludge /	Stockpile &	NO2 & NO3 NC	
	28° 18' 13" E		O & M	C						clarification	dispose to	COD C	
			OH & S	10/10						Chlorination	landfill	NH4 C	
										Maturation pond		PO4 C	Suikerbosrant
												FC's C	spruit

Note: NC and C indicates non compliance and compliance respectively with the requirements and or operation of the treatment facility

Table 3.10 Wastewater Treatment Plant Indicators for Midvaal

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed						Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge	
			Function	C or NC								Parameter / C or NC	
Vaal Marina												pH / no record	
	(Aeration/	Class E	Supervision	NC	2 ML/d	2,0 ML/d	Screening	balancing tank	No	Activated sludge	Sludge ponds	SS / NC	None
(Midvaal - Vaal Marin	clarifier tank)		Operators	C		(in season-	Grit removal			(diffused air)/	Stockpile &	NO2 & NO3 / NC	
Construction)	26° 06' 38" S		O & M	C		at capacity)				clarification	composting	COD / C	
	27° 51' 28" E		OH & S	3/10						Reedbeds		NH4 / NC	
										Cholorination		PO4 / NC	
										Maturation pond		FC's / no record	Vaal dam
Meyerton												pH / C	
	(at 2ML/d	Class B	Supervision	NC	10 ML/d	10 ML/d	Screening	Balancing tank	Sedimentation	Activated	Sludge ponds	SS / NC	None
(Midvaal)	Inletworks)		Operators	NC	(upgraded		Grit removal	(8ML/d module)	(8ML/d module)	sludge /	Drying beds	NO2 & NO3 / C	
	26° 35' 01" S		O & M	C	capacity =					(2ML/d + 8ML/d	dispose to	COD / NC	
	27° 58' 16" E		OH & S	3/10	8ML + 2 ML					modules)	landfill	NH4 / NC	
					modules)					clarification		PO4 / C	Klip rivier
										Chlorination		FC's / NC	
Oheni Muri												pH / no record	
Treatment works	(Effluent	Class E	Supervision	C	1 ML/d	> 1 ML/d	Screening	Balancing tank	No	SBR (2 x reactors	Waste sludge	SS / NC	Partial
(Midvaal - Gelert cc)	storage tank)		Operators	C		(at capacity)	Grit removal			Activated	to drying beds	NO2 & NO3 / NC	
	26° 26' 49" S		O & M	C						sludge/	Disposal to	COD / C	Irrigation to
	27° 57' 01" E		OH & S	3/10						Effluent storage	landfill	NH4 / no record	golf course
										Chlorination		PO4 / C	
												FC's / no record	Klip rivier

Table 3.11 Wastewater Treatment Plant Indicators for Mogale City

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed						Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge	
			Function	C or NC								Parameter / C or NC	
Magalies												pH / C	
	(access rd)	Class E	Supervision	NC	1,10 ML/d	0,35 ML/d	Screening	No	No	Activated sludge/	Waste sludge	SS / C	None
	25° 59' 30" S		Operators	C			Grit removal			clarification	storage dam	NO2 & NO3 / NC	
	27° 32' 24" E		O & M	C						Reedbeds	Sludge disposal	COD / NC	
			OH & S	8/10						Cholorination	to landfill	NH4 / C	
												PO4 / NC	
												FC's / no record	Magalies river
Percy Stewart							**Pretreat mod:**			**Main treatment**		pH / C	
	(Inletworks)	Class A	Supervision	NC	27 ML/d	27 ML/d	Screening	Balancing tank	Sedimentation	**module:**	**Sludge disposal**	SS / NC	None
	26° 04' 35" S		Operators	C	(structural		Grit removal	(Pretreat mod)	(Pretreat mod	Activated sludge/	**to irrigation**	NO2 & NO3 / C	
	27° 43' 47" E		O & M	C	failure reduce				& Main treatm	clarifier	**instant lawn**	COD / NC	
			OH & S	8/10	to 18 ML/d)		**Main treat mod:**		module)	Waste S flocculator	Anaerobic	NH4 / NC	
							Screening			Biofilters/	digestors	PO4 / NC	Blougat spruit/
							Grit removal			Aeration basin	(not operational)	FC's / NC	Hartebeespoort
										Humus tanks			dam
										Chlorination			
Flip Human												pH / C	
	(Inletworks)	Class A	Supervision	C	50 ML/d	22 ML/d	Screening	No	Sedimentation	Activated sludge/	**Sludge disposal**	SS / NC	None
	26° 11' 01" S		Operators	C		(spare cap)	Grit removal			clarification	**to irrigation**	NO2 & NO3 / C	
	27° 46' 31" E		O & M	C						Chlorination	**instant lawn**	COD / NC	
			OH & S	8/10						Maturation pond	Anaerobic	NH4 / C	
											digestors/	PO4 / C	
											thickeners	FC's / no record	Wonderfontein
											(not operational)		spruit

Table 3.12 Wastewater Treatment Plant Indicators for Nokeng Tsa Taemane

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed							Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge		
			Function	C or NC								Parameter	C or NC	
Refilwe -												pH	C	
	(inlet works)	Class C	Supervision	C	1,15 ML/d	1,4 ML/d	Screening	No	No	Activated	Drying beds	SS	C	None
(Nokeng - WSSA)	25° 38' 53" S		Operators	C		(overloaded)	Grit channels			sludge /	Stockpile &	NO2 & NO3	C	
	28° 32' 12" E		O & M	C						clarification	dispose to	COD	NC	Elands river
			OH & S	3/10							landfill	NH4	C	
												PO4	no record	
												FC's	C	
Rayton -												pH	C	
	(inlet works)	Class C	Supervision	C	0,6 ML/d	0,65 ML/d	Screening	No	No	Activated	Drying beds	SS	NC	Yes
(Nokeng - WSSA)	25° 44' 08" S		Operators	NC		(overloaded)	Grit channels			sludge /	Stockpile &	NO2 & NO3	C	Dam for
	28° 32' 51" E		O & M	C						clarification	dispose to	COD	NC	irrigation
			OH & S	3/10							landfill	NH4	C	
												PO4	no record	Bronkhorstspruit
												FC's	C	
Pebble Rock -												pH	C	
	(Splitterbox	Class E	Supervision		0,45 ML/d	0,1 ML/d	Splitter box	No	Settlement	RBC units	No	SS	no record	Yes
(Pebble Rock	settlement		Operators	No		(spare cap)			tanks x 2	(2 x 3 bank rotors)	Removal by	NO2 & NO3	no record	
Homeowners	tanks)		O & M	info						Settler	tanker to	COD	C	Dam for
Association)	25° 36' 17" S		OH & S							Maturation pond	WWTP	NH4	no record	irrigation of
	28° 23' 13" E											PO4	no record	golf course
												FC's	C	

Table 3.13 Wastewater Treatment Plant Indicators for Randfontein

Wastewater Treatment Plant (Owner - operator)	Location (GPS coordinates)	NWA 1998 DWAF Reg Class of Works	Operational skills compliance		Capacity parameters		Unit processes employed							Effluent recycle / re-use (watercourse discharge)
					Design capacity	Operating capacity	Preliminary treatment	Balancing	Primary treatment	Biological / clarification	Sludge treatment & disposal	Final effluent discharge		
			Function	C or NC								Parameter	C or NC	
Randfontein												pH	C	
	(Inletworks)	Class B	Supervision	C	20 ML/d	12 ML/d	Screening	No	Sedimentation	Activated sludge/	Primary sludge	SS	C	Partial
(Randfontein - Enviro	26° 08' 29" S		Operators	C		(spare cap)	Grit removal			clarification	thickening	NO2 & NO3	C	Dust suppression
Metzi Pty Ltd)	27° 40' 55" E		O & M	C						Biofilters/	Sludge disposal	COD	NC	of mine dumps
			OH & S	5/10						humus tanks	to land	NH4	C	
										(not operational)	(Anaerobic	PO4	C	Elandsvlei /
										Cholorination	digestors not	FC's	C	Hartebeespoort
											operational)			dam

It is noted that none of the treatment plants meet the regulatory requirements with respect to all the required parameters. The non compliance is most often related to the effluent quality which is violated or due to the insufficient data or to the deficiency in the skills base required to operate the treatment plant (human resource problem). It is also interesting to note that at the time of the investigatory part of the project, there was a serious treatment capacity deficiency in Emfuleni Local Municipality and a

relatively small deficiency in Midvaal Local Municipality and Nokeng Tsa Taemane Local Municipality. Other municipalities with the exception of Nokeng Tsa Taemane Local Municipality still have spare wastewater treatment capacity (Table 3.14). There are twenty wastewater treatment plants in the study areas and out of these eight plants operated significantly above design capacity and three plants operated at full capacity. For all of these plants, effluent quality violations were a common occurrence. Typical pictures of the wastewater treatment plants are shown in Appendix B.

Table 3.14 Summary information on wastewater treatment capacity in the study area

Municipality	Treatment Plant	Design Capacity ML/day	Operating Capacity ML/day	Overloaded Capacity ML/day	Unutilised Capacity ML/day	Municipal level WWTP Capacity Available (+) or Shortfall (-) Ml/day
Emfuleni	Rietspruit	25	43	18		
	Leeukuil	24	13		11	-42
	Sebokeng	100	135	35		
Kungwini	Godrich	5	4		1	
	Rethabiseng	1,5	1		0,5	1
	Ekangala	2	2,5	0,5		
Lesedi	Devon	1,4	1,5	0,1		
	Heidelberg	5	7	2		0,6
	Ratanda	5	2,3		2,7	
Midvaal	Vaal Marina	2	2			
	Meyerton	10	10			-1,1
	Oheni Muri	1	2,1	1,1		
Mogale City	Magalies	1,1	0,4		0,8	
	Percy Stewart	27	27			28,8
	Flip Human	50	22		28	
Nokeng	Refilwe	1,2	1,4	0,3		
	Rayton	0,6	0,7	0,1		-0.4 (0)*
	Pebble Rock (private)	0,5	0,1		0,4	
Randfontein	Randfontein	20	12		8	8
Westonarea	Hennie v Niekerk	26,5	17		9,5	9,5

** Assuming owners of private plant are prepared to receive sewage from elsewhere in Nokeng*

In the case of informal settlements the current situation shows that less than 1 % of the total population living in informal settlements at the time of the study had no sanitation services at all. However 63 % of the informal population had some kind of pit latrines and 26 % was served with VIP toilets. The majority of the pit latrines were in a sorry state and not operating properly. The summary of findings for the sanitation in informal settlements is shown in Fig 3.4

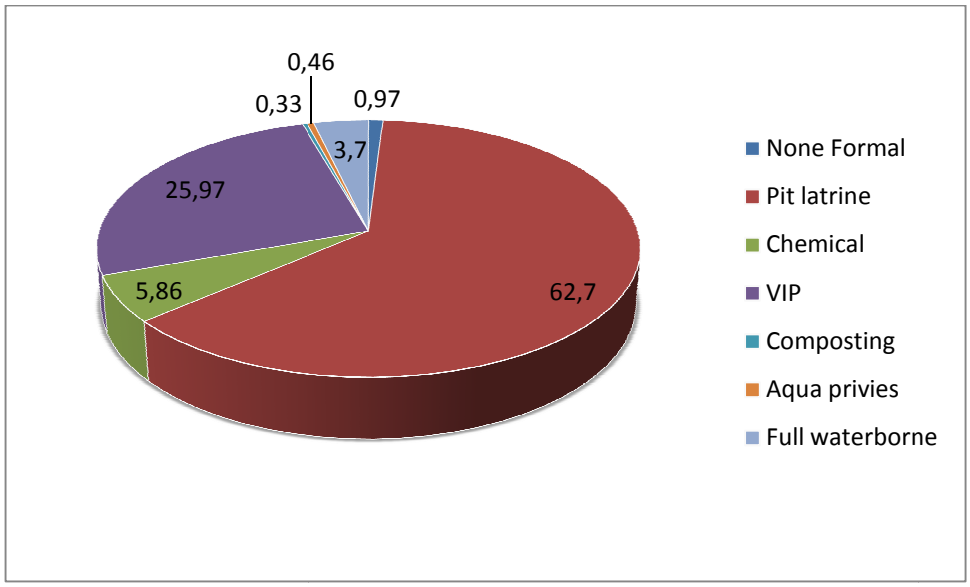


Figure 3.4 Sanitation Percentage Coverage in Informal Settlements

A major factor determining the current choice of sanitation in the informal settlements in the study area is the level of available water supply (Fig 3.5). It is noted that over 50% of the population in the study area had water supply services below the recommended minimum by the RDP standards (< than 25 l/c/d) and only 12 % of the population receives water either as a yard or stand connection. The situation might have changed subsequently after the investigatory part of this study, since projects aimed at reducing water service backlogs began to be implemented shortly thereafter.

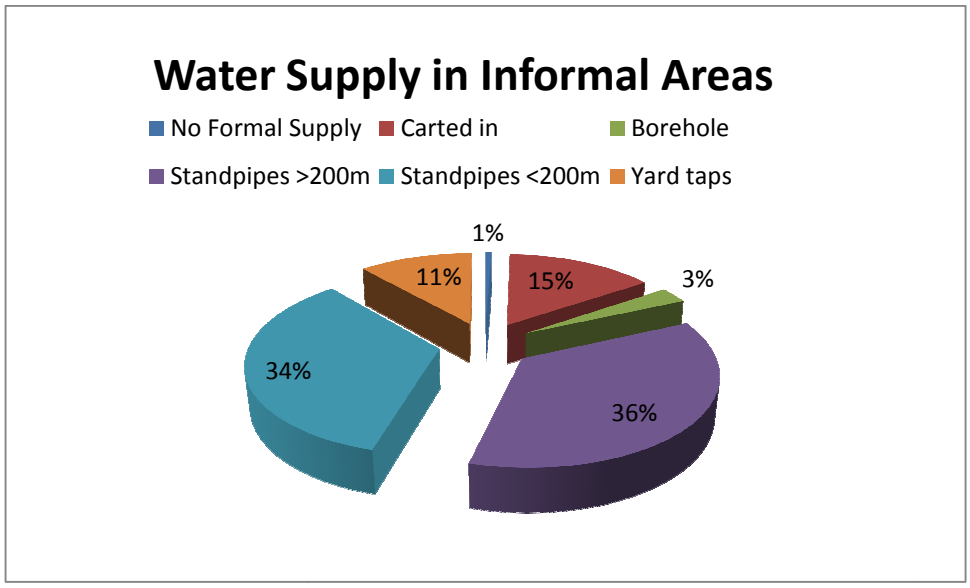


Figure 3.5 Water Supply in Informal Areas

One remaining factor that is of importance to this project is the management of water provision and sanitation services in settlements on top of dolomitic formations. In such cases the provision of water services and waste management/sanitation services becomes technically complex and economically expensive. A priority option is to consider resettling the community to non-dolomitic areas. Formalisation of settlements in dolomite areas can be achieved but in practice tends to prove prohibitively expensive, if all the necessary protective technical measures are to be implemented. However, a current subsoil risk level assessment using detailed geological investigations would have to be done before a major decisive action is taken. In cases where settlements are on top of dolomites and the people cannot be relocated, then special protective measures such as double piping and sealed water leakage proof systems should always be installed for both water supply and wastewater management/sanitation provision.

3. 4 Legal, Institutional and Planning Policy Frameworks

This section systematically reviews the National and Gauteng Provincial systems of Institutional, Legal, Policy and Planning Frameworks. Gauteng Province is the study

area of importance to this research. South Africa, as a water scarce country, has over the years developed a very progressive comprehensive policy and legislative framework to manage its limited water resources, which includes a constitutional right to water and a national Free Basic Water policy. Furthermore, since 1994 a major legislative and policy reform with respect to water and democratic governance has occurred and is founded in the New Constitution of South Africa (Department of Water Affairs & Forestry (DWAF), 2004). In 2010 DWAF was renamed Department of Water Affairs (DWA).

The rapid policy and legislative change that has occurred has also induced significant demand on the limited human and other resources that could be deployed to the implementation of the new policy and legislative framework needed to achieve the desired transformation. There has been a continual search for excellence leading to re-examination of certain policy and legislative aspects over the last 5 years. Despite the apparent problems encountered during its effective implementation the fundamentals of the National Policy and Legislation remain intact and can be viewed as progressive and modern by international standards. Within this framework, water is conceived of, as a social good and vital part of the broader development project.

3.4.1 Policy and Legal Framework

The experience of South Africa makes the point that the last chapter in policy development is never written. Policy is dynamic - it reflects the changing priorities of society and the government and the challenges posed by complex and rapidly changing systems (Pollard and Du Toit, 2008). Marjanovic *et al.* (2011) reveal that South Africa's National Water Act and policy documents such as the National Water Resource Strategy are examples of policies that reflect integrated systems thinking and provide for the development of a holistic understanding which is strategic and adaptive. Sustainability and equity are the principles firmly embedded through an

integrated systems approach. Since 1994 the new water policy was developed with special attention given to the process of defining and adopting it. One of the facets of that policy making process is the concentration on public participation. Elements of the policy and regulatory framework are shown in Figure 3.6.

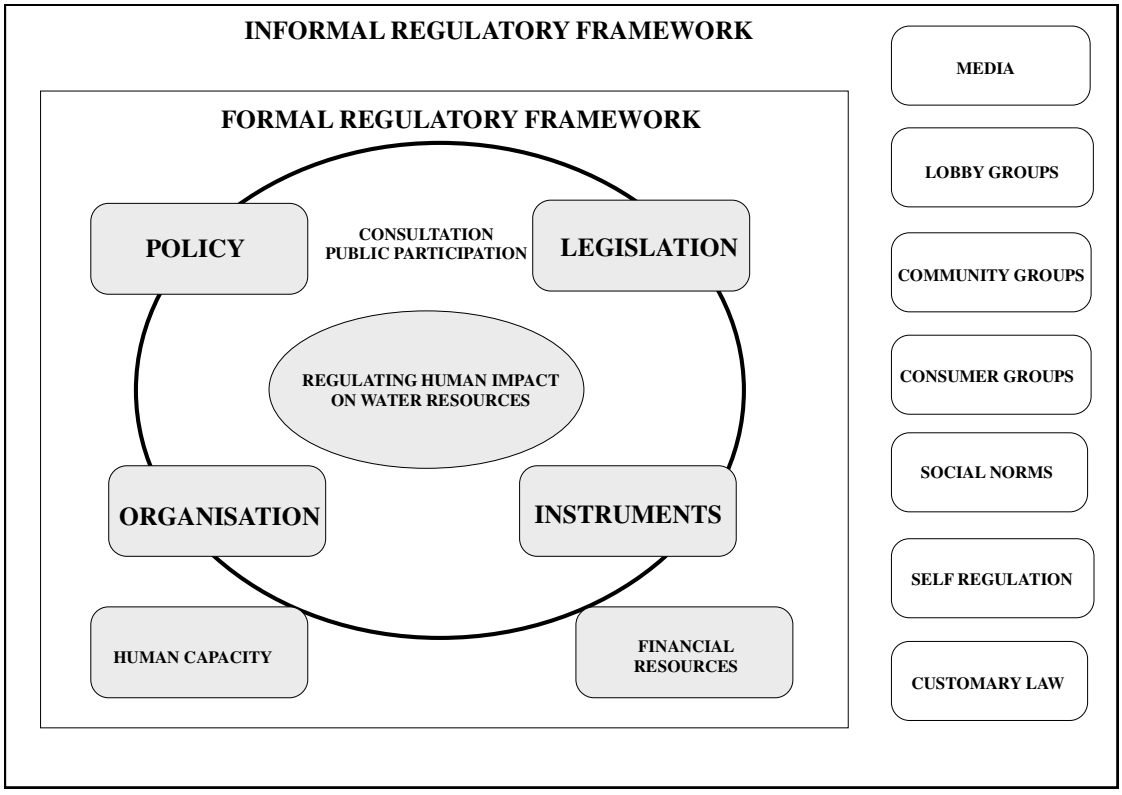


Figure 3.6 Elements of Water Resources Regulatory Framework (Modified from Picciotto *et al*., 2002)

One of the main and distinctive characteristics of the policy and legislative framework in South Africa is that it distinguishes and clearly separates policy and legislation into two main domains: water resources domain (resource management and protection) and water services domain (water services provision and management) while leaving policy and regulation of both domains within the one Department (Department of Water Affairs). Such a distinction is a common practice in many countries but in most of the cases, the policy and regulation of the two domains are located in different departments. International research carried out in the development of a draft integrated strategy for

water regulation shows that water resources regulation is typically dealt with by environmental departments or agencies while water services regulation is often dealt with by an independent regulator, or a range of departments often at local or provincial/state level. For example, in Zambia, water services are regulated by the National Water Supply and Sanitation Council (NWASCO), which regulates urban water supply and sanitation service provision, while water resources regulation falls under the Department of Energy and Water Development. Similarly, in Ghana, the Public Utilities Regulatory Commission is responsible for economic regulation of urban water supply and sanitation, while the Water Resources Commission regulates water resources. The clear distinction and separation of the two domains allows for avoidance of inherent conflicts of interest between water resources protection and water utilization to meet the human needs. Table 3.15 summarises the policy and legislative differentiation between water resources and water services sectors in South Africa

Table 3.15 Policy and Legislative Distinction between Water Resources and Water Services

FIELD	Water Resources	Water Services
Policy framework and legislation	Constitution and the Bill of Rights, White Paper on National Water Policy for South Africa, National Water Act, National Water Resources Strategy	Constitution and the Bill of Rights, Strategic Framework for Water Services, Water Services Act, Water Services Regulatory Strategy
Economic regulation	Raw water pricing	Treated water pricing including free basic water
Technical regulation	Abstraction, discharge, storage including dam safety, ecological and basic human needs reserve, water allocation, etc.	Drinking water quality, access to services, reliability of supply, minimum standards, effluent removal and treatment, discharge quality
Governance regulation	Department of Water Affairs, Catchment Management Agencies, Water User Associations	Water Boards, Water Services Authorities, Water Service Providers
Compliance monitoring and enforcement	Directives, Courts, ability to take action and reclaim costs	Cooperative governance, Directives, Courts as a last resort

3.4.2 White Paper on Water Supply and Sanitation

The White Paper on Water Supply and Sanitation published in November 1994 was the starting point in the development of a new of water policy in South Africa. The principles around which the policy was based are:

- Demand driven and community based development
- Basic services as a human right
- "Some for all" rather than "all for some"
- Equitable regional allocation of development resources
- Water has economic value
- The user pays principle
- Integrated development.
- Environmental integrity.

The White Paper on Water Supply and Sanitation was the foundation for further policy and legislative development that resulted in current Policy and Legislative Framework for the management of the water sector in South Africa (Figure 3.7).

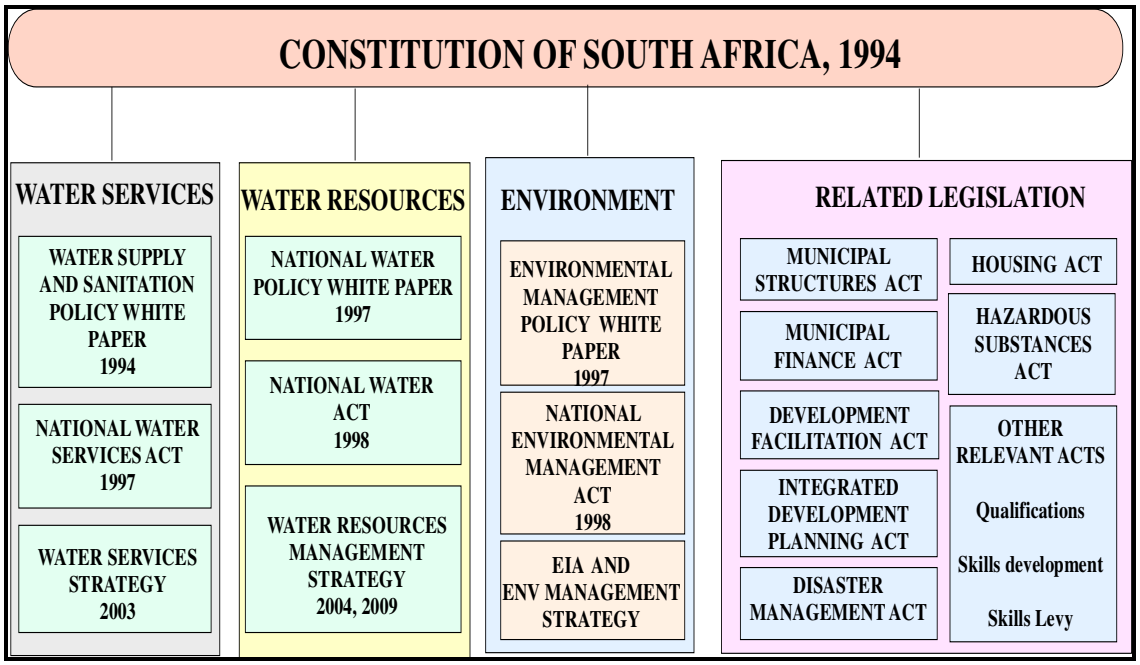


Figure 3.7 Water Resources Management Policy and Legal Framework (Marjanovic *et al.* 2011)

The two main acts of paramount importance in this research are;

National Water Act, No. 36 of 1998: The objective of the Act is to ensure that South Africa's water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons. The Act provides that the National Government, as the public trustee of the nation's water resources and acting through the Minister of Water Affairs, has the power to regulate the use, flow and control of all water in the Republic.

Water Services Act, No. 108 of 1997: The objective of the Act is to provide for the rights of access to basic water supply and basic sanitation by setting national standards and norms. Section 156 of the Act vests the executive authority and responsibility to support and strengthen the capacity of municipalities to manage their own affairs, to exercise their powers and to perform their functions to the state. The state also has the authority to see to the effective performance by municipalities of their functions, by regulating the exercise by municipalities of their executive authority. The Water Services Act gives substance to constitutional requirements.

According to the above Acts, the Department of Water Affairs is the leader of the water sector. It currently performs both implementation and regulatory functions. Its focus is increasingly becoming policy development, macro planning, regulation, sector leadership, oversight and monitoring. A substantial number of its current implementation functions are being transferred to other institutions within the sectors. The sectors' players have an important role to play in meeting the sectoral targets, with Department of Water Affairs playing a leadership and regulatory role to ensure that Government objectives are met. In many parts of the world Governments are ceasing to be providers of services. Instead they focus on initiating, stimulating and facilitating, on enabling policy environment in which various institutional levels can function most effectively (WHO/UNICEF, 2000). There are many different players

in water resources protection and management and the provision of water and sanitation services in SA. The water sector does not have a distinct or independent regulator. Figure 3.8 illustrates the linkages between the institutions that are major role players in the water sector.

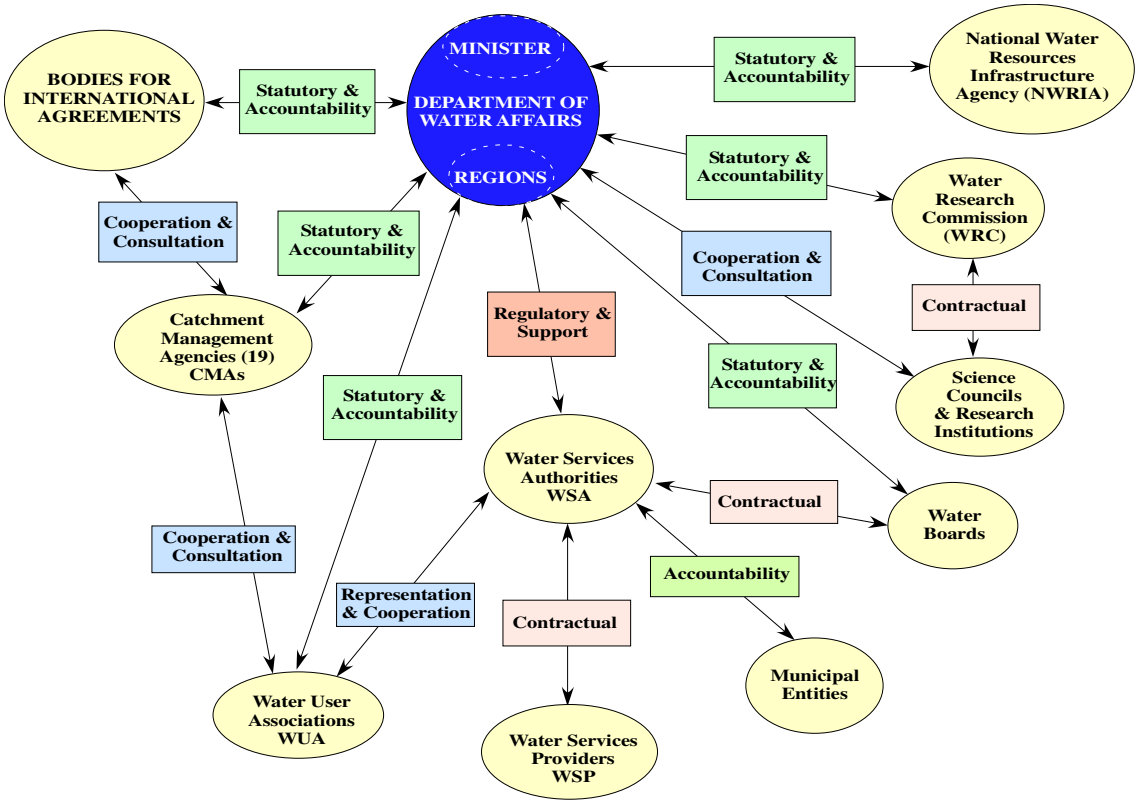


Figure 3.8 Water Sector Institutions in South Africa and the Nature of their Relations and Interactions (after DWAF, 2004)

3.4.3 Institutional Arrangements

The institutional arrangements for water resources regulation in South Africa are relatively complex. Firstly, there is a long chain of regulatory players, as shown in Figure 3.9. The role of the courts, the Water Tribunal and Parliament are often not sufficiently recognised in this chain. Parliament plays a critical role in water resources regulation by establishing the legislation that provides the department with its legal

mandate to regulate water use. In this regard, Parliament also has an oversight role in terms of ensuring that the aims of the legislation are being achieved. Any amendments to legislation in order to enhance the effectiveness of water resources regulation require the approval of Parliament in a legislative amendment.

The courts, and the Water Tribunal, influence regulation through binding rulings that give interpretation both to the meaning of legislation and regulations, but also to the methods used to implement regulation. It is worth noting that a recent Water Research Commission review of cases heard by the Water Tribunal indicates that the DWA lost most of the cases brought to the Tribunal, mainly on administrative grounds rather than on substantive policy grounds. This suggests significant administrative weaknesses on the part of the DWA that must be addressed. There are a number of reasons for this, including major issues of capacity. However, there is also a question of whether the appropriate institutional arrangements are in place. There are, in this regard, two ends of a continuum that can be identified: retaining the regulatory functions within the department and establishing CMAs, or creating an independent regulator whilst the department continues with the management functions of the resource as is happening now.

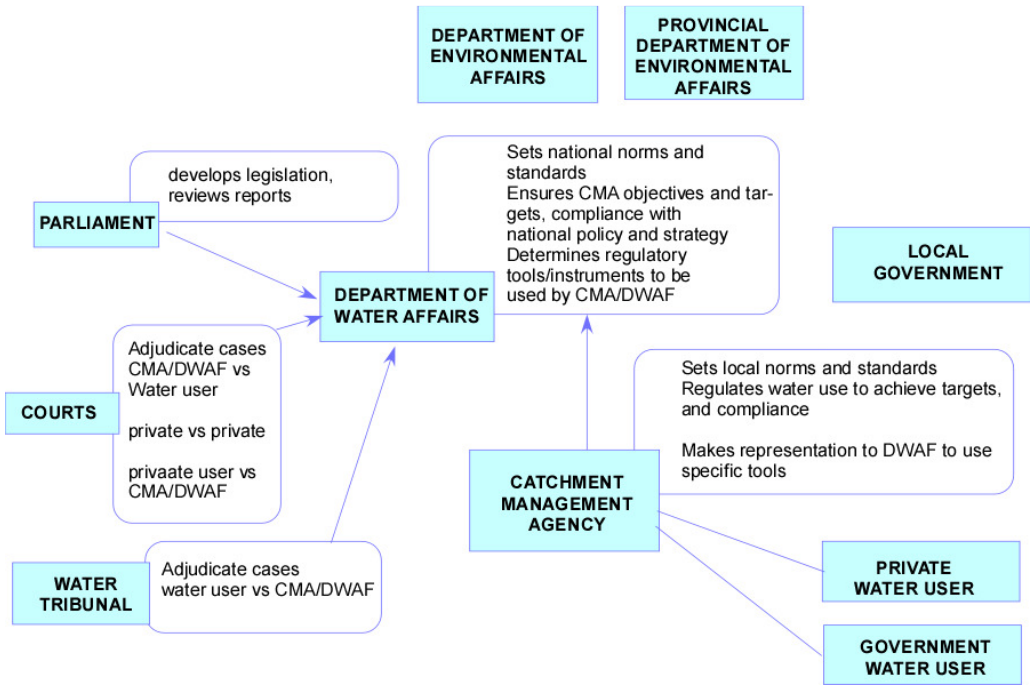


Figure 3.9 Role Players in Water Resources Regulatory Chain in South Africa (Marjanovic *et al.*, 2011)

It is critical that the water resources regulatory chain is fully aligned with the National Water Resources Strategy which is currently under revision. This revision process allows a window of opportunity to insert into the NWRS any issues pertaining to the water resources regulatory strategy that may be required. Two other strategies with which the water resources regulation strategy must be aligned are the Water Services Regulatory Strategy and the regulatory strategy of Department of Environmental Affairs (DEA) for environmental regulation. Consultation with the relevant role players is critical. While existing regulatory mandates exist, in particular under the National Water Act, these have not been fully implemented largely because of a lack of capacity, both in DWA and at the level of CMAs that have either not been established or do not yet have the capacity to implement the existing regulatory activities.

Mechanisms for improved alignment and cooperation with other government departments such as Department of Environmental Affairs (DEA) and the provincial DEAs in particular need strengthening to streamline implementation and regulatory accountabilities and capacities. Institutions that have important regulatory mandates such as CMA's have either not been established or where they have been, lack the institutional capacity to give effect to the key regulatory functions/decisions, in these instances DWA therefore self regulates. This has a profound and material impact on regulatory credibility and effectiveness. The establishment of CMAs should be fast-tracked to assist the clarification of roles and responsibilities, the increase in regulatory capacity and avoidance of the player/referee scenario where possible. A key challenge is that regulatory expertise and skills are not readily available in the country and DWA is not likely to easily attract and or retain the appropriate skills. In this regard, learning from the experience of other departments, such as DEA, and developing a formal programme to develop the necessary skills will be critical to the success of water resources regulation in the country (Marjanovic *et al.*, 2011).

3.4.4 Institutional Reform

The institutional reform process serves two principal purposes. Firstly, to decentralise the responsibility for managing water resources to regional and local levels to facilitate wider public involvement in water matters through established structures of Government, such as municipalities. Secondly, to move the Department of Water Affairs away from the day-to-day water resource management activities towards its ultimate role of developing policy, regulation, planning, monitoring, assessment and providing institutional support. As part of its support role the Department of Water Affairs has embarked on the development of a capacity building strategy to address capacity limitations in the water sector (DWA, 2009). Despite the fact that there are a number of pillars to improved water resources management in South Africa, regulation is seen as a key part of the integrated water resources management (IWRM) armoury, and one which will gain increasing importance as the stress on South Africa's limited

water resources increases. Other important elements of the water resources management framework include infrastructure operation, maintenance and development, monitoring and assessment, research, and appropriate institutional design.

3.4.5 Comparisons with International Norms and Standards

The existing policies, white papers and legislation are sound and in line with best practices across the world. What seems to be lacking is the ability to enforce the implementation of these policies and legislation. This will require a significant and massive investment drive in capacity building of existing stakeholder institutions. The full review of the actual existing legislation and policy conditions in the municipalities have shown that the main problem with water services delivery in South Africa is not National Policy and Legislation but rather human resources capacity, especially in the planning, technical analysis and water management sectors. These deficiencies need to be addressed as a matter of urgency, if any improvements are to be made within a reasonable timeframe. The policy and legislative framework for water resources currently in place is one of the best in the world and is only incapacitated by the lack of resources, especially the human resources at the local level. The framework has tremendous potential to usher a widely effective, sustainable and efficient management of water resources and services in South Africa for many years to come.

3.4.6 Catchment Management Agencies

In every country there are some legal, administrative, or constitutional failures and some inappropriate policies (from a water perspective) which are currently unchangeable. In South Africa the government has decentralised their water services to local municipalities and this has its advantages and disadvantages. In the South African context, Catchment management Agencies are supposed to offer support to the local municipalities in their catchment areas. For this study the three Catchment

Management Units (CMUs) of relevance are Crocodile West CMU, Olifants CMU and the Upper Vaal CMU.

The necessary alignment between the two management systems is not functional because the CMU and the corresponding Catchment Management Agencies are not yet fully functional and operational. Municipalities are however expected to continue meeting the needs and do so often with ad hoc approaches without any appropriate planning imposed inputs from the CMAs. Municipalities currently rely on DWA to fulfil the role of CMAs. DWA tries fulfilling this requirement within the bounds of its limited capacity. However, this problem of alignment between the management systems is expected to be overcome with time as more capacity is created. Many of the current observed problems with service delivery can actually be traced to the lack of alignment and coordination between the two management systems.

3.4.7 Decentralisation Policy

From a policy, institutional and legal point of view in this study another issue that needs specific consideration is the question of centralised versus decentralised systems. The current policy and institutional framework has in fact decentralised water services provision to the level of the municipality since the ultimate responsibility for the service provision rests with the municipality. This is an interesting observation because when one considers that municipalities can differ from being fully urban to mostly rural, one realises that the current Policy, Institutional and Legal Framework in fact allows for full decentralisation of water services covering the full spectrum of large municipal regional systems to individual onsite systems. In other words, no legal and institutional barriers exist in the current policy for the full decentralisation approach to wastewater management systems. This is not generally understood as some municipalities/metros in fact do not allow decentralised wastewater management systems, citing the lack of capacity by private

players to manage the systems. It is worthy of mention that despite the current perception, the situation which has been observed in the field within the eight municipalities studied is reasonable decentralised and the effort to decentralise is visible but the practices remain largely centralised.

The decentralisation of power to the local municipalities and the Catchment Management agencies support the recommendations work of this thesis and in no way a hindrance in as much as the decentralisation creates its own challenges since the institutes do not have capacity to run these functions well. This is also seriously impacted in that there are no adequate tools which give municipalities incentives to enhance performance, develop cooperative investment opportunities and pool expertise and which reduce their ability to pass costs onto adjoining or downstream municipalities (GWP, 2000). In order to ensure institutional sustainability in wastewater management, the responsibility for services should be delegated to the local level, while central authorities remain responsible for strategic planning, policy, and regulatory aspects of sector development (UNDP/World Bank, 2000). This is in line with subsidiarity principle as recommended.

3.5 Planning Framework in South Africa

Since wastewater management is part of a wider set of urban environmental services it must be planned holistically. According to a UNEP (2004) study, holistic planning requires integration of relevant technical, costing, institutional and sectoral issues. Technical integration means that the full range of available, environmentally sound technologies is considered while selecting the most appropriate options for the existing economic situation. Institutional integration implies that all organisations/disciplines that could contribute to the solution are involved and have appropriate roles in the planning process.

The primary instrument of planning in the water services sector is the water services development plan. According to the 3 district municipalities, it is mandatory that all water services authorities develop a water services development plan (WSDP). A new plan must be developed every five years and the plan should be updated as necessary and appropriate in the interim years (Metsweding WSDP, 2006; Sedibeng WSDP, 2007; & West Rand District WSDP, 2007). The WSDP must be integrated with the integrated development plan of the municipality, as required in terms of the Municipal Systems Act. This plan requires the consideration of the physical, social, economic, financial, environmental and institutional aspects of water services provision in a particular water services authority area. Based on the Strategic framework, the water services development plan is supported by business plans which show how the water services development plan will be achieved on an annual basis (DWA, 2004).

3.5.1 Integration of Planning

Integrated planning: The water services development plans (and related business plans) must inform, and be informed by:

- The local government's integrated development plan (IDP), of which it forms part;
- Catchment management strategies and the national water resource strategy;
- Water resource infrastructure plans; and
- Regional water services business plans.

Integration at different levels and across different spheres of responsibility is a critical aspect of successful water services delivery. The integration pathways needed and identified in Figure 3.10 imply that in the absence of the functional Catchment Management Agencies, which are a significant and important part of the integration process, it will remain unachievable. DWA has been trying to overcome this by being

directly involved at the Municipal local level, but due to capacity constraints and incomplete catchment level assessments, plans and strategies; this effort has been largely unsuccessful.

Figure 3.10 indicates that the level of coordination and alignment between different provinces, necessitated by cross provincial boundaries for the catchment management units, remains a big challenge. It is therefore not surprising that the alignment and coordination at the municipal level, as detected in this study, also remains incomplete and non-effective in many instances. Municipalities and other local level institutions which are at the fore-front of service delivery are subjected to unprecedented pressures by the expectations of the local residents. Promises and rhetoric by politicians have only served to fuel the growing pressure. The incapacitated municipalities face growing unrealistic expectations from the public regarding service delivery. These same municipalities also face conflicting messages from the higher levels of government which promises better service delivery to its constituency whilst ironically failing to establish effective institutional structures for sustainable and proper water management.

The only way this can be effectively addressed is to speed up the establishment of effective Catchment Management Agencies and create an environment conducive for high quality planning and integration at local level. This will require a major intervention in the creation of effective and professional planning capacity of the local level institutions. In the current situation, where skills shortage in planning and management is acute in the country, the creation of such capacity probably will not be possible at each and every municipality.

The process of integration for assessment, planning and management for the three relevant levels (national, provincial and municipal) is summarised in figure 3.10. The

effective assessment at each level is a prerequisite for effective planning at all levels. Judging by the information collected during this study, it is clear that the assessment at the national level is effective and appropriate for planning purposes. Considering that base level information is available at a single point of service (DWA), it is reasonable to assume that once the Catchment Management Agencies are up and running much of the Catchment Level Assessment will also be effectively carried out since extensive catchment level assessment is being done by a number of consultants who have been engaged by DWA.

Unfortunately, the same cannot be said for local level assessments for two main reasons:

- The detailed planning necessary at local and site specific levels require a more sophisticated assessment.
- The local level assessment is often left to a municipality. These municipalities do not have the requisite resources (people, data and information and other capacity).

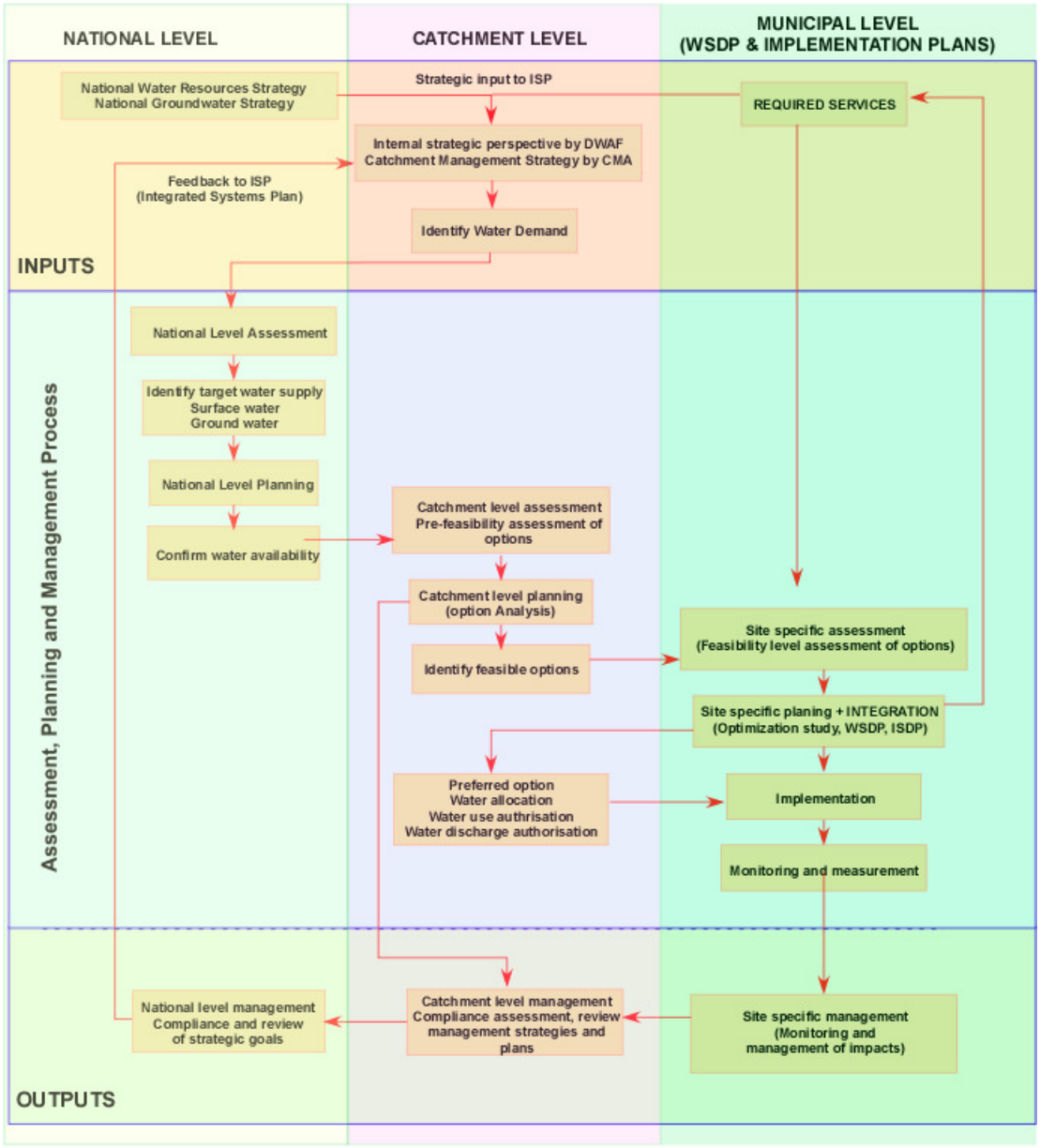


Figure 3.10 Integration Pathways Needed (Marjanovic *et al.*, 2010)

Poor assessment and lack of capacity for effective planning at the local level is sometimes worsened by the appointment of biased and/or inappropriate consultants to fill this capacity gap, which has resulted in unrealistic WSDP goals. It must also be admitted that planning is sometimes negatively affected by the adoption of

inappropriate policies at the provincial level. The Gauteng Province sanitation policy rules out intermediate levels of wastewater technologies and is one case in point.

Figure 3.11 shows that assessment is a highly technical process (at all levels of assessment) and is based on technical expertise and information.

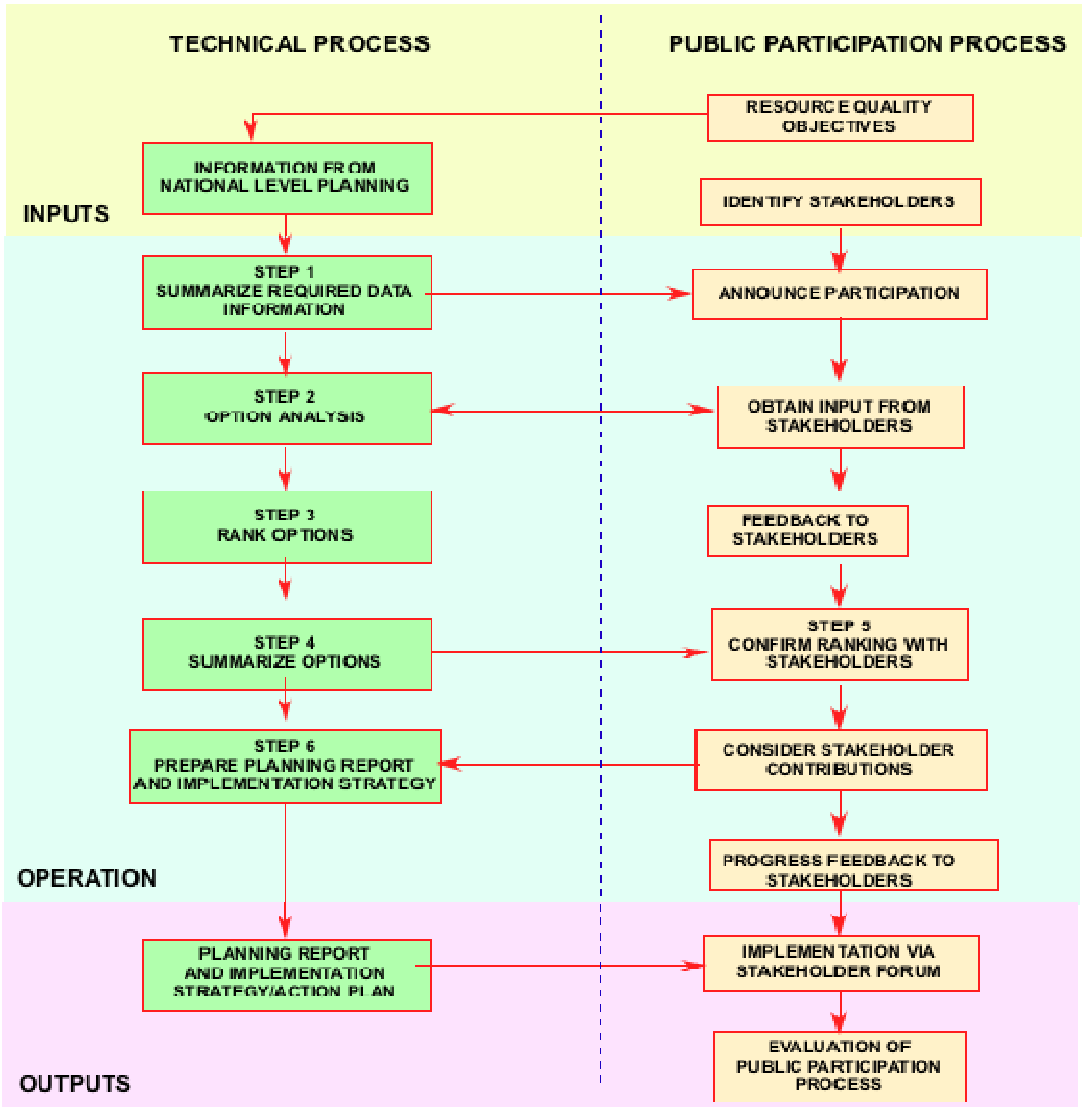


Figure 3.11 Process for Integration of Assessment, Planning and Management (Marjanovic *et al.*, 2010)

It requires a high level of technical analysis such as feasibility and risk assessments which in turn require the corresponding skills level in the institutions responsible for planning. This level is hardly at most of the municipalities studied and consultants are often appointed to provide this service. However, the consulting profession does not have unlimited capacity in the country especially with regard to ready pool of specialised skills. Specialised consultants are assigned to specialised projects particularly at the national level. Some specialised projects at local level are also given to the same expert consultants leaving the more complex task for the less experienced personnel who often have no appropriate capacity. This is a wider acknowledgment problem and efforts have been made to deploy retired engineers in Municipalities to fill the capacity gap with limited success.

3.6 Decision Making within the Current Legal, Institutional and Planning Frameworks

There exists considerable evidence to suggest that the South African planning and decision making process with respect to water supply, sanitation and wastewater management tends to bypass international trends and experiences. A case in point is the Gauteng Provincial Sanitation Policy which calls for either Ventilated Improved Pit latrines (VIPs) or waterborne full level of service "wherever possible", when there are a range of intermediate options in between these extreme options. The main reason for bypassing international trends and experiences was and continues to be, the lack of capacity for proper and informed planning in line with current best practices in management. The South African planning process is based mostly on the local knowledge base and experience and as result most urban water management solutions favour full waterborne sanitation, high technology and energy intensive wastewater treatment technologies even when such systems are obviously hardly affordable for the end user, especially in peri-urban and rural settings (Marjanovic *et al.,* 2009).

The current water services planning is a top down driven process led by DWA. However, in accordance with the intentions of the National Policy, water services planning should be a bottom-up driven process starting at the local level. This is not surprising considering the shortage of capacity present at the local level and the dominant mode of thinking at this level which purports that water services delivery is all about infrastructure provision alone (taps & toilets) and nothing else. The infrastructure can be viewed as the hardware whilst the social and environmental criteria which ensure successful functioning of the systems are the software. The national policy focuses on both the hardware and software issues. If it is adhered to, more effort would be spent on managing expectations resulting in WSDPs which do not restrict wastewater management to infrastructure provision only. Furthermore, a shift would be experienced in the local level planning from the bottom up rather than top down. Water Services are provided to meet people's needs and these needs should be rightly defined by the beneficiaries themselves. The articulation of these needs should not necessarily imply an unaffordable level of service.

3.7 Summary

This chapter highlighted the challenges with water and wastewater management within the eight municipalities chosen for the case study in view of the need for centralisation and decentralisation wastewater management. The current policy and institutional framework has in fact decentralised water services provision to the level of the municipality since the ultimate responsibility for the service provision rests with the municipality but the practices point to centralisation of wastewater management. The recommendations set for the eight municipalities are shown in chapter 6 of this thesis. The status quo findings from the case study were the ones that lead to the need for improvements in planning and wastewater decision making which are covered in chapters 4, 5 and 6.

The water resources policy and regulatory frameworks in South Africa are seen by many to be a good example of how an integrated system should be set up. However, while the Constitution, The National Water Act and the Water Services Act, are highly integrated and modern, in practice a lot is left to be desired on the implementation side as the Institutions envisaged and in charge of implementation have not been established to the full extent or, where they have, lack the capacity to implement the modern policy and legislation. The lack of capacity is particularly evident on the enforcement side and on the technical side where planning and monitoring capacity is especially evident. The main problem with current water resources regulation in South Africa is the lack of compliance monitoring and enforcement is generally poor, primarily due to; understaffing and underfunding, fragmented approaches, slow decision making, lack of focus, confusion in roles and inconsistency of approach. The compliance monitoring and enforcement functions of DWA needs to be structured and aligned to the regulatory framework and will require substantial strengthening, capacity and resources.

CHAPTER 4

REVIEW OF METHODOLOGY AND DECISION MAKING FOR THE CASE STUDY

4.1 Introduction

This chapter describes the methodology followed in execution of this research. The research methodology employed was to establish a clear understanding of sustainable wastewater management and the concepts involved. This understanding formed the foundation for step 2 which was the status quo analysis in study area (eight municipalities in Gauteng). The expected findings of step 2 were formulated as the primary drivers of this research. The status quo analysis identified an unclear and deficient decision making framework in wastewater management in some of the municipalities and this established the justification for step 3 which was the establishment of a clear understanding of Decision Making in Wastewater Management. Literature review and synthesis were the main approach in completing step 3 of the research. With clear understanding of the problem of Sustainable Wastewater Management and the associated decision making framework it was then possible to engage in steps 4 and 5 and develop decision making methodology and the associated decision support tool to enable better decision making in practice. Finally, in step 6, the conclusions were formulated and recommendations were made.

4.2 Case Study Methodology

The purpose of this research was to evaluate the situation in the identified municipalities and provide recommendations and give strategic direction to the province and local government for the achievement of sustainable wastewater

management in areas concerned. The scope of the research focussed on peri-urban, farming and isolated areas within the jurisdiction of the local municipalities. The research covered the following municipalities (Lesedi, Midvaal, and Emfuleni, Kungwini, Nokeng Tsa Taeman, Westonaria, Randfontein and Mogale). The research considered future research needs and prerequisites for effective implementation of decentralised wastewater management systems in the context of Gauteng province in South Africa. The methodology used for the case studies was selected on the basis of, amongst other factors the scientific appropriateness and practical effectiveness in accomplishing the intended goal of formulating an adequate solution to the defined research problem. It comprised of the following;

4.2.1 Literature Review

The research involved an extensive literature review, on current economic, technical, social and environmental costs and benefits of various aspects of centralised and decentralised systems. Literature addressing the following topics relevant to wastewater system was gathered, reviewed, and synthesized with respect to;

- Advantages and disadvantages for decentralised & centralised systems.
- The sustainability of wastewater system and technologies
- Legal and planning policy framework in South Africa
- Multi-Criteria Decision Making Analysis
- Wastewater economics, environmental, technical and social impacts assessments
- Decision support systems

The literature search was able to identify relevant reference points in South Africa and internationally.

4.2.2 Field Visits and Stakeholders Consultation

Field visits were made to the eight municipalities and to the wastewater treatment works in Gauteng. The central research method used in the field visits was interviewing. One hundred and eighty three informal settlements and twenty wastewater treatment works were visited. Interviews with key staff from various sections/departments within the municipalities (technical, finance, housing, town planning) and consultants working on behalf of these municipalities were done. Interviews were held at the municipal offices, sewage treatment works as well as in the informal settlements. The following institutes were consulted; Department of Water Affairs, Department of Environment Affairs, and Department of Provincial Local government as well South African Institute of Civil Engineers (SAICE) engineers seconded to the municipalities.

4.2.3 Ethics Clearance

An ethics clearance application was made to ensure that human rights were not violated during data gathering stage. The application was made to the Wits None Medical Ethics Clearance committee. The Ethics clearance certificate was granted in January 2010.

4.2.4 Document Review

The research involved a search through a wide range of documentation that was available (in forms that range from official statistics, Integrated Development Plans (IDP), Water Services Development Plans (WSDP) and policies). These documents and secondary sources provided information on existing conditions, plans, reported attitudes and opinions. Policies and legislation in place concerning wastewater management were analysed to find how they could be used to provide a platform for the implementation of recommendations. Various research documents from DWA (Department of Water Affairs) and the Water Research Commission (WRC) were

analysed and lessons learnt from such reports were noted and then compared with current practices within the relevant municipalities. The use of tools like MCDA was also analysed within the reports and planning documents used to assess the full extent of their use in planning and decision making. This also provided a check on possible improvement areas within the use of these tools.

4.3 Review of Multi Criteria Decision Making Methodology

Historically, wastewater management has been seen mainly as an economic and a technical issue whilst other aspects of sustainable development criteria have been neglected. In many countries, the selection of wastewater systems and technologies has been done on an ad-hoc basis with more weight being given to the political and economic strength of the recipient communities than whether these technologies are likely to be sustainable (Mara 1994; Zeng *et al.,* 2006). It is now recognised that economic and technical criteria are just part elements in an array of other factors that makes sustainable wastewater systems. According to Foxon *et al.* (2001); Ashley and Hopkinson (2002), the incorporation of sustainability assessment into the decision making process is a key task for all water service providers. There is an urgent need to adopt transparent and stake-holder sensitive decision making processes.

In South Africa, it is a requirement in water services development planning that the plan must take into consideration the physical, social, economic, financial, environmental and institutional aspects of water services provision in a particular water services authority area but there is no prescribed standard way of how this should be done. Borsuk (2008) argues that practical and theoretically sound methods for analysing innovative environmental technologies are needed to inform public and private decisions regarding research and development, risk management, and stakeholder communication. International donors and financial institutions are aware that the failure of many infrastructure projects is because of poor project

identification, lack of consultation with all stakeholders and a lack of a holistic approach to planning and problem solving (Ilemobade, 2003).

Otterpohl *et al.* (1997) point out that it is very difficult to find a scientific approach to define the sustainability of sanitation systems. Some common methods to measure or define sustainability include life cycle analysis, exergy analysis, the MIPS-concept (material intensity per Service Unit) and the sustainability Index (land usage). All the above mentioned methods play a significant role in measuring sustainability but their biggest handicap is that they make the decision making process a preserve for the technical people only. Multi-criteria decision analysis is one key decision making method which involves or incorporates the views of the other disciplines in decision making. The use of MCDA can help in planning and improve the decision making process in the small municipalities.

4.4 Multi Criteria Decision Aid

Malamis (2008) defines Multi criteria Decision Aid (MCDA) as a branch of a general class of operations research models dealing with decision problems under the presence of a number of decision criteria in a structured and systematic way. According to many authors, Multi-Criteria Decision Making is divided into multiple objective decision making (MODM) and multi-attribute decision making (MADM). A multi criterion decision model based on MADM was developed in order to compare the sustainability of the wastewater technologies in this research. Joubert & Stewart (2004) state that multi-Criteria Decision Making (MCDM) is an umbrella term for a wide range of techniques that explicitly include multi criteria in the evaluation of alternatives. Multi sustainable criteria/indicators have been used in monitoring performance, environmental reporting and benchmarking of operations but not much in wastewater system planning and for decision making in this field.

4.4.1 MCDA Process Steps

Belton (2000) states that MCDA provides a rigorous theoretical foundation for a total decision support process incorporating the following key steps;

- Structuring of decision goals in terms of explicitly defined hierarchies of criteria.
- Evaluation of alternative courses of action or strategies in terms of the extent to which they satisfy each of the identified criteria.
- Aggregation across criteria to generate a measure of the extent to which each course of action or strategy satisfies the overall goal represented by criteria.

This research builds on the key steps proposed by Belton (2000) and the chosen procedure was one of mathematical simplicity and high transparency. Community consultation in South Africa was institutionalised with the introduction of the Batho Pele ("People First") policy which stipulates that citizens should be given a choice when services are offered to them. The level and quality of the services they are to receive must also be discussed with and accepted by the community members. The process steps for the MCDA implementation at the municipality level are shown in Table 4.1. The detailed procedure is outlined in Figure 4.1. The stages involved in the detailed procedure are outlined in sections 4.4.2 to section 4.10.1 and a detailed explanation of the systematic procedure for the computational process is found in appendix H.

Table 4.1 Process Steps for MCDA Implementation

Phases	**Description**	**By whom**
Problem Structuring	Defining and understanding the problem. Identifying the alternatives and setting the pertinent criteria for evaluating the alternatives. In this stage the indicators derived from the criteria are also defined	Facilitator & municipal officials Primary stakeholders
Evaluations of alternatives	Developing scoring systems for each of the criteria and scoring the alternatives based on each criteria	Facilitator & municipal officials stakeholders
Aggregation of evaluations	Weights determination of each of the criteria and aggregation of the scores using a weighted summation	Facilitator & municipal officials
Analysis	The results are further analysed for sensitivity to weights and scores and to explore the implied trade-offs	Facilitator
Feedback and refinement	Report on results presented as feedback to the team, and refinement or re-evaluation can be done on the weights if need be	Facilitator & municipal officials stakeholders

(After Joubert & Stewart, 2004)

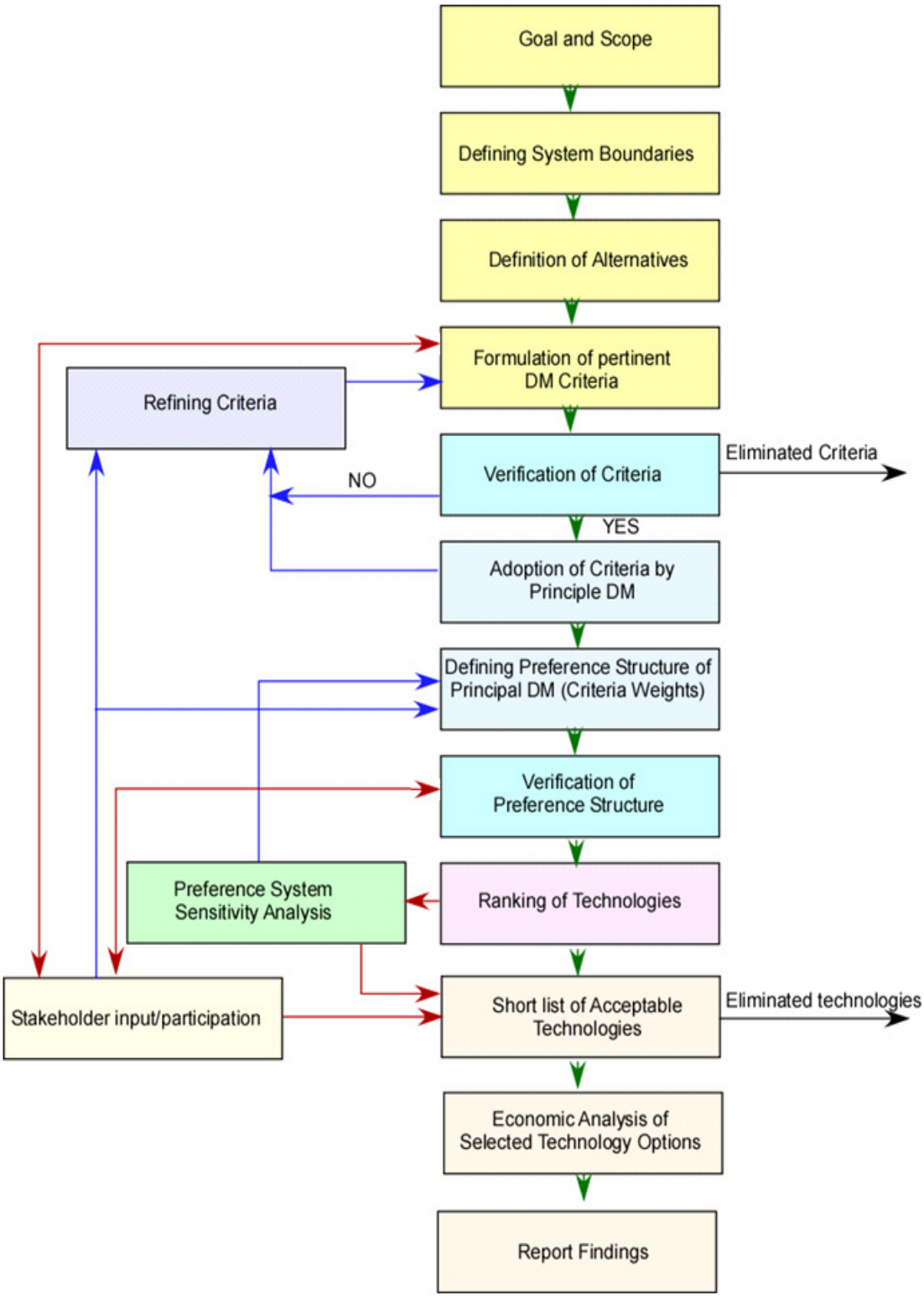


Figure 4.1 Technology Option selection Process and Steps

4.4.2 Goal and Scope Definition

In this stage of the assessment the system boundaries and sustainability criteria are defined. It is convenient to employ a checklist so that key aspects are not overlooked since in the definition of the goal and scope one can rule out sustainable solutions beforehand.

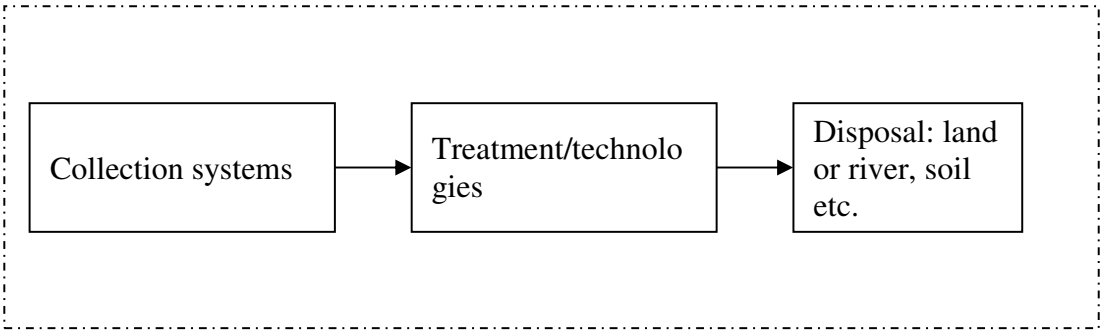


Fig 4.2 System Boundaries for the Research

After defining the goal and scope, the next step is to define the set of alternatives. The process of defining the alternatives usually leads to a better understanding of the range of options available. The majority of earlier literature on MCDA focuses on the exploration of possible solutions, having identified the boundaries of the problem. Belton (2000) argues that the emphasis has been on solution rather than formulation of the problem. Formulation of the problem leads to a better understanding of the nature of the problem and the solution derived is most likely to be sustainable since the understanding gained leads to greater appreciation of the whole system under consideration.

4.4.3 Defining Alternatives

Alternatives represent the different choices of action available to the decision maker. Sometimes the problem is not one of generating alternatives but of identifying an appropriate and manageable set for detailed evaluation from a much larger set of

possibilities. The decision alternatives in this study were the wastewater technologies. Owing to the many possible configurations for the technologies, there was a need to screen the alternatives. The alternatives were chosen on the basis of the available knowledge, sound engineering judgement, and practical experience within the South African environment. The overriding principle of the screening was based on (i) currently employed technologies, (ii) new technologies with potential application in the South African context and (iii) already existing technologies with potential for implementation but not fully implemented in South Africa. The technologies were classified on a scale of 1-5 for suitability for use in centralised and decentralised systems.

4.4.4 Selecting Pertinent Criteria

The choice of criteria is crucial since it is the fundamental basis of the whole method of decision support. Mitchell (1996), states that the geographical diversity of urban, rural, and peri-urban area may mean that an indicator appropriate to one locality may be inappropriate in another. Literature studies reveal that there is an extensive list of indicators that have been used for the urban water assessment (Nilson and Bergstrons (1995); Balkema (1998); Emmerson, 1995; Lundin, 1999; Foxon *et al.,* 2002; Balkema *et al.* (2002)). The common element found in these various approaches is the need for development of a structured classification of criteria, which is forward looking in order to be useful in the local context of decision making.

When analysing decision making in wastewater management the criteria to be used can be plentiful and diverse. The analysis will in most cases include at least the set of 39 indicators listed in the questionnaire in Appendix C. In order for the criteria to be useful the set of criteria needs to be continuously revised since the choice of criteria may change as knowledge advances. This set of 39 criteria was considered to be an initial set which was reduced to manageable number set after ranking the criteria and

carrying out a sensitivity analysis test. Some criteria were eliminated and the remaining ones were deemed appropriate and specific for the local context. The greatest challenge in determination of the pertinent criteria for a specific situation or context is finding the balance of having so many decision criteria with sufficient coverage of the problem or a smaller set which might not fully cover the required areas of analysis but makes the iterations less complex and leads to over simplification of the problem (Munda *et al*., 1994).

A scale for acceptance or rejection criterion was set in agreement with input from all stakeholders. This formed the first iteration of the process. Criteria having a certain level of score were accepted while those below a certain minimum were discarded or eliminated from further iterations. This process then lead to adoption of a defined core set of criteria which was further taken up for evaluation within the decision making process. The criteria adopted in this study are listed and explained in sections 4.5 to 4.8.

4.5 Classification of Criteria

The aim of this research was to develop a methodology for using the local conditions, and technical functions with sustainable development criteria (social, technical and environmental), in the evaluation of different wastewater systems. As stated by Mouritz and Newman (1997), "Sustainability implies different solutions for different places". The challenge of decision making is to link the decision criteria with the local needs of the communities in different places. The context is crucial, as the need for sewage treatment and the potential of different technical solutions vary according to the local conditions.

4.5.1 Social Criteria

Burkhard *et al*. (2000) state that the social aspects are the most difficult issues among the many criteria which may be used to assess the feasibility of water and wastewater systems. According to Panebianco & Pahl-Wostl (2006) the infrastructure can be viewed as the hardware and the social criteria may be regarded as the software. Hence it is this often neglected 'software' side of wastewater systems that may provide a wealth of information regarding the sustainability of a technology in a given setting, along with any potential barriers to its implementation. The criteria in sections 4.5.1.1 to 4.5.1.5 were adopted for the social assessments.

4.5.1.1 Public Acceptability

The public acceptability may be influenced by people's opinions on the aesthetics, potential for odour, familiarity, landscape, cultural identity etc. Foxon *et al*. (2001) states that acceptability to stakeholders' covers acceptability and perceptions of impacts on health and environment. Burkhard *et al*. (2000) argues that the extent to which people are required to alter their everyday behaviour will probably have the largest effect on acceptability. Disgust sensitivity is likely to have an effect on acceptance of onsite/decentralised wastewater systems (Ilemobade *et al*., 2008).

4.5.1.2 Awareness

The process for wastewater technology selection should include community participation within the decision-making process and this public participation programme is more beneficial if the participants are involved in the process and not just informed about the process. Marjanovic *et al.* (2010) reveals that awareness is a major force to reckon with in the acceptability of a technology since lack of awareness mainly leads to acceptance of non sustainable solutions.

4.5.1.3 Institutional Requirements

The main drivers for institutional changes are the skills requirements, managerial complexity and regulatory requirements. Since different wastewater treatment systems require different regulations and control mechanisms, Balkema *et al*. (2002) argue that the requirements should fit in the existing institutional infrastructure of the country or region.

4.5.1.4 Jobs Creation Potential

The number of jobs generated according to the requirements that is created by the application of the proposed management system varies 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. Joksimovic (2006) points out that difficulties in estimating labour requirements for individual unit processes arise from the fact that the labour force is typically distributed to activities dealing with several processes, as well as administration, which makes the development of expressions for individual unit processes more difficult.

4.5.1.5 Health Impacts on Failure

Adewumi (2010) states that the risk of failure is always there in each and every technology but it is the impact of the failure that is critical. Failure occurs when a system does not meet desired performance levels or a system is overloaded beyond its capacity design. Each technology has its own demerits as far as promoting diseases due to contact with the effluent or breeding of vector flies.

4.6 Environmental Criteria

Many sets of sustainability indicators used in literature differ but there seems to be a general agreement and understanding on the environmental indicators (Muga, 2006). In most publications optimal resource utilisation is used as an indicator, particularly addressing nutrients, land, chemicals and energy. Resource utilisation and environmental risk/impact were adopted as the two main criteria for this study.

4.6.1 Resource Utilisation

The main resources under consideration in wastewater management are mainly, energy, water, chemicals and land.

4.6.1.1 Energy

Energy requirements are usually a key aspect since energy costs have been spiralling across the years. All the mechanical wastewater treatment technologies need electrical energy or some form of energy for their functions (Muga, 2006). The energy consumption is a function of the type of equipment used. Some countries have reasonable rates for their energy costs depending on whether they generate their own or import. Hence the energy requirement is a greater factor in technology selection. The energy balance for a particular technology will indicate how much energy is used, produced (for instance biogas), and lost. This study does not take into consideration the energy produced since most plants in the study area did not have the mechanism for biogas production but it is critical in terms of sustainability.

4.6.1.2 Land Requirements

It is known that different unit processes employ 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 biological treatment processes like aerobic, anaerobic and other stabilisation ponds (Adewumi, 2010). The amount and type of land required for wastewater treatment may be limited especially in the urban environment, and the occupation of large land areas by wastewater treatment systems may be unwanted.

4.6.1.3 Chemicals Requirements

The use of chemicals contributes to both the environmental risk and as well as the economics costs. Chemicals increase the environmental footprint of the technologies while at the same time they play a role in lowering pollutants to the environment.

4.6.1.4 Resource Recovery

Technologies which offer high opportunities for reuse of nutrients and the water in the local watershed are deemed more sustainable than those which transport the nutrients and water outside the local watershed.

4.6.2 Environmental Risk

There has been world-wide concern on the impact of untreated wastewater on the environment (Metcalf & Eddy, 2004). Impacts may be on surface water quality, river water quality or ground water quality. Pharmaceuticals drugs taken in by people also find their way into the sewer systems and many of them are not designed to treat these. Hence, the risk of treated or untreated wastewater is high.

4.6.2.1 Groundwater Pollution

Discharging effluent to the ground has its own consequences. While the soil is a natural treatment plant, it also has its limiting capacity and if not carefully considered can cause more harm to people since it may lead to groundwater pollution. The

potential for groundwater pollution is very low for the majority of municipal wastewater treatment processes since the effluent is disposed into rivers.

4.6.2.2 Surface Water Pollution

Surface water pollution is a function of the treatment technology efficiencies in performance and the receiving medium's state depending on the mass loadings permitted to be disposed. Since 100% efficiency in treatment is rarely achieved, it means there is always surface water pollution on discharge but mostly the receiving medium can deal with that in a safe and sustainable way.

4.6.2.3 Air Emissions/Odour

Odour from treatment plants can be a nuisance and source of pollution and is a major factor in acceptance of technologies by communities (Metcalf & Eddy, 2004). Some technologies are high odour generators. The assessment for odour generation would be determined by the potential of the technologies to generate or deal with odours.

4.6.2.4 Noise Pollution

Depending on the degree of mechanisation, technologies can generate substantial noise. Centralised systems have the advantages of being out of sight of people but the noise levels can still be high but with low impact.

4.7 Technical Criteria

Technology is always designed to fulfil a service, for instance sanitation. The functional criteria of the technology indicate the effectiveness of the technology fulfilling the service. Primary indicators proposed for this research were adaptability and flexibility (possibility to extend the system in capacity, or with additional treatment flexibility and ability to cope with fluctuations in the influent), durability

(lifetime), and reliability (proven experience of being successful and sensitivity of the system to malfunctioning of equipment and instrumentation). The following functional criteria can be distinguished.

4.7.1 Performance

Performance refers to required or desired results of wastewater treatment systems. Performance levels are often defined by regulatory effluent standards. The following indicators were used to address performance of the technologies (Metcalf & Eddy, 2004)

- *Biodegradable organics* are principally made up of proteins, carbohydrates and fats. They are commonly measured in terms of BOD and COD. If discharged into inland rivers, streams or lakes, their biological stabilisations can deplete natural oxygen resources and cause septic conditions that are detrimental to aquatic species.
- *Suspended solids (SS)* can lead to development of sludge deposits and anaerobic conditions when untreated wastewater is discharged to the aquatic environment.
- *Pathogenic organisms* found in waste-water can cause infectious diseases.
- Nutrient removal Nitrogen and phosphorus are the principal nutrients of concern in waste-water discharges. Discharges containing nitrogen and phosphorus may accelerate the eutrophication of lakes and reservoirs and stimulate the growth of algae and rooted aquatic plants in shallow streams. Significant concentrations of nitrogen may have other adverse effects as well: depletion of dissolved oxygen in receiving waters, toxicity to aquatic life, and adverse impact on chlorine disinfection efficiency, creation of a public health hazard, and waste-water that is less suitable for reuse.

Considerations were not given to heavy metals concentration because of the stringent Department of Water Affairs (DWA) regulations on the disposal of complex

industrial wastewater into urban sewage systems. It is mandatory under law (DWA, 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.

4.7.2 Adaptability

Given that many factors in the future are uncertain, the ability to respond to and accommodate changes, (for example changes in energy costs, legislation, labour costs, land costs, urbanisation rate) is very critical to the sustainability of the technology. The ability of the technology to adapt to changing circumstances, for instance indication of possibilities for implementation on different scales, increasing/decreasing capacity is critical for sustainability. Adaptability to upgrade is used in this work to reflect the ease with which treatment trains could be upgraded or combined with other processes. Although all technology processes are designed for certain influent conditions, some are more adaptable to changing conditions in terms of flow and quality of inflow. These factors are accounted for by using separate qualitative marks assigned to each technology process in the assessment of treatment trains.

4.7.3 Ease of Construction

According to Loetscher (2002) the implementability of a technology is determined by how easy it is to construct, which depends on the following; required specialised knowledge and skills as well as certain type of site conditions, the coordination among agencies involved, the availability of inputs, and impediments encountered during construction. The time taken for construction from planning to full use of the system can also be a factor in determining if the technology can be constructed easily.

4.7.4 Reliability

Reliability is the rate of probability over time of attaining a performance level under a given set of operating conditions, which means being able to deliver the required services most of the time. The sensitivity of the system concerning malfunctioning of equipment and instrumentation, and fluctuations in utilities all affect the reliability of a technology. Metcalf & Eddy *et al*. (2004) describe three sources of variability in wastewater treatment as;

- Variability in influent flow rate and characteristics
- Inherent variability in wastewater treatment processes
- Variability caused by mechanical breakdown, design deficiencies, and operational problems

4.8 Economic Criteria

In developing countries, economic indicators are often decisive when choosing a technology. Commonly used indicators used in most literature studies are life cycle costs covering costs of investment, construction, operation and maintenance and decommissioning of the plant. Other indicators are affordability, financial risk and willingness to pay. In most cases cost data are hard to find, and many consulting firms or WSPs are not keen to share or publish their data for reasons best known to themselves. In order to undertake a proper economic analysis of wastewater treatment options, data should be sought from projects constructed in the past. All costs should be included and properly evaluated with cost-effectiveness criteria. Cost estimates on a national basis for wastewater treatment systems are difficult to develop, primarily due to varying conditions of each community such as population density, land costs, and local performance requirements (Tsagarakis, 2002). The following economic criteria must be considered.

4.8.1 Life Cycle Costs

The process of evaluations and selecting appropriate wastewater systems or treatment technology should consider the life cycle cost of such systems/technologies including design, construction, operation, maintenance, repair and replacement (Massoud, 2008). Over the operational lifetime of the system the operation and maintenance costs are equally important as construction costs. 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.

4.8.2 Affordability

The cost of wastewater treatment relative to the total budget and the amount of foreign exchange needed for wastewater treatment relative to the total foreign exchange requirements, indicate the pressure on the national or regional budget. Affordability relates to the ability of householders to pay for services delivered (Ashley *et al.*, 2001; Bulter *et al.*, 2003). This is usually based on the income of the lowest income households as percentage of their income.

4.8.3 Financial Risk Exposure

Financial risk exposure relates to the risk of loss to the company or Water Service Provider associated with particular kinds of investment into the employed technologies in cases of failure or there being a radical way of new treatment discovered. Financial risk exposure also covers issues of minimising regret if the plan/project is not completed.

4.8.4 Willingness to Pay

Willingness to pay is a product of the perceptions of the technology in relation to issues of health, safety and environmental benefits (Butler *et al*., 2003. In other words it involves how much people are willing to pay for improved health, safety and other benefits associated with the technology.

4.9 Weighting Process

Most MCDM methods require that the criteria be assigned weights of importance. In a similar manner different decision makers can have different preferences by adopting different weight factors to the same. Usually these weights are normalised to add up to one. Weights have a very specific meaning when using weighted summation in MCDA. The weights are scaling constants which shrink or stretch the scales so to make them comparable (Joubert & Stewart, 2004). The weights combine a comparison of the relative size of the swing from best to worst on different criteria with the notion of intrinsic importance. It is important that the weights are found after the range of worst to best has been defined for each criterion/index.

A relatively simple approach to eliciting weights is the swing weight approach. For quantitative criteria, the number alone would be sufficient, while for qualitative criteria, the levels need to be described in words. The procedure for the ranking was to ask forty local government and municipal officials, if it were possible to improve on one criterion to its best level, which criterion they would choose. That criterion was ranked number 1. The procedure was repeated with the remaining criteria until all criteria were ranked. The highest ranked criterion was then given a weight of 100. The forty participants were further asked how important the swing worst to best on rank 2 criterions was, relative to the rank 1 criterion. The response would generate a percentage score and the same procedure will continue until all the ranked criteria

have scores (percentages values with reference to criterion ranked highest). This exercise was done in July 2009 at the Department of local government and Housing offices in Johannesburg. The weights (w_i) were then found by normalizing them to sum to one by dividing each percentage by the sum of all the percentages as shown by equation 4.1.

$$W_i = p_i / \sum_{i=1}^{m} p_i \qquad \text{Eqn (4.1)}$$

4.9.1 Development of Scoring Systems & Data Assessment

In order to develop scoring systems, levels of achievement on individual criteria need to be defined and associated with interval scale scores. The first step is to define "worst and best" levels for each criterion. The best level is given a score at one end and the worst at the other, e.g. 0 and 10. Next, intermediate levels need to defined and associated with a score. The emphasis is on evaluating the value of the relative gaps between defined levels of the criterion being considered.

4.10 Weighted Sum Method

The weighted sum method (WSM) is the form easily explained to and understood by decision makers from a wide variety of backgrounds, while not placing any substantially greater restrictions on the preference structures than more complicated aggregation formulae. The weighted scores of each technology were summed up and the technology with the highest score is the most favoured one. The magnitude of the scores is unimportant: only the ranking of technologies is important. The range of the scoring system for individual criteria and whether the scale from high priority to low priority is ascending or descending is immaterial provided a consistent system is used for all criteria. The value measurement alternative is computed through maximising the expected utility function, H_j, as in the following:

$$H_j = \sum_{i=1}^{m} w_i v_{ij} \qquad \text{Eqn (4.2)}$$

where m is the number of criteria of alternative j, v_{ij} is the value of jth alternative with respect to the ith criterion, and w_i is the weight of importance assigned to criterion i with the constraints of $w_i \geq 0$ and

$$\sum_{i=1}^{m} w_i = 1 \qquad \text{Eqn (4.3)}$$

The assumption that governs this model is the additive utility assumption. That is, the total value of each alternative is equal to the sum of the products given in equation 4.2. The results from the evaluation are tested with a sensitivity analysis to assess the confidence of the solution.

4.10.1 Sensitivity Analysis

The biggest sceptics of the use of Multi criteria decision making methods claim that it is very subjective and ends up being a political game rather than being objective. Subjectivity is inherent in all decision making, in particular in the choice of criteria on which to base the decision, and the relative weight given to these criteria. According to Belton (2000) MCDA does not dispel the subjectivity, but it simply seeks to make the need for subjective judgements explicit and the process by which they are taken into account transparent (which is again of particular importance when multiple stake holders are involved).

The results of the ranking can never be completely objective because of the weighting procedure, but confidence in the results can be increased by carrying out a sensitive analysis. This was done by looking at the effects on ranking caused by changes in the weighting. The criteria most open to subjective interpretation was selected and the

weights of the criteria were slightly changed, recalculated and the final scores are summed up and re-ranking the technologies was done. Comparisons between the ranking order for different scoring and weighting scenarios indicated the level of confidence that can be given to the results. Minimal changes in ranking order indicate a high degree of confidence in the results. Conversely, wide variations in ranking will indicate that the results should be treated with care.

4.11 Justification of the Methodology

The normal and most common multi criteria decision making methods employed in DSS evaluate all the alternatives against all the criteria simultaneously in order to get as sustainability measure of index. This is usually done with limited economic data thus rendering the whole exercise a rough planning exercise which still needs further analysis of the options. In developing countries, economic indicators are often decisive when choosing a technology. Unfortunately, in most cases cost data are hard to find, and many consulting firms or WSPs are not keen to share or publish their data for reasons best to known to themselves.

Since cost data are hard to get, this research advocates for a two step approach in the normal multi criteria evaluations. The first stage will cover the three main criteria which will be termed stakeholder needs (social, environmental and technical). According to EPA (2004), optimal solution for wastewater treatment is not a technical or economic issue but should be driven by the needs of the stakeholders and once these needs are met can economic factors be used to rule the most optimal solution. This approach springs from the research findings of Nelson and Shephard (1999) who reveal that accountability in wastewater treatment decisions is made up of three dimensions: protection of public health and the environment; community needs and preferences; and practicality or feasibility. In this research the first step of multi

criteria analysis is based on the three main decision criteria and will lead a solution set of technologies which meet the needs of the stakeholders.

The main aim of any wastewater management is to promote public health and improve environmental quality, so it makes sense to first meet the social and environmental needs of the stakeholders by incorporating their needs in the decision making and once the solution set is got then a sensitivity analysis on the main criteria is carried out to build confidence in the data used for the evaluations. If there are no major changes then solution set of technologies goes for further screening based on the sustainability measure employed. The shortlist of technologies from the screening exercise is then sent for detailed economic analysis based on the economic criteria. Economic criteria have their own indicators thus become a mini MCDA process within the broader MCDA analysis based on the economic criterion adopted. The procedure for adopting the criteria and the weighting systems is the same as the one employed in the first stage.

The advantages of carrying out the two stage approach in MCDA analysis is that cost data on the technologies and systems is not easily accessed and in the initial stage there will be so many technologies to be evaluated but doing the first stage eliminates some technologies thus the remaining feasible option set has fewer technologies which at that stage the analysis stops and then a detailed economic analysis be carried out involving total annual costs, specific unit costs and Life cycle costs. If the data is not readily available the municipality can carry out the detailed investigation or appoint consultants to come out with accurate figures on the economic costs of the technologies. Once that data is collected the MCDA process starts again on the basis of the economic data only. This will enable detailed investigations to be carried out which requires detailed costing that the municipal officials can commit to find/get before the final decision making and implementation of the findings.

The results from the detailed economic analysis are then sent to the decision makers to enable them to make sound judgement in a structured and transparent way. The above process can be carried out using excel spreadsheets as a decision support system but this usually requires that users must have a higher understanding of the excel functions. The research aim is to present this methodology that would assist experienced and skilled personnel to ensure the integration of economic, social and environmental considerations in decision-making at all levels in the wastewater sector and hence, develops a simpler graphical user interface in a DSS that will make it easier for people to use.

4.12 Decision Support Systems

The term DSS is used as an umbrella term to describe any computerised systems that support decision making in an organisation. A definition of a decision model is any quantitative or logical abstraction of reality which is used to assist a body of persons in reaching an informed decision. For a DSS to be successful it must be simple, robust, easy to control, adaptive, complete on important issues, and easy to communicate with. According to Power (2004), decision models contain;

- System variables – that describes the environment,
- Structural linkages – showing interdependencies among the system variables, and
- Preferences – regarding the outcome of the decisions.

According to Jensen (1990) a Decision Support System is "a computer program that assists individuals or groups of individuals in their decision processes, supports rather than replaces judgement of these individuals, and improves the effectiveness rather than the efficiency of a decision process". The decision support system must in addition assist the decision makers in evaluating and interpreting the outcome of the

analysis. This is crucial as many incorrect decisions could be made due to a misunderstanding of the variables and interdependencies involved. Loetscher (2002) points out that the main objective of a DSS is to increase the likelihood for good decisions by improving the quality of decision making. Holsapple and Whinton (1996) identified five specialised types of DSS, including text-oriented DSS, database-oriented DSS, spreadsheet-oriented DSS, solver-oriented DSS, and rule-oriented DSS. Decision support system (DSS) practice, research and technology are dynamic and continue to evolve.

4.12.1 Expert Systems

An expert system, also known as a knowledge based system, is a computer program that contains the knowledge and analytical skills of one or more human experts, related to a specific subject. As an artificial intelligence (AI) technique, it has been applied by many of the more practical researchers, in an attempt to prove that AI is a valid science with practical applications. An Expert System provides professional advice through the gathering, codifying and application of accumulated human knowledge and experience in a specific field of expertise. The system developed has problem solving expertise which is tailored to the specialised problem to be solved. According to Safaa *et al*. (2002), a basic expert system consists of three sections, namely;

- Knowledge base;
- Inference or Reasoning engine; and
- User interface.

New technological advances have made it feasible to use artificial intelligence for the monitoring and control of operations in a waste-water treatment plant. Three systems have been developed for that purpose, namely, expert systems, fuzzy control systems, and neural networks.

4.12.2 Review of Decision Support Use

In developing countries, water, sanitation, and hygiene practitioners need a way to choose among the numerous available options for securing safe water and sanitation. According to Palaniappan *et al.* (2008) effectively addressing community needs requires that technologies or approaches be economically, ecologically, and socially appropriate and sustainable. **Decision-making support tools** help address this need, guiding practitioners to the most appropriate water and sanitation solutions. A critical aspect of this research was the review of existing decision support methodologies for selection of water and wastewater technologies. Several efforts have been made in the development of decision support programs as valuable tools 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; Adewumi, 2010). In the field of wastewater treatment engineering, several contributions have been made to arrive at optimum treatment design by the use of computer programs.

According to Agudelo *et al*. (2007), many efforts have been made to define multi criteria methodologies as an aid in the selection of urban water systems. Agudelo *et al*. (2007) argue that the methodologies used in each unique case are not comparable since they differ in objectives and boundaries definitions. The following are some important studies that have employed multi criteria decision aid. 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.

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. 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. Muga *et al*. (2007) avoid aggregation of criteria and presents results in a radar plot which is satisfactory for communication and discussion requirements. All these methods have been used as a form of support for the decision making process. Agudelo *et al.* (2007) acknowledge that complicated software to make complex analysis have been developed, however, the reliability of the results depends on the quality of the input data.

4.12.3 Decision Support Systems in Use

There are a variety of DSS in use in the wastewater field. A summary of the common DSS used or mostly referred to in literature is in sections 4.12.3.1 to 4.12.3.3 and are by no means exhaustive of the possible options. The main reason for choosing the DSS shown in sections 4.12.3.1 to 4.12.3.3 is solely on the basis of their applicability or potential for application in developing countries.

4.12.3.1 SANEX

SANEX is decision support software that aids planning and assessment of sanitation technologies for developing communities. The program is oriented toward developing country applications but may be useful to rural communities in industrialised countries as well. SANEX provides interactive menus for users to identify options and evaluate costs for their specific community needs and values via a “weighting” system. The software then screens out infeasible sanitation options and allows the user to compare remaining options for costs and performance. The Sanitation Compendium can be used in conjunction with SANEX or alone as a resource for information and illustrations of sanitation technologies (Loetscher and Keller 2002).

4.12.3.2 WAWTTAR

The Water and Wastewater Treatment Technologies Appropriate for Reuse (WAWTTAR) program is a decision support tool to aid communities in effective and sustainable treatment and reuse planning. The WAWTTAR program has an extensive database that includes many alternative water and wastewater treatment options emphasising water reuse. This tool is able to compare centralised and decentralised options for wastewater treatment and reuse as well as alternative collection systems. The U.S. Agency for International Development's Environmental Health Project (EHP) originally developed the WAWTTAR program in 1996.

4.12.3.3 COSMO

North Carolina State University has developed a predictive cost-estimation model called COSMO (Costs of Onsite Management Options), which can predict costs for 46 different combinations of pre-treatment options, distribution technologies, and other units which fit together in a treatment train, with varying loading rates, design flows, etc. Costs of equipment, materials, labour, etc. can be varied with local conditions and the characteristics of the site.

Most of these models developed based their assessments on technical and economic criteria without incorporating important factors such as social and environmental factors in the assessments. These factors are crucial in wastewater planning and on them hinge the failure or success of a project. Despite the many DSSs developed in the wastewater management, the chance of Decision Support Systems failing to meet the challenge of real-world problems is reported to be high and even the criteria for judging whether a DSS has been successful or not are often a matter of discussion (e.g. Zapatero, 1996; Newman *et al.*, 1999; Giupponi, 2007). There is therefore a widely-recognised need to develop new decision support tools in this field, with

greater attention to the context specific needs of the users and which can be tangibly applied to solve practical problems.

This research presents a practical tool for decision support system that was developed that is context oriented and enables all sustainable criteria to be evaluated in two steps and across many alternatives (solutions) through the utilisation of Multi Criteria Decision Aid (MCDA) with respect to technical, environmental and social impacts first and later with respect to economics. Earlier studies have used a comprehensive, multi-disciplinary set of indicators but they did not compare conventional/mechanical, package plants, ecological, ponds and land treatment technologies as proposed in this research. Mihelcic (2007) utilises the triple bottom line in assessments of wastewater technologies but uses the target plot analysis in assessment of sustainability. This research considered the use of MCDA in sustainability assessment of wastewater technologies and systems.

4.13 Summary

In spite of a wealth of materials on the types of wastewater systems, there is little material available that describes how communities actually go about making decisions on questions such as posed in this research. For instance, while the literature often alludes to the politics of wastewater decisions, rarely is a community's needs taken into consideration. There is a need for a clear method for the selection of relevant solutions for wastewater and sanitation management. Such a method should be an operational tool, adapted to the planning processes in the municipality and should support decisions of sustainable management. Literature studies show that sustainable indicators are frequently used in reporting, but not in planning and decision making and hence will not contribute to sustainable development. This study is designed to fill this gap. It is based on the premise that communities can make better choices if their needs are addressed within the planning and decision making

process. Sa-nguanduan and Nititvattananon (2010) comment that making a final decision should be based on the decision makers' purposes and context.

The real challenge to MCDA is to help individual or municipal authorities responsible for planning or decision making to make effective and defensible solutions. Multi criteria decision aid is one transparent way of enabling stakeholders to have a say in the decision making thus giving a 'voice to the voiceless' under centralised wastewater management. MCDA adds value to the decision making by helping the decision maker learn about the problem and also helping to elicit value judgements about trade-offs between conflicting objectives. This MCDA tool is to be used as a context-oriented planning tool by water service authorities and is useful in demystifying and communicating the decisions to a wider stakeholder base.

CHAPTER 5

DECISION MAKING METHODOLOGY AND A DECISION SUPPORT SYSTEM FOR WASTEWATER MANAGEMENT IN GAUTENG

5.1 Outline of the Analytical Methodology

From the insights gained by the study of decision making processes in wastewater management and in particular the insights gained by doing a case study for the 8 municipalities in Gauteng a clear algorithm for the decision making methodology for wastewater management in Gauteng emerged and is presented in Figure 5.1. The algorithm was developed on the basis of the information provided by the provincial government and the current practices in the respective municipalities which relates to water supply service levels and choice of sanitation as shown in Table 5.1.

The options for excreta disposal were expanded in order to include decentralised wastewater systems instead of just the centralised systems. According to Marjanovic *et al*. (2010), the Gauteng Sanitation policy only alludes to two forms of wastewater technologies (Full waterborne and VIP) and highlights that intermediary solutions/options will not be considered. Apart from the water supply levels as is the current practice, the algorithm also includes the local context of the area in which the sanitation solutions can be implemented. This was critical in coming up with appropriate sanitation options for the case study, since technology on its own is not sustainable but is a rule function of the local context. The following steps were critical in developing the algorithm;

- Analysis of current practices and solutions to wastewater management

- Analysis of global best practices
- Analysis of the local context (i.e. geotechnics/site specifics of the area
- Analysis of the demographics of the area
- Fusion of current and best practises in order to ensure sustainable sanitation

Table 5.1 Water Supply Levels and Choice of Sanitation (SALGA, 2003)

Water supply level	Typical water consumption (l/c/day)	Options for excreta disposal	Options for sullage disposal
No water supply	<5	VIP	None
Carted water	<10	VIP	None
Borehole	<25	VIP	Soakaway
Public standpipes	20-40	VIP latrines LOFFLOS	Soakaway
Yard tapes	50-100	VIP latrines LOFFLOS Septic tanks Solids free systems	Soakaway sewer
House connection	>100	Septic tanks Solids free systems Conventional	Soakaway sewer

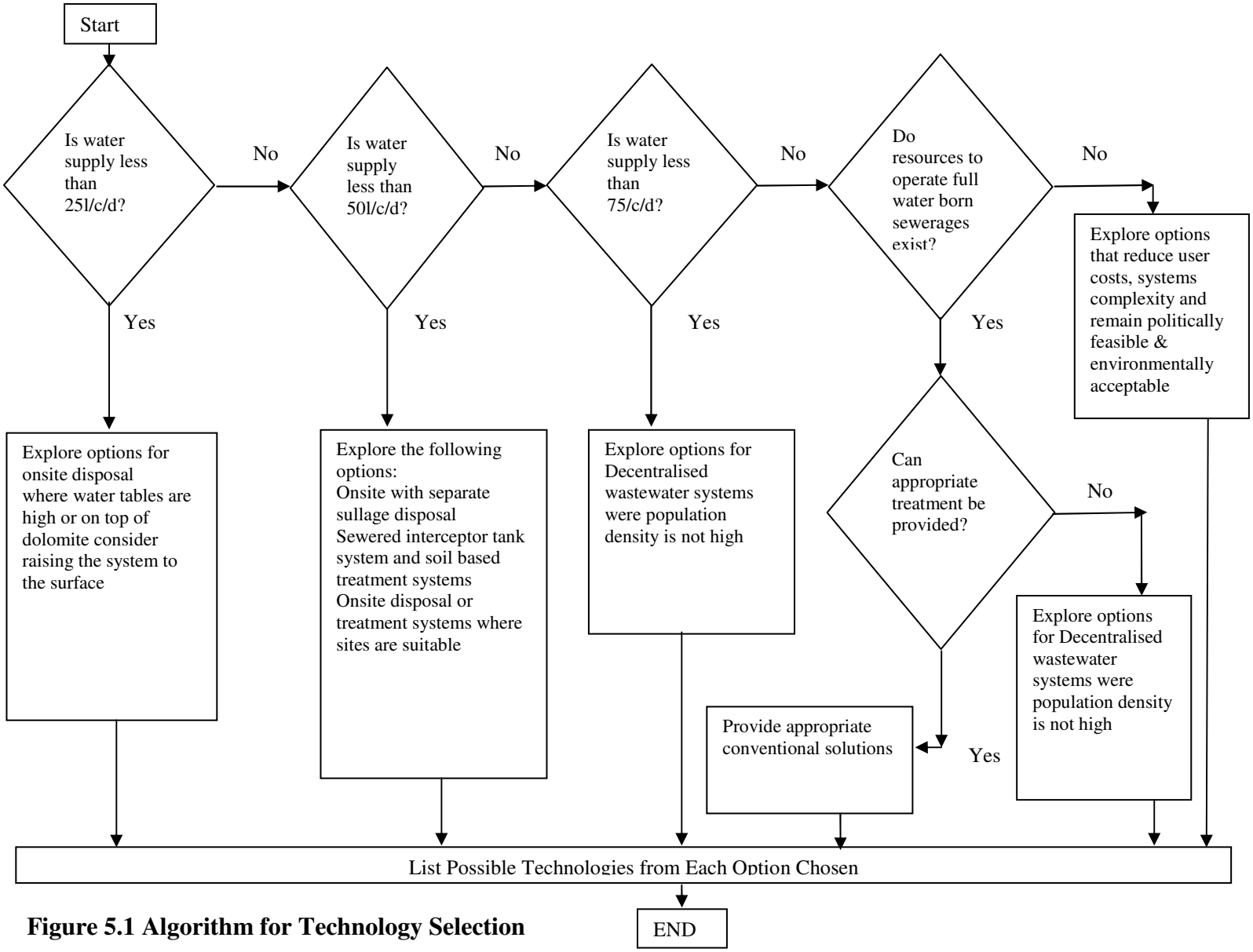


Figure 5.1 Algorithm for Technology Selection

The algorithm in Fig 5.1 output led to the development of a technology database in the DSS in Appendix G. The database includes dry and wet sanitation options for wastewater management. The list presented in this study is case specific for the areas under study and is by no means exhaustive of all the possible options. The algorithm makes it easier to narrow down the options based on the local context and preferences of the stakeholders in technology selections. As can be seen in Fig 5.1, an array of all possible wastewater treatment technologies can be considered from onsite dry sanitation to offsite full waterborne systems which then based on the local context is taken to the next level of analysis using MCDA. The systematic computation procedures for running the model are outlined in Appendix H.

5.1.1 Goal and Scope Definition

Wastewater management is fairly broad and looks at wastewater from a point of generation, collection, separation, conveyance, storage, treatment, reuse and disposal. All these processes are critical for overall wastewater management. This research focussed on the treatment process only (technology). The reasons for focussing on the treatment stage are given in Chapter 4 but in summary it is the stage with the highest environmental impacts as well as resource utilisation requirements. The collection represents 80-90% of total system costs and it is in this area that centralised benefits from economies of scale but it is the diseconomies of scale that people are not aware in treatment costs. Smaller systems loose the advantages of economies of scale that are possible in wastewater treatment capital costs and O&M costs. However, smaller systems also avoid diseconomies of scale that are inherent in sewer systems. Given that collection system costs are roughly 80-90 % or more of total systems cost, collection diseconomies of scale can overwhelm treatment economies of scale, resulting in decentralised systems being the more economical choice.

5.1.2 Defining Alternatives

All municipal authorities in the 8 municipalities were given an opportunity to list the possible technologies that could be utilised in their respective municipalities. These exercises were done in separate meetings with the municipal officials in the 8 municipalities between March 2009 and July 2010. This information coupled with literature studies then led to the development of the algorithm in fig 5.1. The basic philosophy for the development of the algorithm was that the origin of wastewater is water consumption (water supply). Hence, for every level of water supply there is a context specific array of wastewater options. The iterative process is shown in Fig 5.1. This framework enables one to come up with relevant site specific alternatives which are context based and appropriate to the area.

On the basis of literature review relevant to wastewater treatment technologies (Sperling, 1996) and on the basis of the survey carried out as a part of this research a judgement was made as to the suitability of any given technology for either centralisation or decentralised systems. It is noted that all technologies could potentially be applied within the continuum of centralised – decentralised framework, however some technologies are better suited for smaller decentralised systems and vice versa. This suitability factor was used to allocate preference structures to each particular technology within the context of centralised decentralised framework (1- Not suitable, 2- partially suitable; 3-fairly suitable; 4-suitable, 5- Highly suitable). The results of the judgement and analysis process are summarised in Table 5.2 and can be used in technology selection process

Choosing from a large set of technologies can be complex and time consuming, which may cause most officials to disregard decentralised technologies. In order to make the selection much easier this research constructed a technology database in the DSS as shown in figure 5.2 and also highlighted in Appendix G. By double clicking on the technology name, a summary of information of the technology is shown which enables a comparative analysis with other technologies in the database.

Table 5.2 Technology Suitability for Centralised or Decentralised Systems

Technologies	Suitability For		How Suitable for Centralised Systems					How Suitable for Decentralised Systems				
	Centralised	Decentralised	Highly Suitable	Suitable	Fairly Suitable	Partially Suitable	Not Suitable	Highly Suitable	Suitable	Fairly Suitable	Partially Suitable	Not Suitable
Activated sludge	√	√	√							√		
Trickling filter (biofilters)	√	√	√					√				
Rotating Biological Contactors	√	√		√				√				
Aerated lagoons	√	√		√				√				
Anaerobic lagoons	√	√		√				√				
Facultative ponds	√	√		√				√				
Recirculating biological filter		√			√			√				
Submerged aerated biological filter		√			√			√				
Sequence batch reactor	√	√			√			√				
Oxidation ditches	√	√			√			√				
Bio disc units	√	√			√			√				
Constructed wetlands	√	√			√			√				
Living machines		√					√	√				
Aquaculture		√					√	√				
Slow infiltration		√				√		√				
Rapid Infiltration		√				√		√				
Overland Flow		√				√		√				

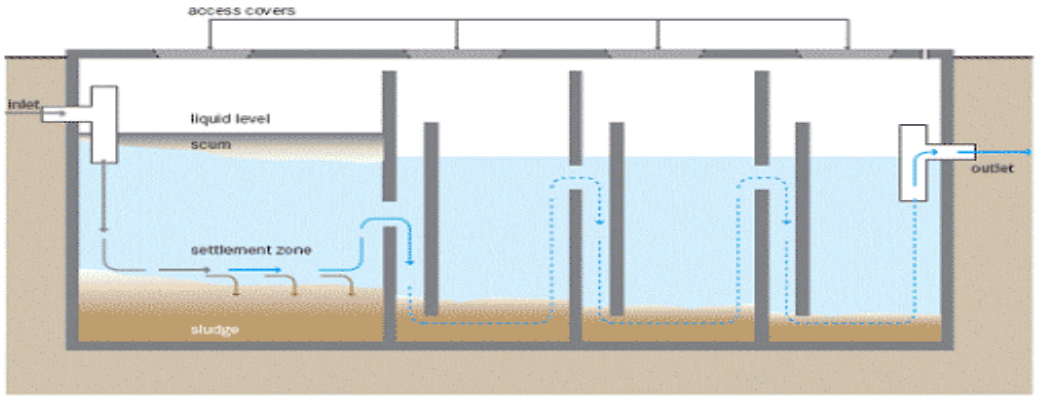
WASTEWATER TECHNOLOGIES FACT SHEETS

Anaerobic Baffled Reactor	Anaerobic Filter	Waste Stabilization Ponds	Anaerobic Pond	Facultative Pond
Free-Water Surface Constructed Wetland	Horizontal Subsurface Flow Constructed Wetland	Vertical Flow Constructed Wetland	Trickling filter	Rotating biological contractor

Technology: Anaerobic Baffled Reactor

Description: An Anaerobic Baffled Reactor (ABR) is an improved septic tank because of the series of baffles over which the incoming wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment. The majority of settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50% of the total volume. The up-flow chambers provide additional removal and digestion of organic matter: BOD may be reduced by up to 90%, which is far superior to that of a conventional septic tank. As sludge is accumulating, desludging is required every 2 to 3 years. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up-flow velocity of the wastewater less than 0.6m/h and the number of up-flow chambers (2 to 3).

Diagram:



Application level: household and cluster systems

Figure 5.2 Dialogue Screen on Technology Factsheets

The database also allows for further addition of technology in the prescribed format in which the user is guided through. The database provides a description of the different technology types which will act as information for educating and providing better understanding of the technologies which will eventually lead to the decision makers having confidence in the decisions they make.

5.1.3 Selecting Pertinent Criteria

This research considered the use of MCDA in sustainable assessment of wastewater technologies and systems. Indicators developed in this study were reviewed and customised to the South African conditions based on the input from the Water Service Providers and provincial authorities and as well with reference to published indicators. In light of field testing experiences, it was recommended that *Ranking* and/or *Rating* be used as initial screening tools as they provide a quick way to filter out criteria that are not sufficiently significant. A set of 39 criteria was initially set (Appendix C) and was consolidated by eliminating overlaps as much as possible. A ranking exercise using a set of questionnaires in Appendix C and was used and criteria were accepted or rejected over the average value score obtained from the ranking. The screening of criteria was done on the basis of the scale shown in Table 5.3.

Table 5.3 Criteria Classification

Classification of Criteria	**Score Range**	**Decision**
Highly Significant	10	Accept
Significant	7-9	Accept
Fairly Significant	5-6	Accept/Reject
Insignificant	<5	Reject

A summary of the questionnaire results is presented in Tables 5.4 to 5.7. In order to be useful this set needs to be continuously revised since the choice of criteria may change as knowledge advances. One new dimension proposed in this research is to define sustainability over a time range say over 40 years, since some criteria may currently not be important but with time they might turn out to be the most important. Hence, in this research what is termed rejected criteria is so for the current time and who knows how things might turn out in the next years to come. The rejected criteria for this research are archived in a set which is not considered in further upstream processes for the decision making.

Table 5.4 Technical Criteria Ranking

	TECHNOLOGY SELECTION CRITERIA	**Scale (From 1 to 10)**
1	Performance (BOD,TSS, N & P % removal)	10
2	Operation & Maintenance Requirements	6
3	Monitoring/Inspection Requirements	6
4	Sensitivity to Variable Flow and Loading	6
5	Relative Operation Complexity	5
6	Reliability	8
7	Ease of Construction	8
8	Local Design Capacity	6
9	Mechanical Complexity	6
10	Sensitivity to Power Shortages	6
11	Information Management Requirements	6
12	Adaptability	7

Table 5.5 Economic Criteria Ranking

	Economic Criteria	**Scale 1 to 10**
1	Cost Per Unit of Water Treated	7
2	End User Cost	8
3	Need for Special Chemicals	6
4	Capital Intensity	7
5	Financial Intensity	7
6	Financial Risk	8
7	Operation & Maintenance costs	9
8	Affordability	9
9	Willingness to pay	7

Table 5.6 Environmental Criteria Ranking

	Environmental Criteria	**Scale 1 to 10**
1	Energy requirements	8
2	Land use requirements	7
3	Chemicals requirements	7
4	Potential for reuse	8
5	Total Environmental Risk	9
6	Groundwater pollution	9
7	Surface water pollution	8
8	Ground water recharge	6
9	Air emissions	7
10	Noise pollution	7

Table 5.7 Social Criteria Ranking

	Social Criteria	**Scale 1 to 10**
1	Public participation	7
2	End user preferences	7
3	Awareness	8
4	Job Creation Potential	9
5	Managerial Complexity	6
6	Local Content Availability and Experience	6
7	Institutional requirements changes	8
8	Health impacts on failure	10

Table 5.8 Sustainable Criteria

Main criteria	**Unit of measure**
Performance	% Removal
Reliability	Qualitative
Adaptability	Qualitative
Ease of Construction	Qualitative
Resource Utilisation	Qualitative
Environmental Impact	Qualitative
Acceptance	Qualitative
Awareness	Qualitative
Job Creation	# of jobs created
Institutional Requirements	Qualitative
Health & Safety Impact	Qualitative

The final set of criteria finally ended with eleven main criteria. The set of eleven criteria is presented in Table 5.8 and is not to be regarded as a final set in any aspect other than representing the final result of this research.

5.1.4 The Weighting Process

A relatively simple approach to eliciting weights is the swing weight approach. For quantitative criteria, the number alone would be sufficient, while for qualitative criteria, the levels need to be described in words. Following the

procedure in Table 4.1 the following weights were calculated using equation 4.1 as shown in Figure 5.3. The same procedure in employed in calculating the main criteria weights is extended to the individual criterion under the three main criteria in order to come up with an individual weight of every criterion regarded for the evaluation.



Fig 5.3 Dialogue Screen on Weights Determination

5.1.5 Assessments

Most comparisons were done on a qualitative scale. Criteria which were quantitatively assessed were job creation and performances. The ranges of percentage removals obtained from literature are shown in Table 5.9.

Table 5.9 Performances of Technologies

Technology	% Removal				
	BOD	TSS	N	P	Faecal coliforms
Mechanical					
Activated sludge	60 - 99	85 - 99	15 - 45	20 - 30	96 - 99.9
Trickling filter (biofilters)	65- 98	42 - 97	15 - 45	20 - 30	95 - 99.9
Rotating Biological Contactors	80 - 95	80 - 90	15 - 50	20 - 30	95 - 99.9
Ponds					
Aerated lagoons	60 - 96	65 - 95	15 - 25	20 - 30	95-99.9
Anaerobic lagoons	30 - 96	35 - 80	15 - 25	20 - 30	95 - 99.9
Facultative ponds	75- 95	90 - 97	43 - 82	10 - 50	90-99.9
Package plants					
Sequence batch reactor	90 - 98	90 - 99	90 - 98	30 - 50	99,9
Oxidation ditches	96-99	96 - 99	95 - 99	30 - 48	99,9
Bio disc units	80 - 95	90 - 99	80 - 95	20 - 30	99,9
Ecological treatment methods					
Free water surface constructed wetland	80 - 95	80 - 95	15 - 25	20 - 30	90 - 99
Living machines	96 - 99.9	90 - 100	75 - 81	45 - 65	95-99
Aquaculture	88 - 98	36 - 98	38 - 65	48 - 72	95-99
Land treat ment					
Slow	90 - 99	90 - 99	60 - 90	80 - 99	99,9
Rapid	75 - 99	58 - 99	38 - 95	40 - 97	90 - 99.9
Overland	70 - 95	60 - 95	75 - 90	40 - 60	99,9

(Derived from: Sperling, 1996; Metcalf & Eddy, 2004; Mihelicic, 2007; Massoud, 2008)

5.1.6 General Assessments Methodology

A questionnaire administered to the decision makers/service providers is shown in Appendix D. The responses derived from the questionnaire are input into the DSS for analysis. The DSS uses a scale of 1-5 to generate a score from a set of questions/statements. The result obtained by summation of all questions/statements is then aggregated to obtain standardised outcome score on the scale 0 to 10 for the technical, social and environmental criteria. Arithmetic mean is used to aggregate the standardised value obtained in questions/statements involved in DSS questionnaires using equations 5.1 to 5.3.

The minimum number of respondents to questionnaires needed to make the methodology developed and the tool implemented a reliable instrument to support effective decision making is 50. This figure is derived from social statistics analysis literature in order to eliminate bias in the decision making and to increase the confidence in the results derived from the decision support system.

$$d_{ave} = \frac{1}{m} \sum_{i=1}^{n} X_{ij} \qquad \text{Eqn (5.1)}$$

Where d_{ave}= aggregation result for assessment criteria j (j = 1, 2, 3, 4…m)

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

The final score on a scale of 0 to 10 is derived from the following positions;

If the Target for an indicator is Maximum score, then

$$\text{Score} = (d_{ave} - d_{low})/d_{max} - d_{low})*10 \qquad \text{(Eqn 5.2)}$$

If the Target for an indicator is Minimum score, then

$$\text{Score} = |(d_{ave} - d_{low})/d_{max} - d_{low}) - 1|*10, \qquad \text{(Eqn5.3)}$$

d_{low} is the lowest value over the range of scale considered

d_{max} is the maximum value over the range of scale considered

5.1.7 Weighted Sum Method

The Weighted Sum Method involves computation through maximising the expected utility function, H_j, as in the following:

$$H_j = \sum_{i=1}^{m} w_i v_{ij} \qquad \text{Eqn (4.2)}$$

where m is the number of criteria of alternative j, v_{ij} is the value of jth alternative with respect to the ith criterion, and w_i is the weight of importance assigned to criterion i with the constraints of $w_i \geq 0$ and

$$\sum_{i=1}^{m} w_i = 1 \qquad \text{Eqn (4.3)}$$

The scores derived from use of the above equations are based on theoretical values, which were formulated using a combination of literature studies and assessments by the researcher in collaboration with Gauteng Provincial local government officials as well as Witwatersrand University postgraduate students for the Wastewater Engineering course. The research initially sought to base the scores from the municipal officials in the case study but due to the low responses (40 out 100 responded) on the questionnaires it was decided to use the above combinations in order to generate data for analysis and input in the decision support system as a way of testing the methodology.

It is noted that within the context of the South African water sector it is extremely difficult to extract the information on what stakeholder requirements are, due to lack of capacity within government institutions dealing with wastewater management and what would be required is an intensive capacity building on wastewater management issues of the relevant stakeholders prior to the identification of the stakeholder needs. This capacity building was beyond the scope of this research and as a result full validation of the model and the methodology is recommended for the next level of research which should be initiated conditional on prior capacity building program implementation.

5.2 Discussion of Results

The results presented in this section are from the outcomes of the questionnaire survey. It should be noted the results presented herein are not conclusive of the research studies since in the case for Municipal officials the responses out of a possible 100 only 50 responded but 10 responses were incompletely filled and could not be used. Despite repeated efforts to get responses there was no commitment to complete the exercise. This might be understood from a practical case in the study areas where municipal officials are bombarded with

questionnaires from different consultants asking the same things in different ways and formats but from the surveys there is nothing tangible they receive that comes from the various researches. On the other hand the responses from the postgraduate students for the wastewater engineering course were encouraging. Out of a possible 45 students 37 managed to complete the questionnaires with high enthusiasm.

5.2.1 Access to Information

The Promotion of Access to Information Act, No 2 of 2000 ("the Act") was enacted on 3 February 2000, giving effect to the constitutional right of access to any information held by the State and any information that is held by another person and that is required for the exercise or protection of any rights. The major challenge in the South African context is the enforcement of such laws. The European Union uses the Aarhus convention Treaty which is similar in some aspects to the Access to Information Act of South Africa.

The Aarhus Convention is a Treaty of the United Nations Economic Commission for Europe (UNECE). Its full title is 'Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters'. The Aarhus Convention represents enforceable binding law in most member states of the European Union (EU), including the UK. It is designed to improve the way ordinary people engage with government and decision-makers on environmental matters, it is expected that the Convention will help to ensure that environmental information is easy to get hold of and easy to understand. The application and enforcement of such Act to the research would have added value resulting in a broader participation and meaningful decision making process.

5.2.2 Comparative Criteria Ranking

The results highlighted in Fig 5.4a and Fig5.4b shows that Technical Officials and Postgraduate students ranked Technical and Economic criteria higher than the social and environmental criteria. The result of the survey generally confirms the traditional thinking that economics and technology are the key pillars of sustainability. This research challenges this thinking and proposes a paradigm shift which considers the stakeholder needs first. This outlines the importance of non-technical considerations in choosing the technologies. Optimal solution for treatment is not a technical or economic need but should be driven by the needs of the users and the environment in which the technology would function. There is a need for a paradigm shift in thinking and the methodology developed in this research will help in changing the traditional thinking and move onto the critical thinking required for sustainability.

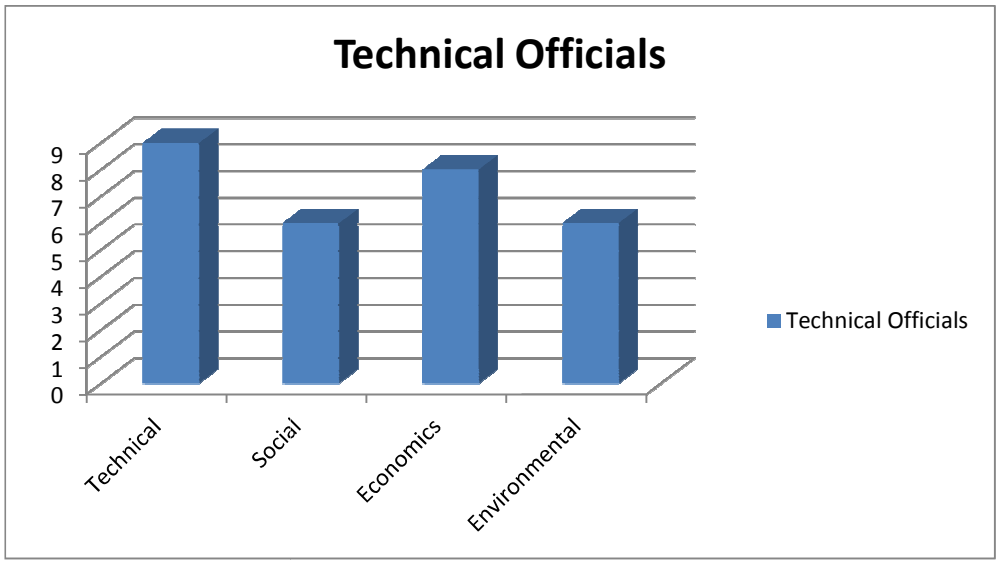


Fig 5.4a Ranking of Main Criteria- Technical officials

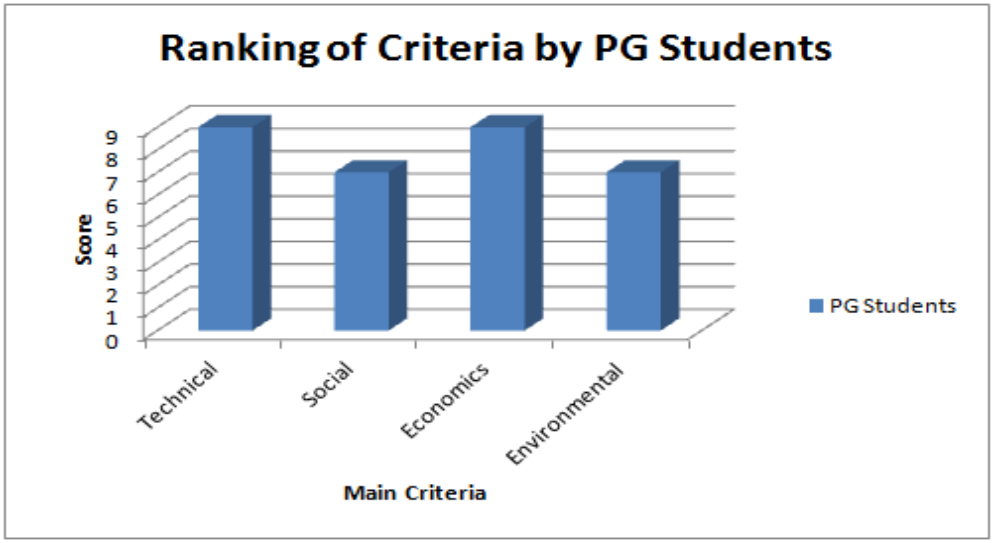


Fig 5.4b Ranking of Main Criteria- PG Students

5.2.3 Ranking of Technical Criteria

In terms of technical criteria the research survey results are in agreement with literature studies since what's more critical about any technology is its performances in terms of removal efficiencies and its reliability in providing its objective function without fail. Fig 5.5 shows that performance was ranked higher than other criteria within the technical category.

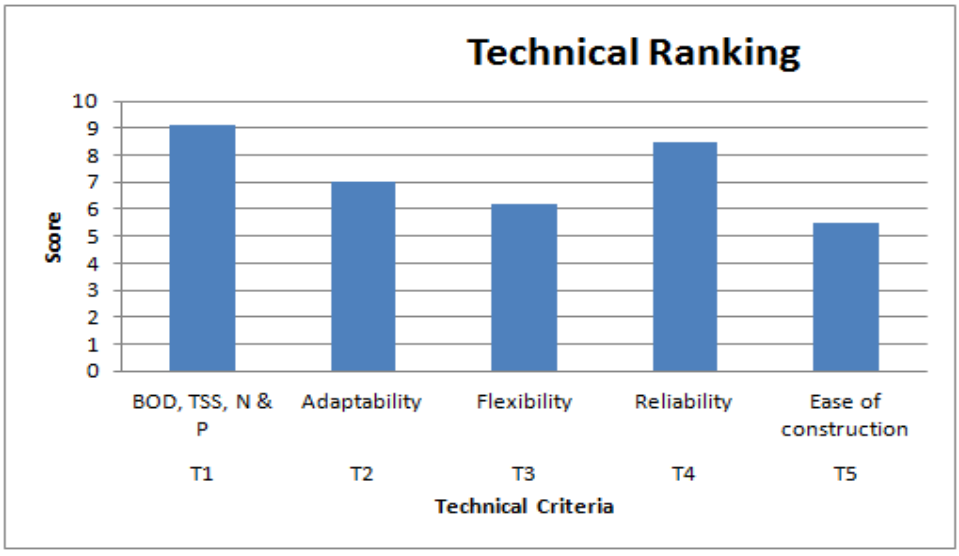


Fig 5.5 Ranking of Technical Criteria

5.2.4 Ranking of Environmental Criteria

Fig 5.6 shows that energy requirement was ranked higher than other criteria within the resource utilisation category while water pollution (surface and groundwater) was ranked higher than others in the environmental risk category. Energy is of critical importance since its costs have a domino effect on the economy. Overall all environmental criteria scored higher except for aesthetics and noise pollution. This is an encouragement in terms of environmental management since most policy and thinking is anthropocentric but the thinking shown here is eccocentric.

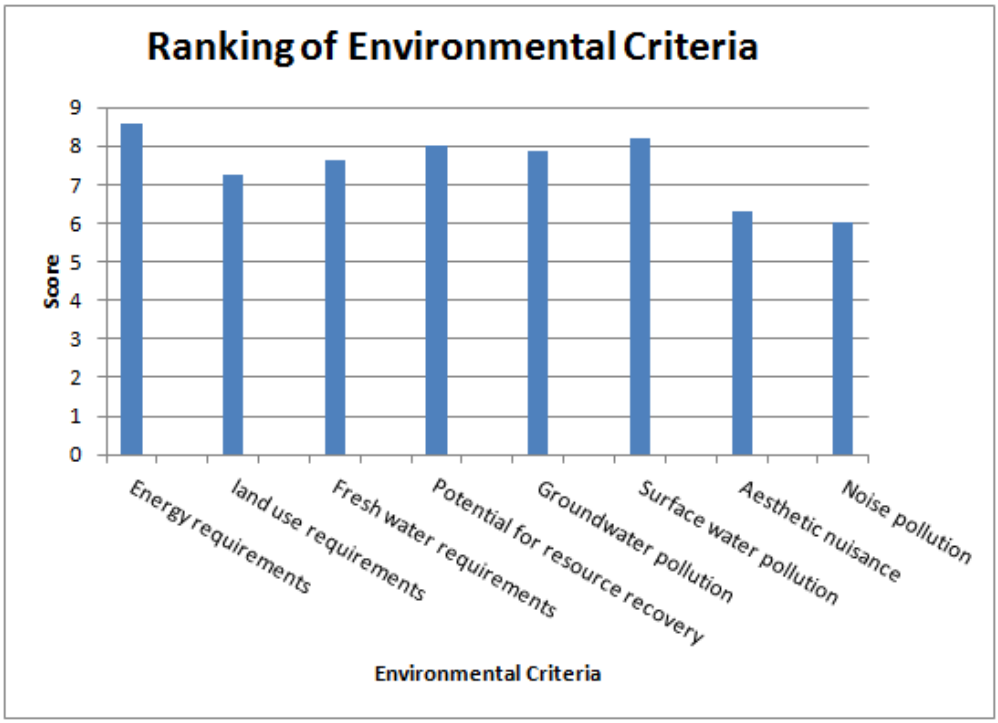


Fig 5.6 Ranking of Environmental Criteria

5.2.5 Ranking of Economic Criteria

Fig 5.7 shows that O & M cost were ranked higher than other criteria within the Economic category. This is surprising since in most cases in practice it is the capital costs which have more say in determination of the viability/feasibility of a

project despite the fact that people perceive reoccurring costs as being more important. One possible explanation is that the decisions in practice are made by the people paying for the construction of the project (client/government) thus for them their cost is most important. On the other hand the users (homeowners) consider their cost and O&M which are actually user costs as this is what determines the rates and taxes. None of the respondents could be considered in the role of a client but more as users.

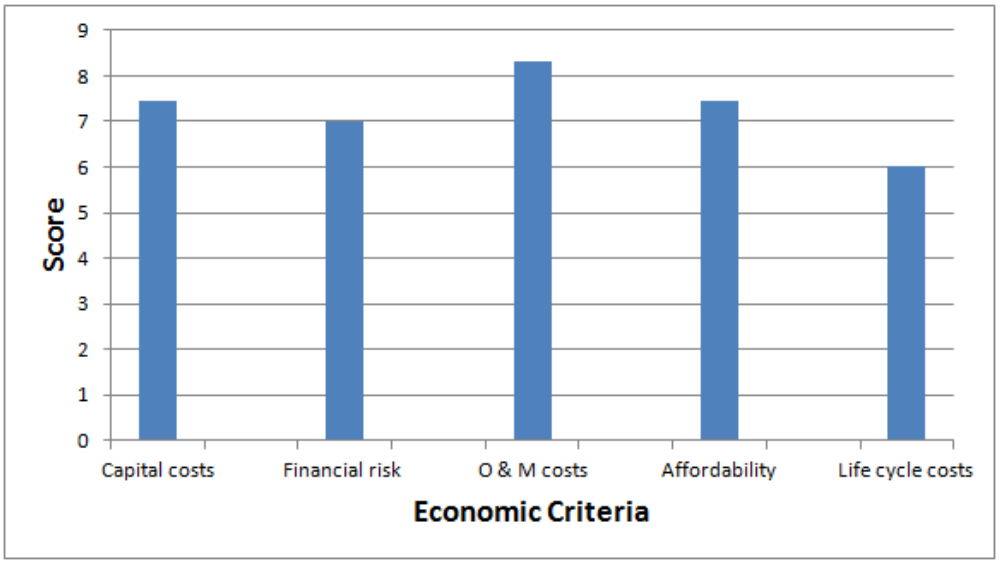


Fig 5.7 Economic Costs Ranking

5.2.6 Ranking of Social Criteria

Fig 5.8 shows that health impact was ranked higher than other criteria within the social category. The objective function of any wastewater treatment plant is to meet the goal of public health and it is not surprising that the survey results also concur with that.

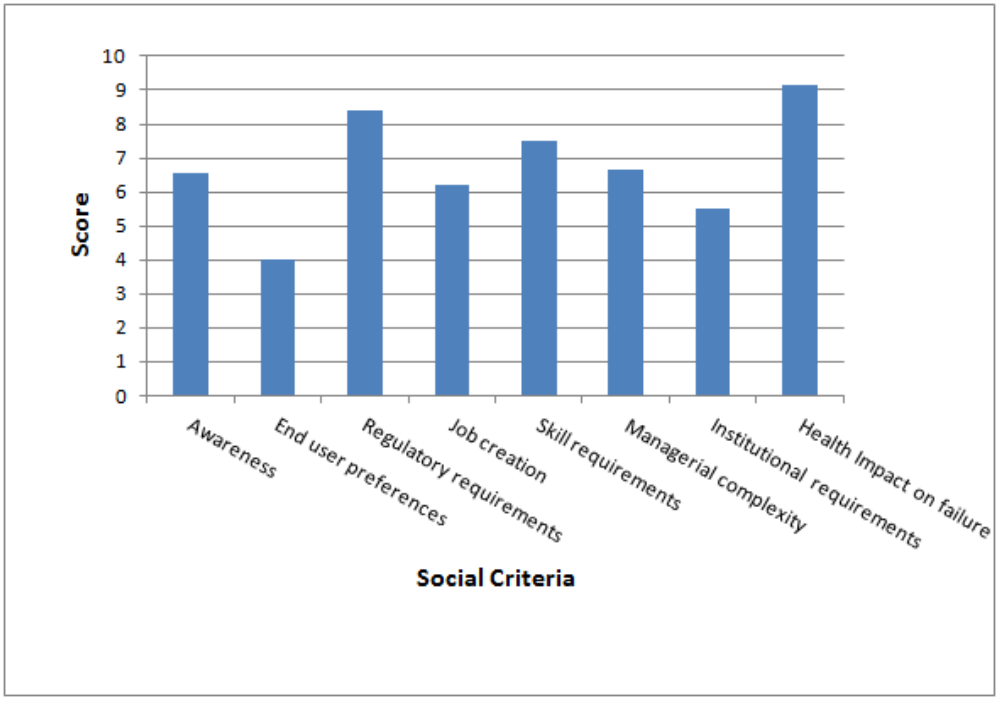


Fig 5.8 Social Criteria Ranking

5.2.7 Perceptions to Wastewater Systems

Fig 5.9 shows that decentralised systems are perceived to perform better than centralised systems. This rational is not surprising since the analysis comes from postgraduate students who are deemed to have more theoretical knowledge of wastewater systems. The results also show a bias since the students had gone through the Wastewater Engineering course which in a way contributed to the bias since the course seeks to challenge conventional thinking in wastewater management. Technical officials' survey reveals the opposite and the explanation is simply that they have not had chance to explore the new knowledge on decentralised systems available and also have a high inertia to change to the critical thinking required.

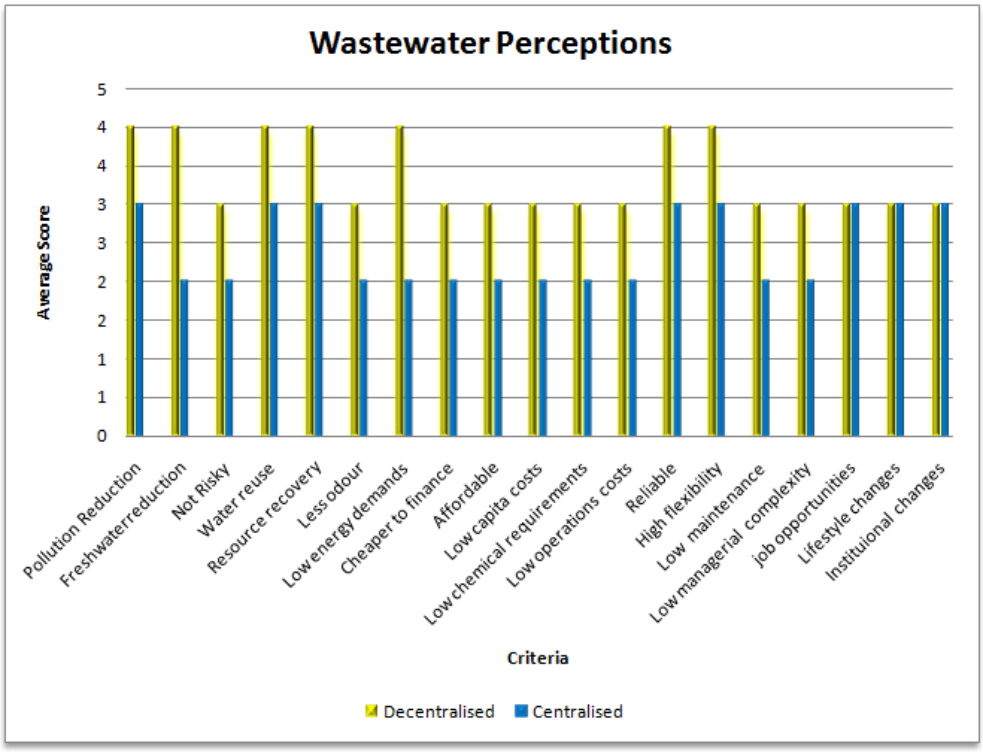


Fig 5.9 Perceptions to Wastewater Systems

5.2.8 Results of the first step MCDA Evaluations

The main criteria normalised weightings for the case study were as follows; technical (0.4), social (0.3) and environmental (0.3). The weightings were derived using the swing method at a workshop held with the municipal officials. The full computational procedures for the model are explained in appendix H. The evaluations using MCDA show that land treatment systems, followed by package plants, ecological and stabilisation ponds are more sustainable than the mechanical systems (Figure 5.10). The mechanical systems have high requirements for resources in terms of energy and may require the use of chemicals in some instances. The advantages of the land treatment systems are their low odour potential, as well as high performance in removals of BOD, TSS, N, P and faecal coli forms. Land treatment systems and lagoons both have lower energy requirements although they have high land requirements.

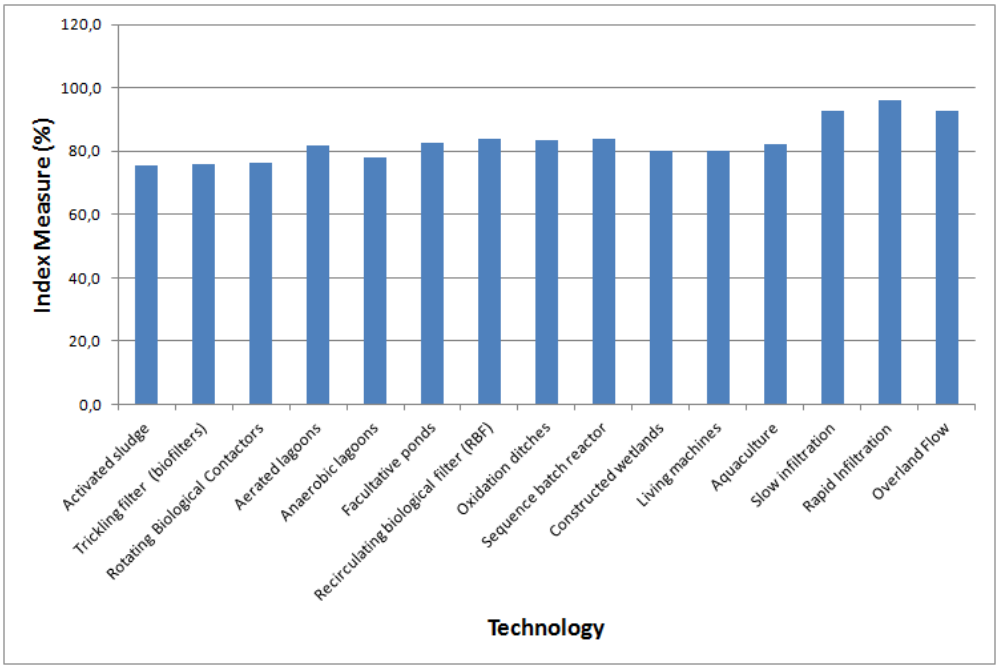


Figure 5.10 Ranking of Technologies

The overall results from the calculation are ranked through a bar chart as shown in Fig 5.10, with the most sustainable technologies having a higher percentage score or length on the chart. Table 5.10 shows the scale used for analysis and for acceptance for the possible sustainable solutions.

Table 5.10 Sustainability Index Classification

Classification of Choice	Sustainability index (%)	Sustainability Ranking
Excellent	80 - 100	Highly Sustainable
Very Good	70 - 80	Sustainable
Good	60 – 70	Partially Sustainable
Fair	40 - 60	
Poor	<40	Unsustainable

5.2.8.1 Technologies Shortlist

Based on the scale highlighted in Table 5.8, all the technologies having a score above 80% were shortlisted for further assessment after a sensitivity analysis test. Table 5.11 lists the shortlisted technologies.

Table 5.11 Technology Ranking Shortlist

Rank Number	Technology
1	Rapid Infiltration
2	Overland Flow
3	Slow infiltration
4	Recirculating biological filter (RBF)
5	Sequence batch reactor
6	Oxidation ditches
7	Facultative ponds
8	Aquaculture
9	Aerated lagoons
10	Living machines
11	Constructed wetlands

5.2.8.2 Sensitivity Analysis

The results of the ranking can never be completely objective because of the weighting procedure, but confidence in the results can be increased by carrying out a sensitive analysis. This was done by looking at the effects on ranking caused by changes in the weighting. The criteria most open to subjective interpretation was selected and the weights of the criteria were slightly changed, recalculated and the final scores are summed up and re-ranking the technologies was done. Comparisons between the ranking order for different scoring and weighting scenarios indicated the level of confidence that can be given to the results. Minimal changes in ranking order indicate a high degree of confidence in the results. Conversely, wide variations in ranking will indicate that the results should be treated with care. The results or the set of solutions generated from the iterations becomes the short list of technologies to go for a detailed economic analysis. The economic feasible options are reported to the decision makers who then make the final decision.

The decision support system as it stands relies on 39 criteria which are evaluated in three iterations in order to get the criteria rankings (iteration1: questionnaire and result is weighting system; Iteration 2: verification and validation of criteria- resulting in a new weighting system and iteration 3: using the swing method to get final criteria weights) and as result the analysis can be tedious and a smaller set of important criteria would make the process simpler. In order to reduce the criteria set to a smaller number of criteria one approach is to carry out a sensitive analysis and determine impact of changes in initial weighting coefficients on final technology rankings. This would result in identification of criteria to which the particular decision making case is not sensitive to and those criteria can be eliminated from the decision making process.

Such a sensitivity analysis is beyond the scope of this research as it would require redoing the questionnaires with different groups of people to generate small changes of preference structures (criteria weights). Ad-hoc changes to criteria

weights by a user of the system is deemed inappropriate for sensitivity analysis purposes as it introduces personal bias and would make analysis invalid. For this reason it was not carried in detail in this research but to a limited extent in the first ranking of the technologies. The only sensitivity tests done were by varying the weight percentages of technical and the environmental main criteria over the range ±20%. The sensitivity test carried on the technical main criteria showed that there were no significant changes in the rankings. The environmental criteria proved to be the one more sensitive to weight changes but the rank order in terms of the categories of the technologies remained the same in as much there were rank changes within the categories depended on the increase in weighting for the environment.

5.3 Detailed Economic Evaluation

In developing countries, economic indicators are often decisive when choosing a technology. Unfortunately, in most cases cost data are hard to find, and many consulting firms or WSPs are not keen to share or publish their data for reasons best to known to themselves. Since cost data are hard to get this research advocates for the incorporation of the economic criteria for analysis in the decision making after the set of solutions derived from the MCDA utilising social, environmental and technical criteria. This will enable detailed investigations to be carried out which requires detailed costing that the municipal officials can commit to find/get before the final decision making and implementation of the findings. The results from the detailed economic analysis are then sent to the decision makers to enable them to make sound judgement in a structured and transparent way.

It is noted that in the absence of detailed cost information for South African conditions despite serious efforts made to obtain it, the Latin America and the Caribbean data was used to demonstrate the application of developed methodology (Table 5.12). It is obvious that this does not give results of a

practical value but it goes to demonstrate the strengths and weaknesses of the methodology. Only limited cost information was obtainable for selected technology options from South Africa: onsite dry & wet technologies and sewered waterborne systems. Other researchers like Adewumi (2010) attempt to carry out the detailed costing for the South African context using treatment trains approach in life cycle costing but this does not cover some of the technologies utilised in this research especially the land, package and ecological treatment units considered but such an attempt is a step in the right direction.

Table 5.12 Comparative Cost for Treatment Technologies

TECHNOLOGY	AVERAGE CAPITAL USD/M^3.d	AVERAGE O & M USD/M^3.d
Rapid Infiltration	800	45
Overland Flow	1450	120
Slow infiltration	1700	100
Recirculating biological filter (RBF)	1050	150
Sequence batch reactor	2000	60
Oxidation ditches	1300	50
Facultative ponds	750	90
Aquaculture	900	90
Aerated lagoons	700	120
Living machines	2000	200
Constructed wetland	800	85

Plant size is 3.8 X 10^2 - 3.8 X 10^3 m^3/day (After Tsagarakis, 2002)

Modified from UNEP, Sourcebook of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean.

Note: Figures converted from US$/gpd in original source, Reed *et al*. (1999).

5.3.1 Results of the Economic Analysis

The Caribbean data only accounts for the capital and operation and maintenance and it was on this basis that the final ranking was done. Using the swing method as outline in section 4.4, the normalised weights for the economic criteria were 0.7 and 0.3 respectively for capital cost and operation cost. The results from the evaluation using MCDA is shown in figure 5.11. The results show that land treatment system (Rapid infiltration), ponds and the ecological treatment methods (constructed wetlands and aquaculture) are more sustainable than the package plants. This is because the capital costs for the package plants are higher than those for the land and ponds treatment methods.

It should be noted that sustainability measure should not be limited to now but should be over a defined period say at least a minimum of forty years. Since what might not be sustainable now i.e. the high capital costs for the package plants might end up being feasible as the technologies start to be mass produced. It suffices to say that under present conditions the land, ecological and ponds treatment technologies are more sustainable but sustainability also has the connotation of the present generation having a knowhow of the needs of future generations. In view of this, this research advocates for continual review of the criteria and the dynamics involved with the changes in the economics and breakthrough in technologies which might occur in these decentralised technologies.

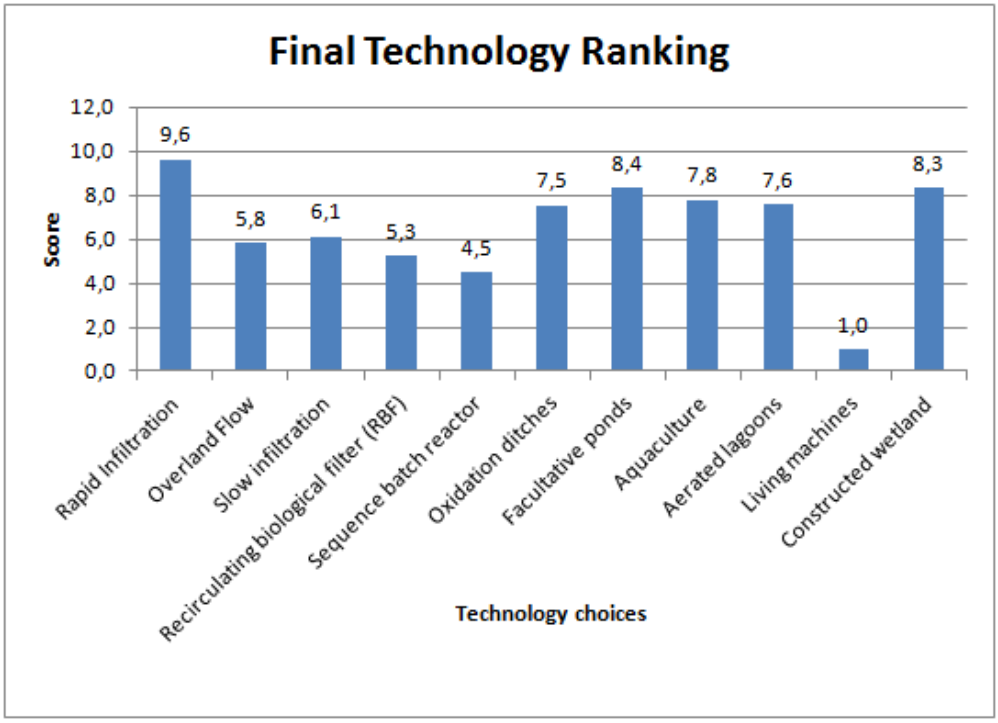


Figure 5.11 Final Ranking of Technologies

The results from the detailed economic analysis are then sent to the decision makers to enable them to make sound judgement in a structured and transparent way. The results from the methodology employed imply that technologies under decentralised wastewater systems appear to be more sustainable. The above assessments are all employed in the decision making support system developed for this study. It has a simpler graphical user interface which enables the user to navigate through and apply the methodology described here for selection of wastewater technologies

5.4 Results for a Hypothetical situation

This section considers the results which would be obtained if all the technical, environmental, social and economic data were available. The results are based on the evaluation of sustainability of five major wastewater treatment classes (mechanical, pond systems, ecological systems, package systems and land

treatment technologies) using a set of sustainability indicators adopted for this study. The expected overall results prove the point that sustainability of a wastewater treatment technology is a function of economic, environmental, technical and social dimensions, and the selection and interpretation of indicators is influenced by an area's local context. The context is important since the need for reliable and appropriate wastewater management as well as the performance of the technologies is a function of the local conditions.

Mechanical treatment systems and package plants are overall less sustainable than ecological systems, ponds systems and land treatment systems. Mechanical and package plant systems have high capital and operation and management costs which will translate to high user costs leading to them being not affordable. Mechanical and package plants have high energy requirements and have low labour requirements per plant capacity. Despite these setbacks in attaining overall sustainability, mechanical systems and package plants have high performance in removing biochemical oxygen demand, total suspended solids, and pathogens.

Of the five systems under consideration, land treatment and ecological systems are most likely to pose the least overall economic and environmental impact. The findings of the this research also concurs with other related studies which reveal that the advantages of land and ecological treatment systems include lower capital and low potential to produce odour. These systems have low energy requirement and high removal efficiency for (biochemical oxygen demand, total suspended solids, nitrogen, and pathogens). Although these systems are less mechanised they can create more jobs per plant capacity than larger mechanical systems. Based on the sustainability indicators adopted in this research, ponds and land and ecological treatment systems are more sustainable choices.

5.5 DSS Implementation

This section describes the function of the Decision Support System and acts as a guide to the users.

5.5.1 Introduction

The Decision Support System is a Web based system developed on Microsoft Technologies. The advantages of using the web based technology over other forms like disc or computer based technologies are as follows;

- No special configuration or changes are need on user's PCs, just requires a browser and every PC has one.
- Lower costs: less time spent talking to stakeholders over the phone, elimination of printed materials, authenticated users update their municipal details
- Centralised data is secure and easy to backup and manage.
- Updates can be made quickly and easily and are immediately available.
- Information is accessible to a wide audience anywhere in the world.
- Available 24 hours a day, 7 days a week.
- Online training can be completed at user's own time and pace.
- Stakeholders located at different locations, on the road or even abroad, all have direct access to current information.

The front end of the DSS is implemented using some of the latest development tools from Microsoft; including AJAX enabled C-Sharp development tools. The back end is driven by Microsoft SQL Server 2005. DSS System is implemented with two access modes: Unauthenticated users and Authenticated users.

5.5.2 Unauthenticated Users

Unauthenticated users have access to the system's non-secure sections. These sections give details on the system. The sections are navigable using links at the top of the screen as well as sub-links within the pages (Fig 5.12 to 5.14). Also available on this section is a login link that provides an option to capture user credentials.

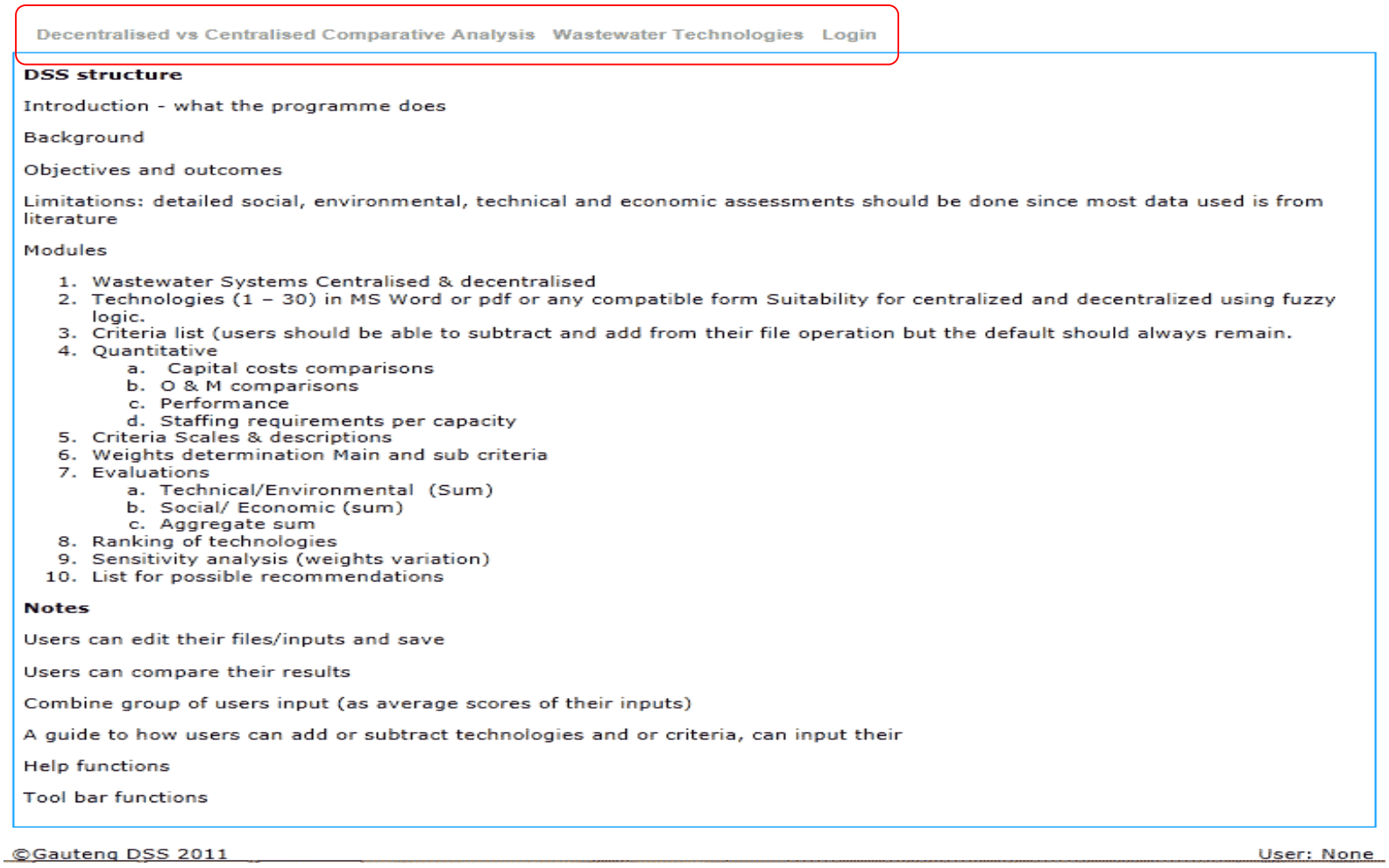


Fig 5.12 Introductory page *Highlighted at the top is the main links. At the bottom is an indicator of the logged in user, in this case, None*

Decentralised vs Centralised Comparative Analysis | Wastewater Technologies | Login

APPENDIX 1 DECENTRALISED VS CENTRALISED COMPARATIVE ANALYSIS

Furthermore, the survey and extensive review of the current trends in sanitation and wastewater management worldwide has resulted in the conclusion that decentralization of wastewater management is the trend that will not escape South Africa but also a trend that should become highly desirable by South African Policy Makers because of the advantages that it offers when compared to conventional sanitation and wastewater management approaches. These advantages of decentralized wastewater management can be summarized as:

1.1 Financial planning and financial risk

The smaller system size of decentralized system allows closer matching of capacity to actual growth in demand. Decentralized capacity can be built house-by-house, or cluster-by-cluster, in a "just in time" fashion. This prevents backlogs building up and provides a number of other important benefits. It moves capital costs for capacity to the future, typically reducing the net present value of a decentralized approach. The result is often a more economical approach than building centralized treatment capacity or extending sewers (depending on many other factors) (Figure 1). Spreading out capital costs also typically means that a community will incur less debt, compared to the borrowing requirements of a large up-front capital investment for capacity. This can reduce the financing costs for the community. The "build-as-you-go" aspect of decentralized systems also means that if less growth occurs than first predicted, the community is not stuck with overbuilt capacity and a large debt load that must be spread across fewer than expected residents. Making decentralized investments over time also means that a community can easily adjust its technology choices as improved or cheaper technologies become available.

Further, expensive nutrient removal technologies can be targeted to only the locations that are nutrient sensitive, as opposed to upgrading treatment of all the community's wastewater at a centralized plant (something to be established by the Catchment Management Agencies). Some potential financial disadvantages of decentralized systems are that the large number of systems can increase design, permitting, financial, and other transaction costs of a wastewater service strategy. Also, lenders may perceive individual and small wastewater system debt as riskier investments compared to municipal borrowing, so that the unit costs of debt may be higher. This is not always the case as municipalities may be the signatories even for small cluster systems. Decentralization also concentrates the financial risks of individual system failures on individuals or clusters of residents, in contrast to the insurance-like spreading of risks of failure across large numbers of users that centralized systems can provide. For both centralized and decentralized systems, it is very important that financial planning provides for depreciation and eventual replacement of wastewater management assets.

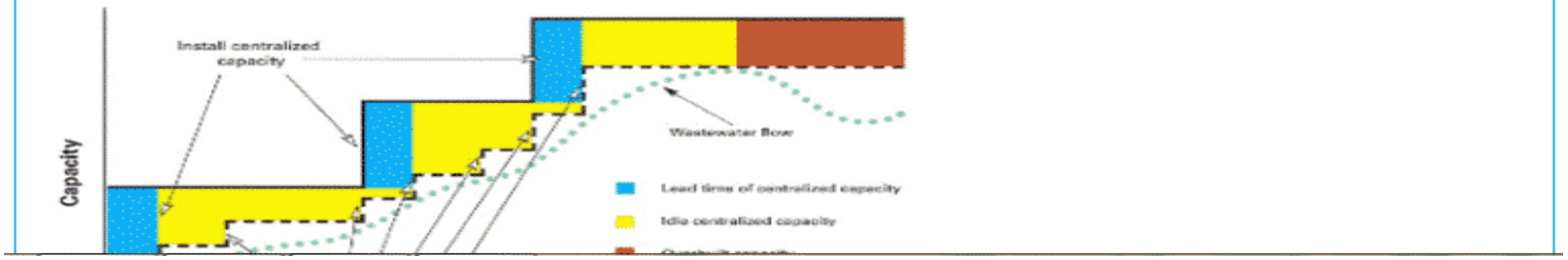


Fig 5.13 Decentralised vs Centralised (*information on the non – secure section)*

Decentralised vs Centralised Comparative Analysis | **Wastewater Technologies** | Login

WASTEWATER TECHNOLOGIES FACT SHEETS

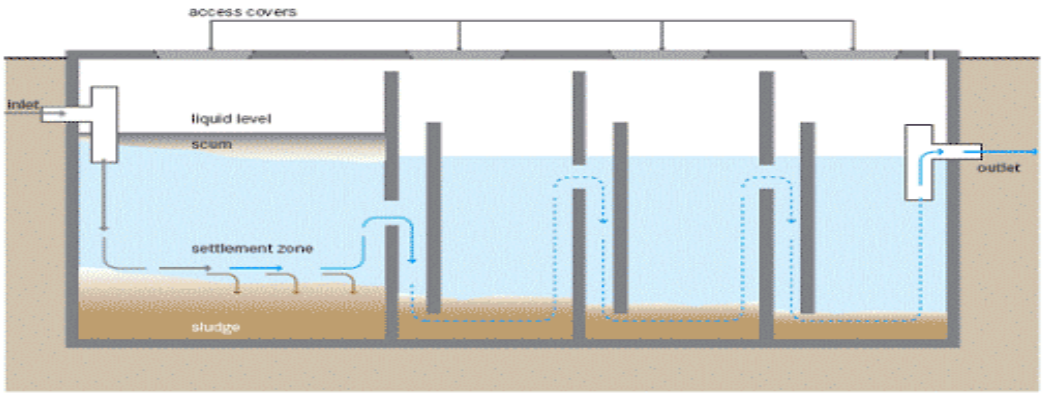
Anaerobic Baffled Reactor | Anaerobic Filter | Waste Stabilization Ponds | Anaerobic Pond | Facultative Pond

Free-Water Surface Constructed Wetland | Horizontal Subsurface Flow Constructed Wetland | Vertical Flow Constructed Wetland | Trickling filter | Rotating biological contractor

Technology: Anaerobic Baffled Reactor

Description: An Anaerobic Baffled Reactor (ABR) is an improved septic tank because of the series of baffles over which the incoming wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment. The majority of settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50% of the total volume. The up-flow chambers provide additional removal and digestion of organic matter: BOD may be reduced by up to 90%, which is far superior to that of a conventional septic tank. As sludge is accumulating, desludging is required every 2 to 3 years. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up-flow velocity of the wastewater less than 0.6m/h and the number of up-flow chambers (2 to 3).

Diagram:



Application level: household and cluster systems

Fig 5.14 Wastewater Tech. Fact sheet: *Sub – links highlighted.*

5.5.3 Authenticated Users

There are 2 types of authenticated users, Administrators, and ordinary users. The Administrators has additional functionality access to the system than ordinary users, mainly the ability to create users.

5.5.4 Authenticating User

The diagram below provides the form for logging in. Users put in their user name and password and if correct, they get access to the system. From the details supplied, the system also retrieves the user type (Administrator or Ordinary) and stores it in a session.

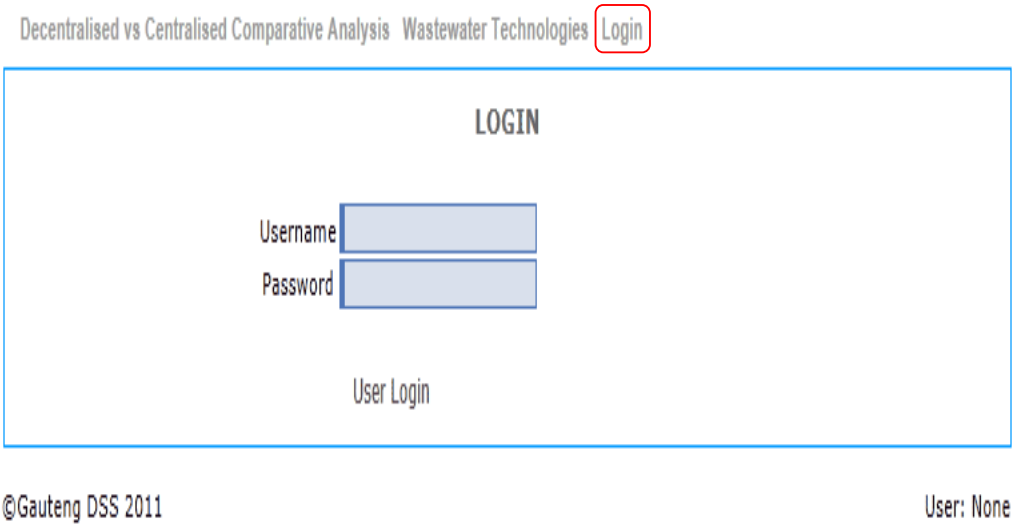


Fig 5.15 Login screen

Upon successful authentication, the user is redirected to the default page and provided with the links for the secure section of the system – as shown in Figure 5.16.

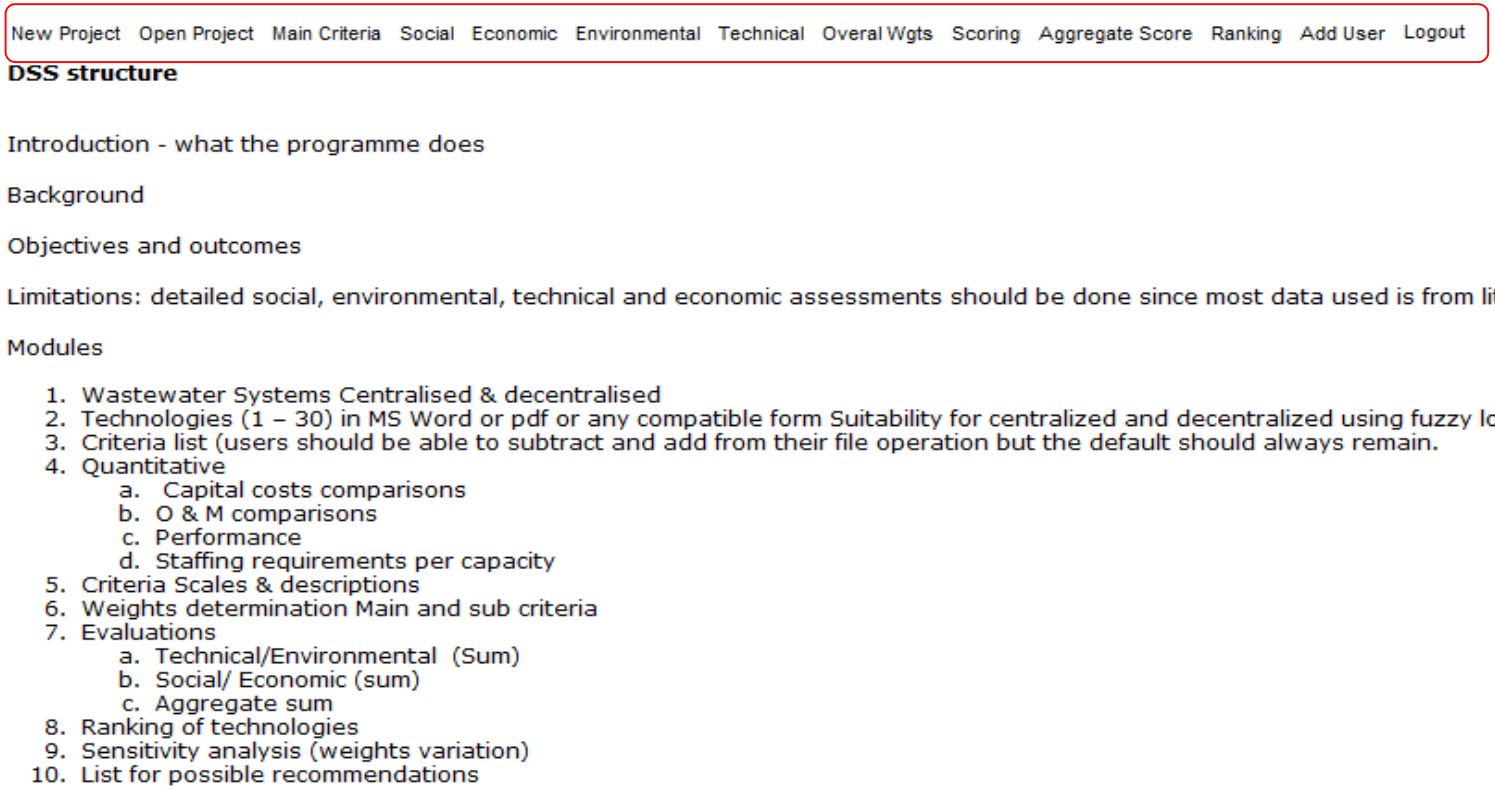


Fig 5.16 Default page (Default page: highlighted at the top is the main secure navigation)

5.5.5 New Project

The new project link presents the user with a form where one captures the project details as shown in Fig 5.17. Highlighted at the bottom is the user who is logged in.

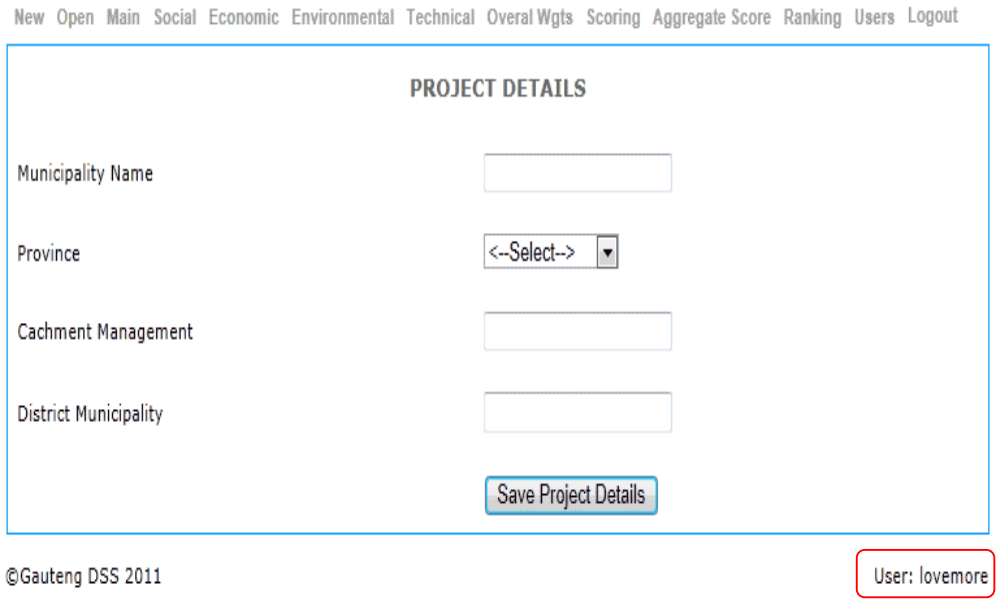


Fig 5.17 New Project Screen

Once these details have been captured, the project sessions are set. These sessions are used throughout the activity of capturing for the specific project until reset by either creating another project or opening an existing project.

5.5.6 Open Project

This link gives a list of all the projects currently active on the system as shown in Fig 5.18 Selecting a specific project initialises the project sessions which will be used during the activity of that particular session as seen in Fig 5.19.

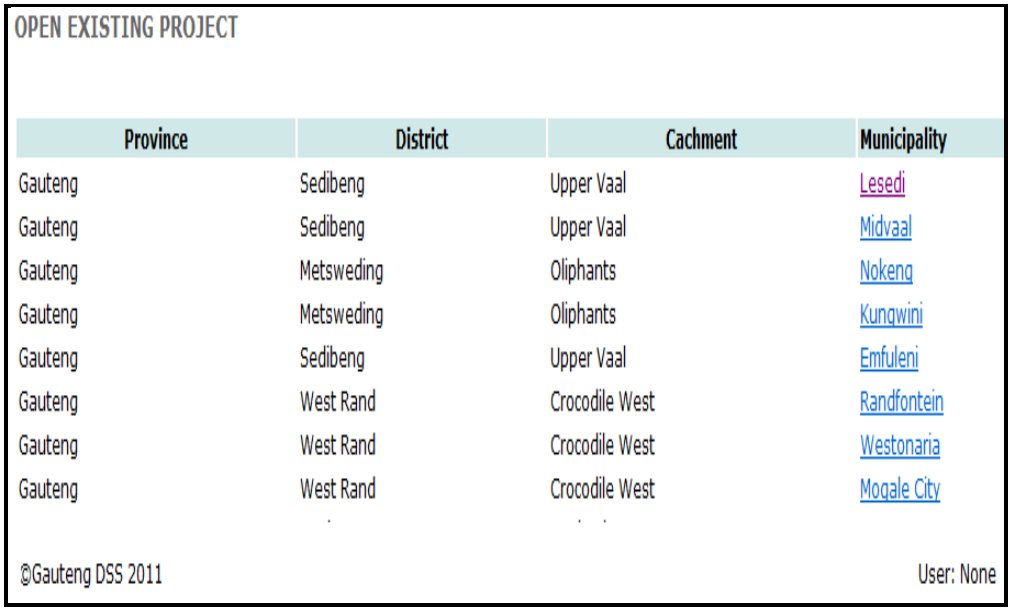


Fig 5.18 Open Project Screen: *Project List*

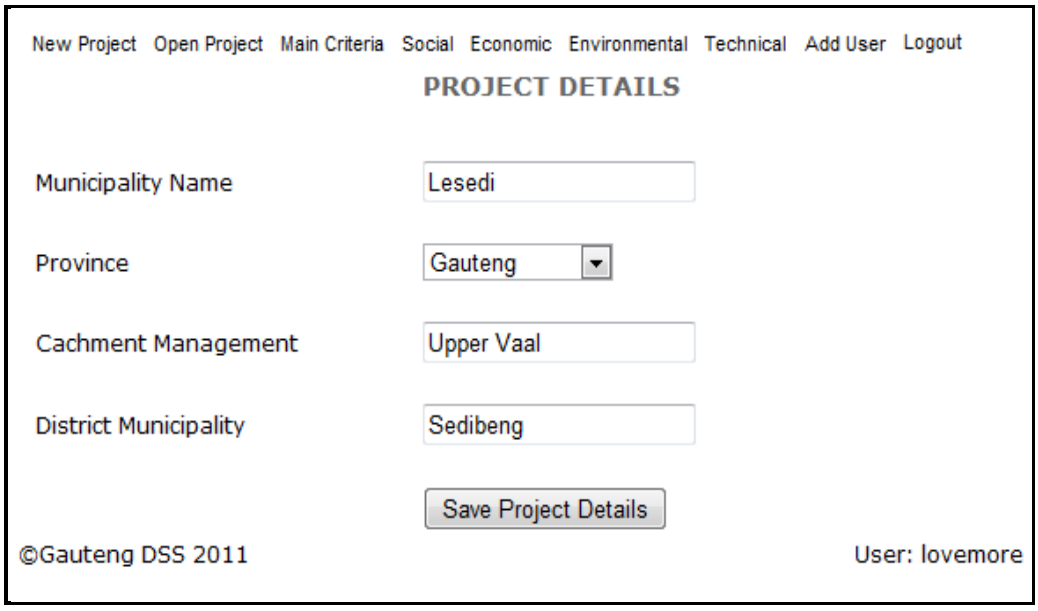


Fig 5.19 Open Project Details

5.5.7 Main Criteria

This link provides two options. If you are using the Open Project option, the page loads pre-loaded with the details of the project that is opened, with the user is allowed to edit the details. If the New Project screen is being used, the page loads

an empty form and the user can capture the details for the main criteria for the new project as shown in Fig 5.20.



Fig 5.20 Main Criteria Screen Preloaded with Existing Values

N.B: *The numbers in red are automatically calculated as you enter the values in the text boxes.*

Rank the criteria/goals according to their importance by assigning a % mark. When the initial percentages are captured the system calculates the percentages weights for the four main criteria. The same procedure is repeated for the sub-criteria under each of the four main criteria. The weight score for the sub criteria is multiplied by the weights from the corresponding main criteria to come up with a weight for each individual sub criteria weight which will be used in the final scoring process.

5.5.8 Weights

There are four forms on this section; Social, Economic, Environmental & Technical (Fig 5.21 and Fig 5.22). All the four forms either preloads with saved information or present an empty form. The figures in red are automatically calculated while you enter the values in the text boxes.

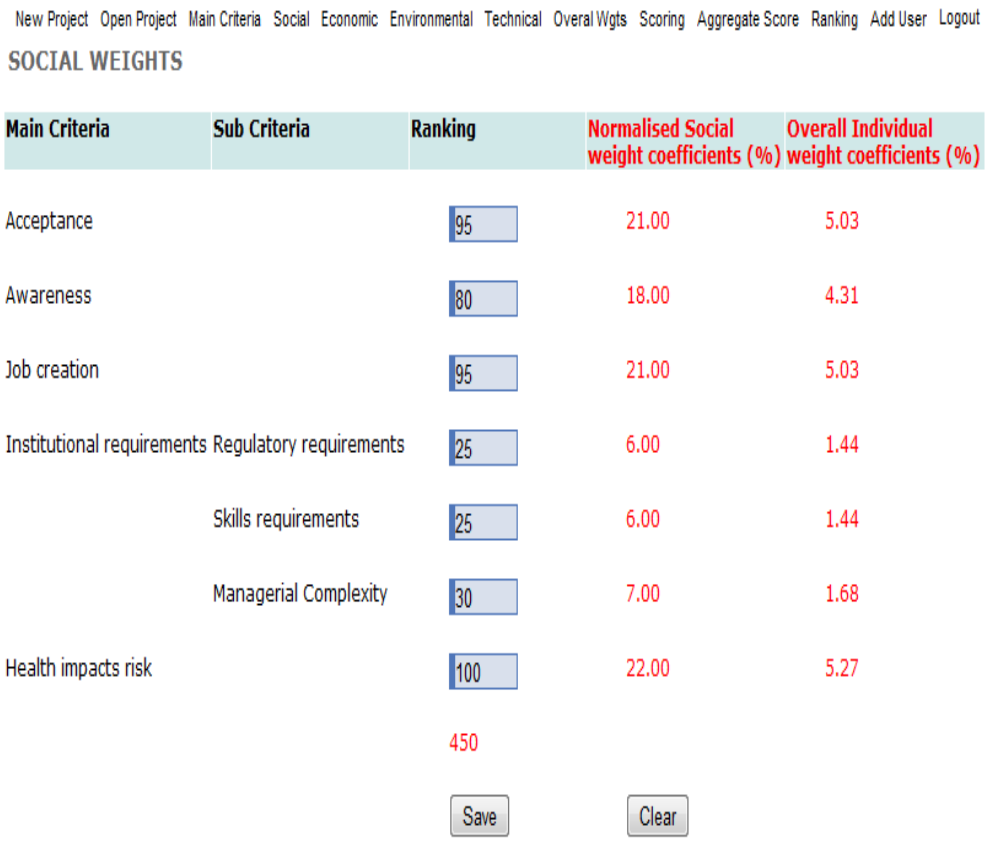


Fig 5.21 Social Weights Screen Preloaded with Existing Values

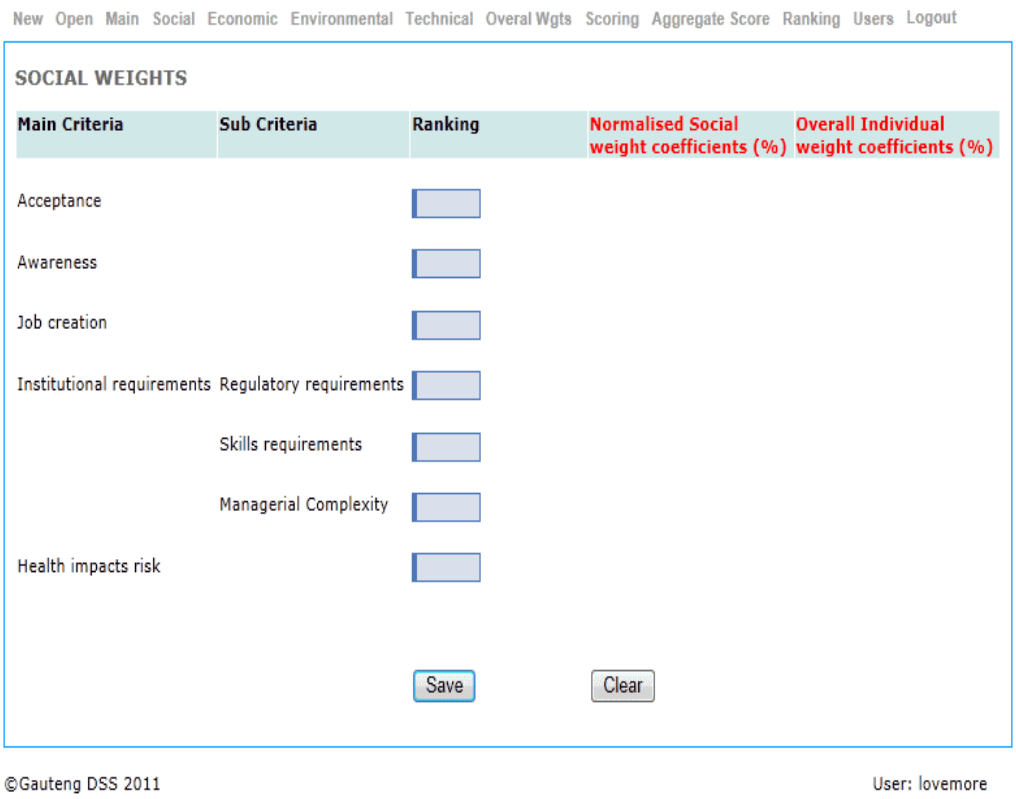
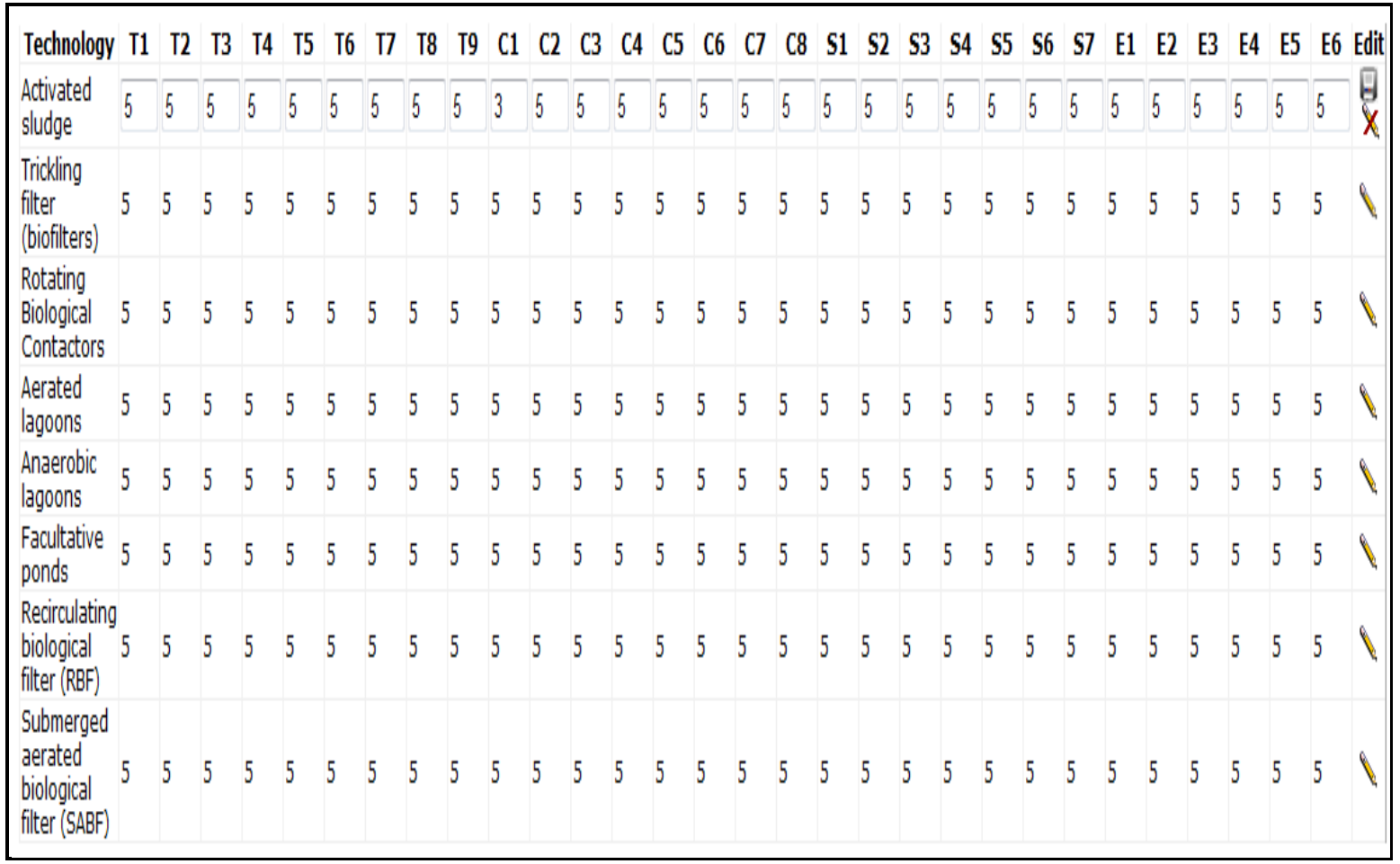


Fig 5.22 Blank Social Weights Screen

5.5.9 Evaluation

Scoring allows the scores of the technologies to be captured in a grid like format. The implementation is such that the scores are captured per technology, i.e. per row of the grid as shown in Fig 5.23. The scores are derived from the responses from the questionnaires.

The pencil icon to the right of the grid opens the specific line for input/editing. When open, this icon is replaced with two icons, a floppy disk icon and a cancelled pencil as shown in Fig 5.23. The crossed pencil icon as seen in Figure 5.23 allows user to cancel any changes made to the row and close the edit mode of the row without saving any changes – used to discard changes without saving. The disk like icon is a save button. Any changes made to the row are saved on the system and the edit mode of the row is closed when you click on the icon. The values shown in Fig 5.23 are default values.



Technology	T1	T2	T3	T4	T5	T6	T7	T8	T9	C1	C2	C3	C4	C5	C6	C7	C8	S1	S2	S3	S4	S5	S6	S7	E1	E2	E3	E4	E5	E6	Edit
Activated sludge	5	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Trickling filter (biofilters)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Rotating Biological Contactors	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Aerated lagoons	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Anaerobic lagoons	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Facultative ponds	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Recirculating biological filter (RBF)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Submerged aerated biological filter (SABF)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	

Fig 5.23 Scores Screen

5.5.10 Aggregate Score

The aggregate score is the product between the individual criterion weights and the scores derived from the questionnaires. After the individual criteria weights are determined, they are listed and are then multiplied with the score from the assessment questionnaires to come up with an overall score for the technology. The overall score is converted to a percentage which is termed the Sustainability index. Table 5.13 shows the overall scores of each technology against the sustainable criteria and the last column of the table shows the sustainable index measure as a percentage score.

5.5.11 Ranking

Ranking aggregates the details captured in the previous section (Aggregate Score) and sums the technology values captured. The ranking screen is a none entry screen and no values are captured on this screen.

5.5.12 Wastewater Technologies

The next section covers wastewater technologies and has about 16 forms. The implementation is just the same as the on weights; however, this is just a data input section. There are no automatic calculations and values captured are captured as is.

Table 5.13 Sustainable Index Score

Technologies	Technical				Environmental		Social					Sum	SSI
	T1	T2	T3	T4	C1	C2	S1	S2	S3	S4	S5		
Activated sludge	61,20	55,82	42,74	40,87	98,62	121,79	48,72	58,12	46,15	54,70	51,28	680,01	**75,6**
Trickling filter (biofilters)	62,74	55,82	42,74	40,87	110,95	131,16	48,72	58,12	30,77	51,28	51,28	684,44	**76,0**
Rotating Biological Contactors	69,57	35,52	55,56	36,32	98,62	140,53	40,60	58,12	46,15	54,70	51,28	686,98	**76,3**
Aerated lagoons	65,98	45,67	34,19	40,87	123,27	168,64	48,72	58,12	46,15	54,70	51,28	737,60	**82,0**
Anaerobic lagoons	60,68	65,97	47,01	18,16	147,93	159,27	32,48	33,90	30,77	54,70	51,28	702,16	**78,0**
Facultative ponds	61,71	40,60	47,01	31,78	147,93	168,64	48,72	43,59	46,15	54,70	51,28	742,11	**82,5**
Recirculating biological filter	80,51	71,05	51,28	45,41	147,93	140,53	48,72	29,06	46,15	27,35	68,38	756,37	**84,0**
Oxidation ditches	80,51	71,05	51,28	45,41	147,93	149,90	48,72	14,53	46,15	27,35	68,38	751,21	**83,5**
Sequence batch reactor	80,51	71,05	51,28	45,41	147,93	140,53	48,72	29,06	46,15	27,35	68,38	756,37	**84,0**
Constructed wetlands	67,01	55,82	42,74	49,95	160,26	168,64	28,42	24,22	46,15	37,61	39,89	720,69	**80,1**
Living machines	72,14	45,67	29,91	36,32	147,93	187,38	40,60	38,75	30,77	23,93	68,38	721,78	**80,2**
Aquaculture	76,92	65,97	59,83	45,41	123,27	168,64	36,54	33,90	61,54	41,03	28,49	741,54	**82,4**
Slow infiltration	72,56	81,20	51,28	63,57	147,93	168,64	44,66	48,43	46,15	51,28	56,98	832,69	**92,5**
Rapid Infiltration	72,56	81,20	55,56	63,57	172,58	159,27	44,66	48,43	46,15	51,28	68,38	863,64	**96,0**
Overland Flow	73,33	81,20	55,56	59,03	160,26	159,27	44,66	48,43	46,15	51,28	56,98	836,15	**92,9**

5.6 Guidelines for DSS Use

This MCDA tool is to be used as a context-oriented planning tool by water service authorities and is useful in demystifying and communicating the decisions to a wider stakeholder base. The DSS can use all the four main criteria in its evaluations and there are many possible combinations of the use of the criteria. The systematic computation procedures for running the model are outlined in Appendix H. There are 2 main models which can be considered for comparative analysis of the technologies in Gauteng. This research mainly focuses on the Model 1 but also can be used for Model 2.

Model 1: Three main criteria (technical, environment, and social) are considered. The economic criteria are then evaluated on the solution set from the main criteria evaluations. The economic criteria are initially left out since data is always not readily available. The first evaluation using the main criteria screens out unsustainable options and it makes sense to do a detailed economic analysis on the remaining sustainable criteria in order to come up with sustainable solutions for possible implementation. This is in agreement with the objectives of wastewater treatment which are to safeguard public health and the quality of the environment. Once these critical needs are met then their viability or feasibility can be determined on an economic basis.

Model 2: All four main criteria are considered in the evaluation in line with sustainable development requirements but this method is not accurate enough since there is always a challenge of data quality and availability but where all the data is present, it makes sense to do the evaluations in a single step.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The overall objective was to develop a clear methodology for wastewater systems selection and to produce a practical planning tool to aid in decision making for municipalities in South Africa and other developing countries. The planning tool generated was used for the comparative evaluation and selection of wastewater systems technology with respect to technical, environmental and social in one step and then carrying out a detailed economic analysis on the finite solution set as second step. In order to fulfil the objectives of the research and achieve the desired research output, a rather unique methodological approach was followed;

- This approach posed a set of fundamental research questions with reference to a particular real life situation (Case study approach). This was done through a detailed literature review.
- The research questions were answered by the analysis of the existing situation (status quo analysis) for particular case (study area).
- The status quo analysis findings were then used to understand and identify the problems/challenges in the current decision making processes.
- This resulted in the need to propose and develop a new approach to decision making which offers a useful decision making support tool in the form of a user friendly decision support system.
- This research advocated for the use of sustainable indicators in a pro-active context based input to planning, utilising Multi Criteria Decision Aid (MCDA) for comparative analysis and assessment of the sustainability of wastewater systems.

The DSS developed (with a user friendly graphical interface) incorporated the advantages and disadvantages of wastewater systems, databases for wastewater technologies as well as MCDA methodology. The research proposed a unique 2-step approach utilising MCDA in the selection of wastewater treatment technologies. The development of a two step approach utilising MCDA in the selection of wastewater treatment technologies was a key output of this research.

The selection of the most suitable technology or wastewater system can be tedious, time consuming and complex. The decision support system developed in this research makes the process simple and easier to use for the decision makers. The DSS proved to be a straightforward method for giving not only an application but also the comparative analysis of the technologies and systems. Applying this methodology and the DSS could contribute to proper planning strategies for wastewater management and be an accessible tool for building effective communication channels with stakeholders. MCDA process enables decision makers to appreciate the problem and be confident in their decision making tasks. This MCDA tool is to be used as a context-oriented planning tool by water service authorities and is useful in demystifying and communicating the decisions to a wider stakeholder base.

Apart from the developed methodology, some of the major outcomes of this research are;

- The development of an Algorithm for drawing a set of site specific solutions for technology options. This algorithm can be used to derive the context specific alternatives/options to be used in the MCDA process evaluation. It has been shown that for every level of water supply there is always a possible set of technologies that can be derived. The local constraints associated with the technologies are incorporated in the algorithm. The solution set (technology options) from the algorithm can then taken for the MCDA analysis.

- The results from the MCDA assessment show that decentralised technologies are more sustainable than centralised wastewater technologies (based on the local context). This differs from the current thinking prevalent in the municipalities and among many researchers. Most researchers and professional experts have stated that sustainability is inherent in the technologies but this research shows that sustainability is a function of the needs of the stakeholders and the local environment in which the technology operates. The optimal solution for wastewater treatment is not a technical or economic issue but should be driven by the needs of the stakeholders. Economic factors can then be used to choose the most optimal solution, only after the stakeholders' basic needs are met.

As pointed out in the Case Study findings in Figure 6.1, decentralised wastewater management is the way to go for Gauteng Municipalities as long as they exist in poly-culture with centralised systems. This is because no clear demarcation exists between centralised and decentralised systems. In principle there is a continuum from full decentralisation (individual systems for each household) to fully centralised system (all households in a community connected to a single wastewater treatment.

The methodology followed in this research and the development of the DSS met the initial objectives of this research which were;

- To improve or restructure the current planning and decision-making process so that consideration of socio-economic, technical and environmental issues is fully integrated in the process. This also ensures a broader range of public participation.
- To develop a decision support system incorporating multi criteria based on the use of sustainability indicators for wastewater system and technology selection in South Africa.

- To undertake a review and catalogue the economic advantages and disadvantages of decentralised wastewater systems relative to larger scale centralised systems.
- To provide the appropriate technical information necessary for informed decision-making on wastewater management.
- To provide recommendations on wastewater management for the case study areas.

This research implies a necessity for a paradigm shift in wastewater management practices to a system which minimises current and future environmental and human health negative impacts. The use of the DSS incorporating multi criteria decision analysis will aid local authorities in making informed decisions and enhance their planning capabilities. It has been clear in this research that if sustainable indicators are to contribute substantially to the increased sustainability of urban water systems, they must be applied not only in a retrospective way but in a future oriented manner for planning and decision making. This research provides a methodology and a tool to help communities save financial resources and improve the current planning and decision making. Users of this research will be able to make better qualitative and quantitative context based comparisons and assessment of sustainability of centralised and decentralised wastewater system options.

6.2 The Limitations of the Study

The research initially sought to analyse the economic advantages of centralised and decentralised systems using 8 municipalities in Gauteng as a case study. During the research process, it became evident that there is a serious lack of good quality data to use for life cycle cost analysis. This resulted in a change of focus from the initial aim of analysis of economic advantages of centralised and decentralised wastewater management systems to the development of a methodology to support decision making with limited or insufficient data. This led to the use of multi criteria analysis utilising MCDM methods to deal with the

challenge of limited quantitative and qualitative data. The verification and full validation of the developed methodology and associated model is beyond the scope of this project and could be explored in future research. However, the methodology was partially tested through the input from 40 municipal officials and 37 other researchers input as a means of testing the weakness and strengths of the methodology.

In wastewater management, technology selection is one aspect and is by no means the only critical consideration. Sustainable wastewater management has to satisfy a variety of criteria which include economic, social, institutional and environmental aspects. These are possibly more important in developing countries as the current technologies in use were simply adopted from Western models and practices. The limitation of this research is that it considered the treatment technology part of the wastewater systems and did not consider the collection, storage and conveyance aspects which usually account for 80-90% of the wastewater systems costs. The research focused on the wastewater treatment aspect only because it is where the risk from health and environmental impacts is high and also the fact that the detailed cost data required for economic comparisons for full wastewater systems were not available.

6.2.1 Limitations of the Methodology and DSS

- It is emphasised that the methodology which resulted from this research is suitable for situations in which new wastewater management facilities are being considered. This was not the case in the eight municipalities studied (although 8 of the treatment plants were operating beyond design capacity -in the Sedibeng District there were already advanced plans to build one regional centralised treatment plant to meet their needs). As such the application of the methodology could not be verified and validated using the existing data set for the selected eight municipalities. If sufficient economic data were available the methodology could be verified using

scenario analysis whereby the existing plants would have been considered as one of the options for the future.

- The methodology needs to be reviewed in view of the difficulties encountered in seeking stakeholders' responses via the questionnaires. The responses were critical in determining weights for the main criteria; this problem is true for any methodology open to participation responses. The major obstacle was encountered in defining the preferences structures of the criterion weights. The exercise was voluntary, and consequently some institutions did not respond and this could not be enforced since the ethical requirements from Witwatersrand University states that participants can withdraw anytime they want. The obstacles encountered do not reduce the value of the methodology, since responding to questionnaires become the duty of the municipal official once the methodology is adopted by the decision makers, which was not the case in this research.

- The data used as a trial run for the model was a combination of input from 40 municipal officials and 37 postgraduate students. The combination sets of data were used because of the low responses from the municipalities and also because of different people attending the workshops which were set as part of the programme as outlined in Table 4.1. This arrangement where municipal officials would sent representatives or themselves was beyond the control of the researcher. The advantage of using the combined data was that if afforded the opportunity to test the methodology. From the model output this was successful, although a quantitative cannot be given to assess the degree of confidence in the data.

- The range of capacities over which the wastewater technologies are compared and assessed is a major factor in coming up with fair and reasonable comparisons between technologies. This has to be critically assessed and in this research the scale issues over the technologies were not fully considered. This does not nullify the database use but implies there is room for improvement.

6.3 Future Research

- Development of a database to capture relevant wastewater technologies fact sheets should be initiated. This will help to undertake an objective comparison of centralised and decentralised wastewater systems that are case specific for the South Africa wastewater industry. The developed database should be readily available to the public or at least all stakeholders and should be a driving force of knowledge sharing.
- Development of a comprehensive database to capture relevant wastewater systems life cycle costs should be initiated in order to undertake an objective comparison of centralised and decentralised wastewater systems for the South Africa wastewater industry. The developed database should be readily available to the public or at least all stakeholders and should be a driving force of knowledge sharing.
- The use of outranking methods in the MCDA methodology has to be investigated and assessment made on what would be the outcome of the decision process since there has been severe criticism of weighted sum method on the basis of the assumption of its compensatory approach since in nature some process/environmental effects cannot be compensated.
- The next level of approach is to use this methodology in a new project for wastewater since this model has been validated using other models in literature and other research findings and hence need a physical model to be compared to.
- The use of fuzzy logic in a multi criteria decision making process should be explored since there is so much uncertainty in the data and fuzzy logic sets with their aspects of degree of membership might improve the precision of the decision making process.

6.4 Case Study Recommendations

The status quo analysis of the case study area revealed that the lack of **empowered bottom-up decision making** on the required levels of service is one main problem and is a major shortfall of the current planning process. This

research recommends that the current planning process for water services be revisited and become more bottom-up approach aligned**,** especially in water and wastewater management. The use of multi criteria decision aid tool is one way that enable different stakeholders to be engaged in the decision making process. Relevant technical choices in sanitation must be tailor made to suit local conditions and these choices must be integrated and coordinated with the decisions made regarding water supply and housing. No major advances in wastewater management are to be expected unless this critical area is readdressed. It is especially noted that before selecting a particular sanitation technology type, the full range of requirements (stakeholders, costs and benefits, technical, environmental and social issues) should be considered.

The outcomes of the research also include the following recommendations to Gauteng provincial government;

- The creation and establishment of the Provincial Water Services Capacity Enhancement Centre. Briefly, the objective of the Centre is to supplement and support current institutional policies and mechanisms in a single formal entity that provides direct support to municipalities in water services planning and management. The centre will assist with IWSPs and WSDPs development and relevant mentoring roles and the establishment of an integrated approach through alignment and checks at all levels and in close collaboration with all role players, etc. Furthermore, the centre is a formal capacity building facility that provides hands-on training in water services provision and management to municipal employees in the province for the needed skill base establishment. This centre will empower the stakeholders to identify their needs.
- The review of the Gauteng Provincial Sanitation Policy and accompanying amendments to allow and facilitate the following;
    - Intermediate water and sanitation levels of service provision use;
    - Further extended decentralisation of wastewater management functions;

- Innovation in water services management and extended scope of allowable technical solutions;
- More effective resource protection and demand management policies and strategies;
- More effective intrinsic value recovery at wastewater treatment facilities;
- Establishment and integration of the recommended Provincial Water Service Capacity Enhancement Centre into the sanitation policy and strategy;

- The adoption of appropriate Sanitation and Wastewater Management Models for planning and decision making within each Municipality which encompass the local context whilst incorporating sustainable criteria. This will likely result in each municipality in Gauteng province having non-uniform, diverse and innovative management solutions that will include all available technology choices to effectively meet the needs of their unique set of situations. For example, after consideration of the sustainable development aspects of sanitation and wastewater management, it is expected that an overall plan will emerge calling for centralised or decentralised technologies or a hybrid consisting of the two.
- Adoption of the water and sanitation strategies for the informal settlements shown in Table 6.1.
- Institutional reform is needed across the water sector to overcome fragmentation, strengthen accountability and consolidate capacity to support social transformation and economic growth. There are currently more than 300 public institutions in the water sector, excluding water user associations. The pool of available sector expertise cannot support this vast number of institutions, and the overhead costs are high.

The indications (from the DSS output and as well practically what is on the ground) are that the sustainable future of wastewater management should and will be characterised by a higher degree of emphasis on decentralisation than currently

is the case. Figure 6.1 shows the expected wastewater management trends in Gauteng in the future. The figure reiterates the findings stated previously with the illustrations showing that a greater extent of decentralisation is to be expected in wastewater management systems. In many ways this is a desired situation from the sustainability point of view, despite the fact that this is not commonly recognised by the water sector at present. The current situation is characterised by water services (also housing etc.) backlogs which are significant and fundamentally a legacy of the past. One way of effectively addressing these backlogs rapidly is to do so in the context of smaller, more decentralised sanitation and wastewater management technologies delivery, especially in view of the fact that current "centralised" wastewater management facilities are almost all working at or beyond their maximum design capacity. It is worth noting that the lead time for any significant wastewater management facility of the centralised type is rarely shorter than 5 years. In short addressing the backlogs in an effective manner will require serious consideration of the shorter lag time decentralised approach for service delivery.

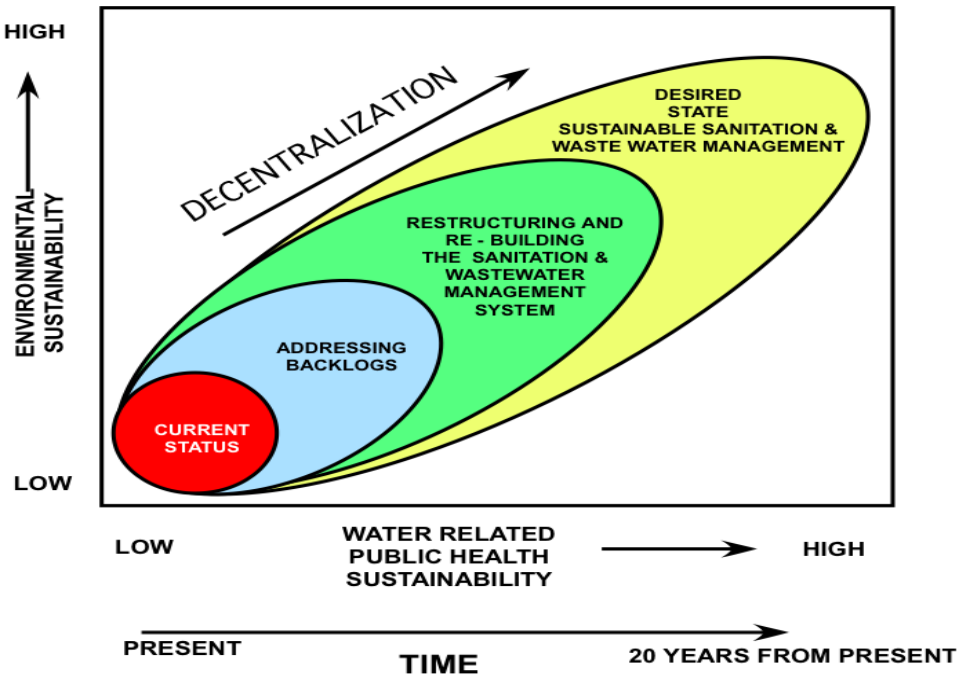


Figure 6.1 Services Interventions and Relevant Time Frames

The initial case study findings were instrumental in setting the directions of the research. The status quo analysis made it possible to understand the current decision making process in the municipalities and the approach followed was to improve the current process by eliminating its weakness while consolidating its strengths. From the status quo analysis, a need to develop a methodology that would assist in the planning and decision making process was identified. The structured methodology employing MCDA tool for the comparative analysis of decentralised and centralised systems enabled sound conclusions to be made in this research.

Table 6.1 Sanitation Strategies for Informal Settlements in the Study Area

MUNICIPALITY GROUP	Primary Recommendation - Prefered at the level of available information			Secondary Recommendation - Acceptable solution if Primary Recommendation is not Accepted				Interim WWM solution for informal settlements prior to their relocation or formalization (for the duration of the relocation /formalization process)		
				Critical technical criteria		Option description System type & technology	Budget estimate (per person)	Water supply level (min)	Sanitation technology	Budget estimate (per person)
	System Character and Prerequisites	Scope of Work	Cost Estimate	Population size (people)	Water supply level					
Westonarea, Randfontein, Mogale City	Centralised system type with Full WB technology; Prerequisite is: Water supply level: > 75 L/c/d (house connections) to all population served, All informal settlements to be relocated to sewage catchments of under-loaded WWTP's	Collection network only (use existing WWT capacity)	Westonarea R 80 m, Randfontein R 10 m; Mogale City R 100 m	Pop > 50000	> 75 L/c/d, (house connection)	Centralised system, Full WB technology, Central WWTP	R 3500 to R 6000 pp	25 L/c/d	Dry, on site (Amalooloo)	R 500 - R 1500
				10000 < Pop < 50000	50 - 75 L/c/d, (house or yard connection)	Decentralised system, Full WB technology	R 2500 to R 10000 pp			
				2000 < Pop < 10000	50 - 75 L/c/d (house or yard connection)	Decentralised system, Full WB technology	R 2500 to R 4000 pp			
				2000 < Pop < 10000	25 - 50 L/c/d, (yard connection)	Decentralised system, Wet on site technology	R 3000 to R 5000 pp			
				Pop < 10000	25 L/c/d, (public standpipe)	Decentralised system, Dry on site technology	R 500 to R 2000 pp			
Emfuleni & Midvaal	Centralised system type with Full WB technology; Prerequisite is: Water supply level: > 75 L/c/d (house connections) to all population served, All informal settlements to be relocated to catchments of new wastewater treatment plants to be constructed to handlle excess loads of current WWT facilities	New WWT Plants to be constructed to receive excess loads from existing WWT facilities and new loads from rellocated or formalized informal settlements.	Emfuleni - 50 ML/d of new capacity @ R 15 m/ML/d +Collection system @ 150 to 200 m Midvaal - 5 ML/d of new capacity @ R 15 m/ML/d +Collection system @ R 10 to 20 m	Pop > 50000	> 75 L/c/d, (house connection)	Centralised system, Full WB technology, Central WWTP	R 3500 to R 6000 pp	25 L/c/d	Dry, on site (Amalooloo)	R 500 - R 1500
				10000 < Pop < 50000	50 - 75 L/c/d, (house or yard connection)	Decentralised system, Full WB technology	R 2500 to R 10000 pp			
				2000 < Pop < 10000	50 - 75 L/c/d (house or yard connection)	Decentralised system, Full WB technology	R 2500 to R 4000 pp			
				2000 < Pop < 10000	25 - 50 L/c/d, (yard connection)	Decentralised system, Wet on site technology	R 3000 to R 5000 pp			
				Pop < 10000	25 L/c/d, (public standpipe)	Decentralised system, Dry on site technology	R 500 to R 2000 pp			

Table 6.1 Sanitation Strategies for Informal Settlements in the Study Area (Continued)

MUNICIPALITY GROUP	Primary Recommendation - Prefered at the level of available information			Secondary Recommendation - Acceptable solution if Primary Recommendation is not Accepted				Interim WWM solution for informal settlements prior to their relocation or formalization (for the duration of the relocation /formalization process)		
				Critical technical criteria		Option description System type & technology	Budget estimate (per person)	Water supply level (min)	Sanitation technology	Budget estimate (per person)
	System Character and Prerequisites	Scope of Work	Cost Estimate	Population size (people)	Water supply level					
Nokeng, Kungwini, Lesedi	For all new settlements with more than 50000 people and >75 L/c/d water supply levels (house connections) to all population served, Centralized or Cluster New Wastewater Treatment facilities at secondary or advanced secondary WWT technology. For settlemens with less than 50000 people Secondary Recommendations are valid	New WWT Plants to be constructed to receive new loads from rellocated or formalized informal settlements.	R 3500 to R 6000 per person served + collection system at app. R50000 per connection	10000 < Pop < 50000	50 - 75 L/c/d, (house or yard connection)	Decentralised system, Full WB technology	R 2500 to R 10000 pp	25 L/c/d	Dry, on site (Amalooloo)	R 500 - R 1500
				2000 < Pop < 10000	50 - 75 L/c/d (house or yard connection)	Decentralised system, Full WB technology	R 2500 to R 4000 pp			
				2000 < Pop < 10000	25 - 50 L/c/d, (yard connection)	Decentralised system, Wet on site technology	R 3000 to R 5000 pp			
				Pop < 10000	25 L/c/d, (public standpipe)	Decentralised system, Dry on site technology	R 500 to R 2000 pp			

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APPENDICES

APPENDIX A TYPICAL INFORMAL SETTLEMENTS PICTURES

Mogale City

Joe Slovo





Mpandelene kerkpoort





Orient Hills





Soul City/ Tudor





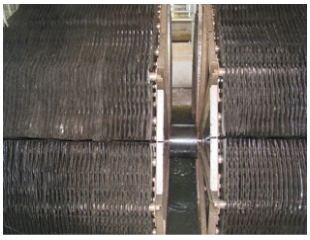




APPENDIX B TYPICAL WASTEWATER TREATMENT WORKS PICTURES IN STUDY AREA

Nokeng: Pebble Rock Package Plant





Westonarea local Municipality: Hennie van Niekerk








APPENDIX C GENERAL QUESTIONNAIRE

I would like to request a few minutes of your time to assist this research being undertaken by Harmony K Musiyarira (0618759m) in partial fulfilment of the requirements for the PhD at the University of the Witwatersrand. The anticipated time for participation is twenty minutes. The survey is investigating the preferences of professionals in the water and wastewater fields have for sustainable criteria used in selection of technologies used either in decentralised or centralised wastewater systems. I express my appreciation in advance for your valued participation with this survey and assistance to make a contribution to a better future. Your details are not required and your answers will be treated with confidentiality.

Section A: Technical Criteria Ranking

From your experience in relation to wastewater systems and technology selection, please rank in the tables below, in order of priority from **1** (least important) to **10** (most important) the critical issues you would consider:

Table C 1 Technical Criteria Ranking

	TECHNOLOGY SELECTION CRITERIA	**Scale (From 1 to 10)**
1	Performance (BOD,TSS, N & P % removal)	
2	Operation & Maintenance Requirements	
3	Monitoring/Inspection Requirements	
4	Sensitivity to Variable Flow and Loading	
5	Relative Operation Complexity	
6	Reliability	
7	Ease of Construction	
8	Local Design Capacity	
9	Mechanical Complexity	
10	Sensitivity to Power Shortages	
11	Information Management Requirements	
12	Adaptability	

Table C 2 Social Criteria Ranking

	Social Criteria	**Scale 1 to 10**
1	Public participation	
2	End user preferences	
3	Awareness	
4	Job Creation Potential	
5	Managerial Complexity	
6	Local Content Availability and Experience	
7	Institutional requirements changes	
8	Health impacts on failure	

Table C 3 Economic Criteria Ranking

	Economic Criteria	**Scale 1 to 10**
1	Cost Per Unit of Water Treated	
2	End User Cost	
3	Need for Special Chemicals	
4	Capital Intensity	
5	Financial Intensity	
6	Financial Risk	
7	Operation & Maintenance costs	
8	Affordability	
9	Willingness to pay	

Table C 4 Environmental Criteria Ranking

	Environmental Criteria	**Scale 1 to 10**
1	Energy requirements	
2	Land use requirements	
3	Chemicals requirements	
4	Potential for reuse	
5	Total Environmental Risk	
6	Groundwater pollution	
7	Surface water pollution	
8	Ground water recharge	
9	Air emissions	
10	Noise pollution	

Table C 5 Perceptions on Decentralised Systems/Technologies

Decentralised Systems/Technologies	Strongly disagree	Do not Agree	Neutral	Agree	Strongly agree
They reduce pollution					
Reduces freshwater usage					
Are not risky					
Offers opportunities for water reuse					
Offers opportunities for resource recovery					
Do not produces odour					
Have low energy demands					
Cheaper to finance					
Affordable					
Have low Capital Costs					
Low Chemical requirements					
low Operation Costs					
Reliable					
Highly flexibility					
Have low performances in pollutants removal					
low requirements for maintenance					
Have low managerial complexity					
Creates more job opportunities					
Calls for less changes in lifestyle					
Calls for minimal institutional changes					

Table C 6 Perceptions on Centralised Systems/Technologies

Centralised Systems/Technologies	Strongly disagree	Do not Agree	Neutral	Agree	Strongly agree
They reduce pollution					
Reduces freshwater usage					
Are not risky					
Offers opportunities for water reuse					
Offers opportunities for resource recovery					
Do not produces odour					
Have low energy demands					
Cheaper to finance					
Affordable					
Have low Capital Costs					
Low Chemical requirements					
low Operation Costs					
Reliable					
Highly flexibility					
Have low performances in pollutants removal					
low requirements for maintenance					
Have low managerial complexity					
Creates more job opportunities					
Calls for less changes in lifestyle					
Calls for minimal institutional changes					

APPENDIX D TECHNOLOGY ASSESSMENT QUESTIONNAIRE

I would like to request a few minutes of your time to assist this research being undertaken by Harmony K Musiyarira (0618759m) in partial fulfilment of the requirements for the PhD at the University of the Witwatersrand. The anticipated time for participation is twenty minutes. The survey is investigating the efficient management of Peri-urban, Farming and other Isolated Wastewater Areas, through the Application of an Integrated Wastewater Management approach for nine (8) municipalities in Gauteng. The responses from this survey will form the basis on which solutions addressing institutional, administrative, capacity building, coordination issues will be derived. I express my appreciation in advance for your valued participation with this survey and assistance to make a contribution to a better future. Your details are not required and your answers will be treated with confidentiality.

Table D.1 Technical Criteria

	UNIVERSITY OF THE WITWATERSRAND	DATA COLLECTION FORM				
	TECHNOLOGY TYPE					
TECHNICAL	Indicators/ Statements	Unit of Measurement				
Performance	BOD removal					
	TSS Removal					
	N Removal					
	P Removal					
	FC Removal					
Reliability		Very Significant	Significant	Moderate	Lowly significant	Insignificant
	Risks of failure or frequent breakdowns					
	Shock load susceptibility					
	Possibility of user abuse					
	Probability of not meeting effluent requirements					
	under normal operating conditions					
		Very Significant	Significant	Moderate	Lowly significant	Insignificant
Ease of construction	Easy to construct					
	Materials readily available					
	Skills readily availability					
	Low time for construction					
Adaptability		Very Significant	Significant	Moderate	Lowly significant	Insignificant
	Adapt to meet more stringent effluent standards					
	Easy addition of units or upgrade					
	Flexibility to change in flow					
	Adapts easily to change in influent quality					

Table D.2 Environmental Criteria

ENVIRONMENTAL	Indicators	Unit of Measurement				
		Very High	High	Medium	Med-low	Low
Resource utilisation	Energy requirements					
	Chemical requirements					
	Land use requirements					
	Nutrients Extraction without reuse					
Environmental Risk		Very Significant	Significant	Fairly Significant	Lowly significant	Insignificant
	Surface water pollution					
	Solid waste generation					
	Groundwater pollution					
	Air Pollution					
	Noise pollution					

Table D.3 Social Criteria

SOCIAL	Statements	Unit of Measurement				
		Very High	High	Medium	Med-low	Low
Acceptance	Level of trust and confidence in the technology					
	Perceived safety for everyone & reliabilty					
	Pleasant aesthetics					
	Calls for minimal lifestyle changes.					
Awareness		Very High	High	Medium	Med-low	Low
	Implementation allows public education to be maximised					
	Current level of awareness about the technology					
	Information on the technology is readily available					
Job creation		Very Significant	Significant	Fairly Significant	Lowly significant	Insignificant
	Creation of jobs for people					
Institutional		Very Significant	Significant	Fairly Significant	Lowly significant	Insignificant
Requirements						
	Calls for radical institutional changes					
	Creates managerial complexity					
	Skills requirements					
	Regulations requirements					
Health impacts		Very Significant	Significant	Fairly Significant	Lowly significant	Insignificant
	Waterborne diseases cases per year					
	Respiratory diseases related to air pollution					
	Exposes people to disease causing agents					

Table D.4 Economic Criteria

ECONOMIC	Indicators	Unit of Measurement				
Costs						
	Capital					
	O & M costs					
		Very Significant	Significant	Moderate	Lowly significant	Insignificant
Affordability						
	Energy cost					
	Maintenance Costs					
	Management costs					
	Inabiity of the locals to pay for O & M costs					
		Very Significant	Significant	Moderate	Lowly significant	Insignificant
Willingness to pay	Perceived Environmental benefits					
	Perceived Health benefits					
	Perceived Safety benefits					
	Perceived Performance					
		Very Significant	Significant	Moderate	Lowly significant	Insignificant
Financial Risk Exposure						
	Capital risk					
	Infrastructure risk					
	Opportunity risk					

APPENDIX E COMPARATIVE COSTS

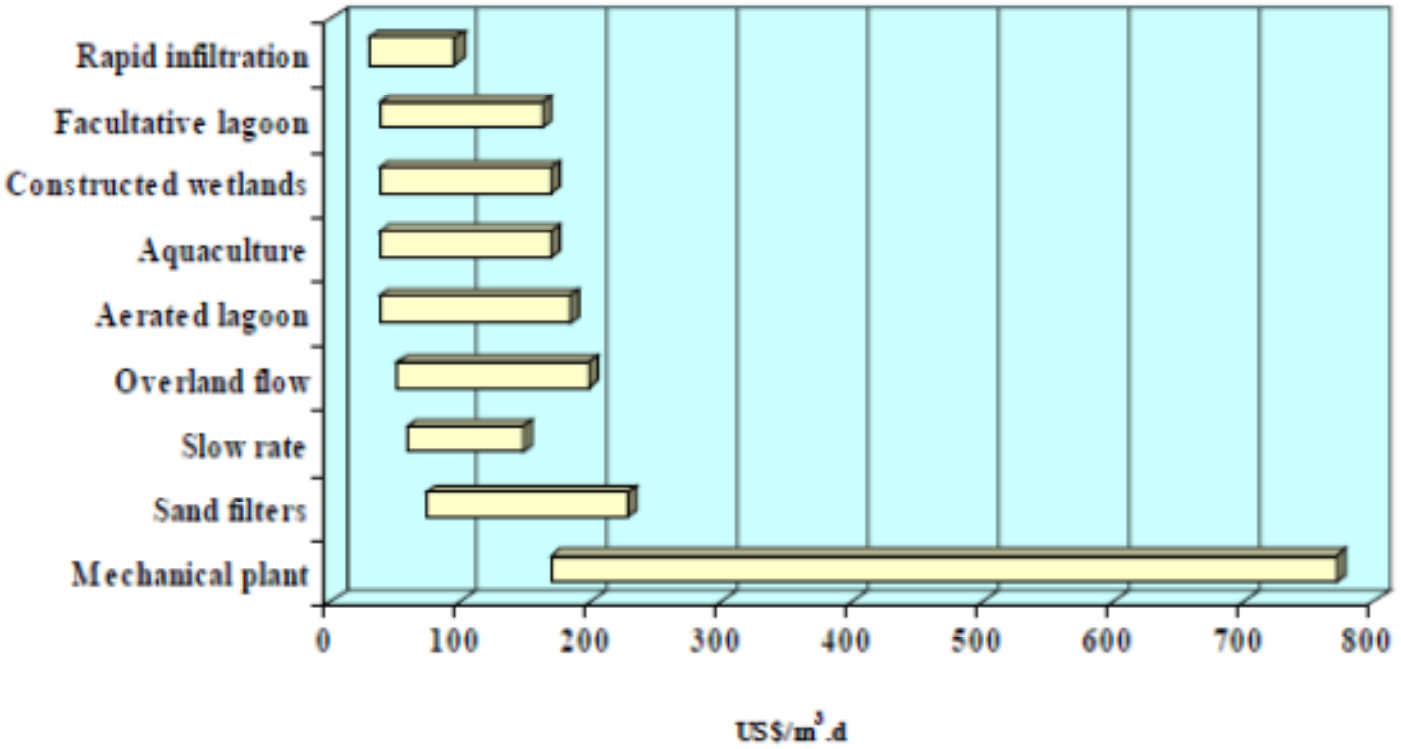


Fig E.1 Comparative Construction Cost (UNEP, 1997).

APPENDIX F CENTRALISED VS DECENTRALISED ANALYSIS

The survey and extensive review of the current trends in sanitation and wastewater management worldwide has resulted in the conclusion that decentralisation of wastewater management is the trend that will not escape South Africa but also a trend that should become highly desirable by South African Policy Makers because of the advantages that it offers when compared to conventional sanitation and wastewater management approaches. These advantages of decentralised wastewater management were extracted from Rocky Mountain Institute research (2004).

F.1 Financial Planning and Financial Risk

Closer matching of capacity and growth in demand is possible with smaller decentralised systems allowing for a smaller increment allowance for spare capacity. This allows for spreading capital expenses compared to large up-front capital layouts associated with centralised systems. This allows for less debt burden to communities and flexibility in adjustment for changed growth patterns as well as improved treatment technology adjustments as these are developed. Adopting decentralised systems implies that in the event that less growth occurs as predicted, communities will not be tied down to overbuilt capacity. Going for the decentralised approach gives flexibility for choice adjustment on technologies as improved or cheaper technologies become available.

Further, expensive nutrient removal technologies can be targeted to only the locations that are nutrient sensitive, as opposed to upgrading treatment of all the community's wastewater at a centralised plant (something to be established by the Catchment Management Agencies). Some potential financial disadvantages of decentralised systems are that the unit costs of debt may be higher on decentralised systems since they are in their infancy stage and financiers may

perceive them to be riskier investments compared to conventional systems.

F.2 Community and Watershed Impacts

Decentralised systems allows for more scope for growth management strategies, as it allows for cluster-style development. It also may result in a more distributed pattern of negative impacts on the water environment as well as public health than centralised systems.

F.3 Onsite and Neighbourhood Impact

Decentralised systems being near to communities require greater awareness and participation by communities to avoid failures of the systems. This increases the knowledge base for the stakeholders unlike in the centralised systems where the only time people get close to it after flushing is when they pay their municipal bills.

F.4 Capital and Operation and Maintenance costs

Smaller systems loose the advantages of economies of scale that are possible in wastewater treatment capital costs and O&M costs. However, smaller systems also avoid diseconomies of scale that are inherent in sewer systems. Given that collection system costs are roughly 60-80 percent or more of total systems cost, collection diseconomies of scale can overwhelm treatment economies of scale, resulting in decentralised systems being the more economical choice.

F.5 Integration with other Infrastructure

Decentralised systems being in closer proximity to wastewater sources provide cost-effective opportunity for water reuse at site and neighbourhood scale. The volume produced for reuse might not be adequate for large consumers of wastewater reuse but it will be significant for small users.

F.6 Management

If a centralised management approach for decentralised systems is followed it would imply the same costs for management as centralised system. The management structure is very fundamental in determining the costs of managing these systems.

F.7 Reliability, Vulnerability, and Resilience

Although reliability and vulnerability to natural hazards and inadvertent disruptions may vary or be independent to system scale, the risks and costs of system failure would on average be less for decentralised systems due widely distributed impacts being limited compared to a large centralised failure.

F.8 Decentralisation Benefits, Costs, and Considerations

This section presents the potential benefits of the decentralisation of wastewater management, the apparent costs and the issues that need detail consideration in planning and implementation of decentralised systems. It is noted, that despite the fact that the current state of wastewater management in the municipalities studied is characterised by the decentralised approach, most of the considerations listed below have never been considered in the planning process. The discussion is grouped in the following categories and is extracted word for word from the Rocky Mountain Institute Report (2004): xxv – xxx with comments from the researcher in line with applicability for the case study area.

- Financial Planning and Financial Risk
- Community and Watershed Impacts
- Onsite and Neighbourhood Impacts
- Capital and O&M Costs
- Infrastructure Synergies: Benefits of Integration
- Management

- Reliability, Vulnerability, and Resilience
- Impacts Beyond the Watershed

Table F.1 Financial Planning and Financial Risk (Rocky Mountain Institute, 2004)

Decentralisation benefit: By (typically) moving capacity costs to the future, the net present value of costs for decentralised systems is reduced compared to centralised systems of similar or even somewhat higher nominal costs.
Decentralisation benefit: Decentralised systems can reduce the net present value of wastewater system costs by deferring or downsizing the need for replacement systems.
Decentralisation benefit: Decentralised systems can help extend the useful service life of existing conventional infrastructure.
Decentralisation benefit: The small unit size of decentralised systems allows closer matching of growing demand for wastewater capacity; therefore, less money is tied up in overbuilt capacity.
Decentralisation benefit: Decentralised systems can shorten project lead time - e.g. the construction period, further reducing the cost of tying up funds unproductively.
Decentralisation benefit: In cases when future demand fails to meet expectations, additional scheduled increments of decentralised capacity can be foregone, avoiding the cost of overbuilt centralised capacity.
Decentralisation consideration: Because cluster systems tie-up more time and money in permitting and implementation than do conventional onsite systems, developers may favour onsite systems and the potential benefits of cluster systems may be foregone.
Decentralisation benefit: The flexibility of decentralised resources allow managers to adjust capital investments continuously and incrementally, more

exactly tracking the unfolding future, with continuously available options for modification or exit to avoid trapped equity.

Decentralisation benefit: Modular, short-lead-time technologies valuably temporize: they buy time, in a self reinforcing fashion, to develop and deploy better technologies, learn more, avoid premature decisions, and make better decisions. The faster the technological and institutional change, the greater the turbulence and the more uncertain are future needs, the more valuable this time-buying ability becomes.

Decentralisation benefit: Smaller, quick-to-build units of decentralised wastewater capacity offer flexible options to planners seeking to minimize regret, because capacity can be added or foregone to match actual demand.

Decentralisation benefit: Shorter lead-time and smaller size reduce the planning horizon, consequently decreasing the amplification of errors in forecasting demand with the passage of time.

Decentralisation benefit: Because decentralised systems often cost less to plan and design than centralised systems, they generate less exposure to lost costs if a plan is turned down by voters or regulators.

Decentralisation benefit: Short lead-time units of decentralised wastewater infrastructure expose a utility to the financial costs of construction delays and capital cost escalations far less than large, slower-to-build treatment plants and major collection system expansions.

Decentralisation benefit: The low operating costs of many decentralised technologies expose a utility and system users to less financial risk from variation and escalation in energy and other operating costs.

Decentralisation benefit: Even when per unit operating costs of decentralised systems are higher, overall system costs may be less susceptible to inflation and other cost escalations when decentralised systems carry less excess capacity than centralised systems.

Decentralisation benefit: A decentralised strategy for capacity expansion is less likely to result in sunk costs in older technologies and instead allows for rapid

response to technological change.

Decentralisation benefit: Decentralised systems may allow upgrades to be focused on a small subset of a community's capacity, saving substantial capital costs.

Decentralisation cost: Decentralised systems may increase the transaction costs of upgrading facilities.

Decentralisation cost: Decentralisation concentrates the direct financial risks (e.g. replacement costs) of system failure or inadequacy on individuals and small groups, in contrast to the insurance-like spreading of these financial risks in centralised and regional systems. This concentration of risk can impose catastrophic costs on users.

Decentralisation consideration: Real impacts of failure, exposure to liability for harm to others or to penalties under law, and the financial resources to survive a finding of liability for a wastewater system failure vary in unclear ways with system scale.

Decentralisation consideration: Some technologies used in decentralised wastewater systems may allow a project to be reversed and downsized more easily than typical centralised systems, which have a higher proportion of assets in custom-constructed components or buried in the sewer network. However, centralised treatment systems may have greater value for in-situ reuse, and the market for used conventional wastewater treatment plant components is probably stronger than that for used decentralised system components.

Decentralisation benefit: Decentralised systems, by spreading costs over time rather than concentrating costs up front, are more likely to not require borrowing, or to require less borrowing, than centralised systems.

Decentralisation benefit: By reducing borrowing increments, decentralised systems strain a utility or community's financial resources less, thereby improving its financial indicators, which may lead to better terms on debt (e.g. as a result of better bond ratings).

Decentralisation cost: To the extent decentralised systems require a community

to increase the number of times it borrows funds, they may increase the "transaction costs" associated with borrowing.

Decentralisation cost: To the extent decentralised systems shift borrowing from a community or utility to entities with smaller assets and revenue sources (e.g. individual homeowners for onsite systems, homeowners' associations for cluster systems), lenders may perceive debt as a riskier investment and the cost of debt, for instance, the interest rates, may increase.

Decentralisation consideration: Decentralised systems may be more or less eligible than conventional systems for certain grants, low-interest loans, and other alternative financing.

Decentralisation consideration: Decentralised systems allow a community to shift project costs and financing costs to developers or private property owners.

Decentralisation consideration: Financial planning for any scale of wastewater system must provide for depreciation and replacement of assets.

Table F.2 Community and Watershed Impacts (Rocky Mountain Institute, 2004)

Decentralisation benefit: Decentralised wastewater systems expand the toolbox of strategies to manage growth and promote "smart growth": they can help avoid sewer-induced sprawl and help direct the location and form of growth as desired by the community.
Decentralisation cost: In communities without adequate planning, zoning, and other growth management tools in place, decentralised systems can result in haphazard growth and its attendant costs.
Decentralisation benefit: Through reduced density or improved site layout (e.g. with cluster development), decentralised systems can help reduce the proportion of impervious surface in a landscape, thereby cutting pollutant loading to surface water bodies and maintaining groundwater recharge.
Decentralisation benefit: Smaller systems can help a community resist unwanted annexation or regional sewer extensions, thus maintaining the community's character, independence and control over other services.
Decentralisation benefit: Decentralised systems likely keep more money circulating within a local economy—supporting local income and creating local jobs—than centralised or regionalized systems of similar lifecycle cost.
Decentralisation benefit: Decentralised systems avoid the hydrologic impacts that centralised collection systems can cause or contribute to. These include lower water tables, drawdown of aquifers, and reductions in stream base flow.
Decentralisation consideration: Direct stream flow augmentation from any scale system may be beneficial or detrimental.
Decentralisation consideration: Smaller wastewater systems may have a more or less impact than larger systems on surface water chemistry and ecology, and thereby create economic implications for communities, depending on many factors.
Decentralisation benefit: Installation and operation of decentralised systems are

likely to cause fewer disturbances to riparian zones than larger sewer systems.

Decentralisation consideration: Smaller wastewater systems may generate greater or lesser public health risks than larger systems, depending on regulations, enforcement, technology, design and construction, O&M, and other factors.

Decentralisation consideration: Occupational health and safety risks and hazards to the public vary by technology and system scale and should be considered when system choices are made.

Decentralisation benefit: Smaller systems are less likely to raise questions over the distribution of their costs and benefits.

Decentralisation benefit: Maintaining decentralised systems as permanent solutions avoids the "double payment" problem sewers can create.

Decentralisation benefit: Centralization increases the expertise required of system managers and operators, and therefore the compensation required to retain them, perhaps to a point that generates ill will in some small communities.

Decentralisation benefit: Decentralizing infrastructure units tends to reduce the political and economic "stakes" involved in a wastewater facility decision. This can reduce community conflict and its associated costs.

Decentralisation benefit: By breaking borrowing needs into smaller amounts that occur periodically as a community grows, decentralised systems can help avoid mistrust and rate shock brought on by large borrowing for capacity that will not be fully used for years.

Decentralisation benefit: Smaller systems lend themselves to local decisions, enhancing public comprehension and legitimacy.

Table F.3 Onsite and Neighbourhood Impacts (Rocky Mountain Institute, 2004)

Decentralisation cost: While centralised wastewater systems are essentially out of sight and mind for most property owners (excepting payment of sewer bills), onsite and cluster systems require greater awareness and participation, with attendant non-monetary costs.
Decentralisation benefit: Centralization intensifies undesirable system characteristics that induce public resistance and loss of value for neighbouring properties.
Decentralisation consideration: Visual impacts of wastewater systems on sites and neighbourhoods may occur with any scale system.
Decentralisation benefit: Odour control is typically less of a concern with smaller systems.
Decentralisation consideration: Both centralised and decentralised systems can be noisy or quiet, depending on the technology chosen.
Decentralisation benefit: Decentralisation allows for preservation of open space and its attendant values without the costs of unnecessary infrastructure.
Decentralisation cost: The greater the degree of Decentralisation, the greater the limit on development density. Where higher density is desirable, this may result in an inability to maximize property value.
Decentralisation benefit: Advanced decentralised systems may allow the development of otherwise undevelopable property, thereby creating or maintaining property value.
Decentralisation consideration: Serving areas with decentralised systems rather than sewers can affect the affordability of properties.
Decentralisation consideration: System scale may affect how a building or set of buildings can be located on a property, which may impact development costs and property value.
Decentralisation consideration: Some wastewater systems may increase the

value of the subject property or adjacent properties because of a perception that the system is particularly novel, sustainable, or valuable environmentally.

Decentralisation consideration: Decentralised systems displace and constrain other uses of a site to a lesser degree than centralised systems. The cumulative impact of dispersed, lower impacts of decentralised systems in this respect, versus more intense and concentrated opportunity costs of centralised systems, is not clear.

Decentralisation benefit: In retrofit and repair/replacement situations, decentralised systems generally require less disruption of properties and neighbourhoods.

Table F.4 Capital and O&M Costs (Rocky Mountain Institute, 2004)

Decentralisation cost: Smaller systems miss economies of scale in wastewater treatment systems.

Decentralisation cost: Very small wastewater facilities require higher capacity per capita in order to manage variability in hydraulic loads produced per connection.

Decentralisation consideration: Smaller systems are more likely to use alternative sewers that do not require extra treatment plant capacity to manage infiltration and inflow loads typical of gravity sewer systems.

Decentralisation consideration: Minimum design flow requirements may result in onsite and cluster systems that are under loaded, affecting their ability to function properly.

Decentralisation consideration: Decentralisation can be used to isolate waste generators that produce high hydraulic or mass loads (e.g., BOD loads of restaurants, hydraulic and pollutant loads of industrial facilities) in order to reduce the capacity and treatment needs such facilities place on public systems.

Decentralisation cost: High effluent standards tend to favour centralised treatment.

Decentralisation cost: Smaller treatment systems typically require more material per unit of capacity.

Decentralisation consideration: As system scale decreases, per unit costs of treatment plant construction typically increase.

Decentralisation benefit: Smaller systems avoid diseconomies of scale in wastewater collection systems.

Decentralisation benefit: Smaller systems can avoid the high costs of installing large pipes and can take maximum advantage of alternative technologies that cost less to install.

Decentralisation benefit: Smaller systems have shorter pipe lengths per connection served.

Decentralisation benefit: Smaller systems have a lower ratio of large pipes versus small pipes, thus reducing the use of more expensive large pipes.

Decentralisation benefit: Smaller systems may need fewer manholes or none at all.

Decentralisation benefit: Smaller systems often have lower requirements for pumps than larger systems.

Decentralisation consideration: Land area requirements and siting constraints may favour or disfavour smaller systems.

Decentralisation consideration: Smaller systems are more likely to use "off the shelf" technologies, while larger systems tend to require more sophisticated, customized engineering. However, smaller systems may require more sensitivity to site conditions throughout a service area. A decentralised approach may have greater up-front planning costs.

Decentralisation consideration: The sum of permit fees paid to entities outside the community may be less or greater for decentralised systems than centralised ones. Transaction costs to obtain permits may push decisions toward more or less Decentralisation.

Decentralisation cost: Because of the large number of treatment units and effluent discharge points inherent in decentralised systems, capital costs of equipment for monitoring equivalent to that undertaken at centralised wastewater treatment plants would be substantially higher.

Decentralisation consideration: Depending on the treatment technology chosen, monitoring capital costs per capita may be lower or higher for decentralised systems than for centralised systems.

Decentralisation cost: Smaller systems lose economies of scale that are possible in wastewater system operation and maintenance.

Decentralisation benefit: Decentralisation resulting in different technology choices may dramatically shift the nature and frequency of required O&M activities, in some cases reducing O&M costs below that of a centralised system

serving the same area.

Decentralisation cost: For a given technology, labour costs exhibit economies of scale; decentralizing the treatment technology will result in increased labour costs per unit of capacity.

Decentralisation consideration: Decentralisation usually results in different technology choices, which may have lower or higher labour costs per unit of capacity across the whole system than a more centralised system would.

Decentralisation consideration: Decreasing treatment plant size for a given technology will tend to lose economies of scale from bulk purchase of chemicals, but many decentralised technologies require no chemicals or less than those required for some centralised systems.

Decentralisation consideration: Decentralised systems may require more or less routine parts and materials replacement than centralised systems serving the same population.

Decentralisation consideration: Technologies used for decentralised systems tend to generate lower quantities of biosolids or require less biosolids handling. This may reduce the per capita costs of residuals management.

Decentralisation cost: Because decentralised treatment systems are dispersed, they probably require more travel for inspection, operation, and maintenance than more centralised systems.

Decentralisation consideration: Periodic permit fees and other fees paid to government bodies in order to operate a wastewater system can range from nonexistent to substantial and may or may not be significant on a per capita basis.

Decentralisation cost: Because of the large number of treatment units and effluent discharge points inherent in decentralised systems, costs for ongoing monitoring equivalent to that undertaken at centralised wastewater treatment plants are substantially higher.

Decentralisation consideration: Depending on the technology chosen, ongoing monitoring costs per capita may be lower or higher for decentralised systems than

for centralised systems.

Decentralisation consideration: Insurance to cover the costs of repairing or replacing a failed system or system component would constitute an operating cost if chosen, but is only just beginning to be available to wastewater system owners.

Decentralisation benefit: To the extent that a sewer system adds to property value, using instead an onsite system results in lower property tax payments.

Decentralisation cost: In the specific case of ownership of onsite systems by a private responsible management entity, the onsite system becomes a taxable asset, and the taxes become an additional cost in comparison to a publicly owned sewer system.

Table F.5 Infrastructure Synergies: Benefits of Integration (Rocky Mountain Institute, 2004)

Decentralisation benefit: By avoiding the capital and operational expenses of large re-distribution networks, decentralised wastewater systems provide opportunities for cost-effective reuse of water at the site and neighbourhood scale.

Decentralisation cost: Onsite and cluster systems do not provide the quantities of water necessary for large water users such as industrial facilities and large landscapes, which in some communities will be the most cost-effective application of wastewater reuse.

Decentralisation consideration: Integration of wastewater and storm water systems can be considered, under particular conditions, across a range of scale.

Decentralisation benefit: Decentralised systems allow for closer control of sources contributing to biosolids, which may provide benefits in improved biosolids quality. Further, new approaches to dry or ultra-low-water sanitation systems based on urine/faeces separation offer opportunities for improved capture and use of nutrients in human waste.

Decentralisation cost: Decentralised systems do not provide the necessary control and scale to cost-effectively produce energy through sewage sludge digestion and combustion of the resulting methane.

Decentralisation consideration: Additional opportunities for integration of wastewater and other systems may be favourable for decentralised systems, while others may be more appropriate for centralised systems.

Management

Decentralisation consideration: Management activities generally exhibit economies of scale, which can be attained either by centralised systems or "centralised management of decentralised systems." In some cases management requirements for decentralised systems are simpler and less costly than those for centralised systems.

Reliability, Vulnerability, and Resilience

Decentralisation consideration: System reliability depends strongly on the

inherent reliability of the chosen treatment processes and on proper operation and maintenance - factors that can vary with or be independent of system scale.

Decentralisation consideration: As a whole, decentralised systems may be somewhat less vulnerable to natural hazards and deliberate sabotage, but are perhaps more vulnerable to system misuse and inadvertent interference. Much depends on the particular technology, local conditions, and prevention and mitigation measures.

Decentralisation consideration: Diversity of treatment units, ease of repair, and other factors may make decentralised systems more resilient than centralised ones, but technology choices and local conditions will affect comparative resilience.

Decentralisation benefit: On average, the risks and costs of wastewater system failure are probably less for decentralised systems than centralised systems, because the consequences of small, widely distributed failures are limited while the consequences of large, concentrated failures can be severe.

It is noted that management is the set of activities necessary to ensure a physical wastewater system (whether a single centralised plant or thousands of onsite systems) meets performance requirements. That is, management activities ensure a wastewater system is properly designed, constructed, operated, and maintained. In the centralised wastewater field, typically a regulator oversees design and construction of facilities and tracks their performance, while a separate entity administers the system and provides O&M and other functions to run the facility (and collection system). Management is often inadequate in the centralised wastewater field, particularly for small wastewater systems as has been observed in some treatment plants visited. In South Africa many small systems have inadequate institutional capacity—often referred to as "TMF capacity," for "technical, managerial, and financial capacity"—and cannot properly operate and maintain their systems, or plan and budget for future upgrades and rehabilitation. This is often due to poor choices in wastewater system architecture—

centralisation of facilities in communities where decentralised systems would be adequate and typically simpler to operate and maintain.

The decentralised wastewater field has had its own struggles with management. Too often the regulator has only minimal responsibilities for tracking the performance of onsite systems after they are built, and O&M is left to homeowners and other entities with little capacity to ensure systems are kept up. This is the main reason for these systems not being appropriately supported by DWA or larger METRO Municipalities such as Johannesburg. As a result, for effective decentralised wastewater systems a considerable emphasis has to be placed on developing policies, programs, guidelines, and institutions to ensure that decentralised systems are properly designed, constructed, operated, and maintained.

Appendix G Wastewater Technologies Fact Sheets

This section is derived from a number of sources but the two main sources were the Factsheets on technologies by the United States Environmental Protection Agency (USEPA) and as well as from a Compendium of Sanitation Systems and Technology Handbook. The technologies under consideration were placed under five categories, namely Mechanical, Package plants, Ecological plants, Ponds and Land treatment systems. The main sources of this data are as listed here; USEPA –Technology Factsheets (Package plants, Living machines, Land systems) (2000); Crites & Tchnobaloglous, 2000; Metcalf & Eddy, 2001; EAWAG (Mechanical systems and Stabilisations ponds), 2008; Six technologies are described in Tables below and the rest is in the database for the DSS but with the same format as the one presented here which enables the comparative analysis to be made.

Table G.1 Waste Stabilization Ponds (WSP)

Waste Stabilization Ponds (WSP) ***(Data Source: Adopted from EAWAG- A Compendium of Sanitation Systems & Technologies, 2008)***
Description: Three main categories of stabilization ponds/lagoons are in common use worldwide. The experience in South Africa has not been satisfactory mainly due to lack of basic maintenance and frequently overloaded systems operating above the design capacity. This is unfortunate as this technology can reliably deliver desired effluent quality if designed and operated properly. Waste Stabilization Ponds (WSPs) are large, manmade water bodies. The ponds are filled with wastewater that is then treated by naturally occurring processes. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and design characteristics. For the most effective treatment, WSPs should be linked in a series of three of more with effluent being transferred from the anaerobic pond to the facultative pond and finally the aerobic pond. The anaerobic pond reduces solids and BOD as a pre-treatment stage. The pond is a fairly deep man-made lake where the entire depth of the pond is anaerobic. Anaerobic ponds are built to a depth of 2 to 5m and have a relatively short detention time of 1 to 7 days. The actual design will depend on the wastewater characteristics and the loading; a comprehensive design manual should be consulted for all types of WSPs. Anaerobic bacteria convert organic carbon into methane and in the process, remove up to 60% of the BOD. Anaerobic ponds are capable of treating strong wastewaters. In a series of WSPs the effluent from the anaerobic pond is transferred to the facultative pond, where further BOD is removed. A facultative pond is shallower than an anaerobic pond and both aerobic and anaerobic processes occur within the pond. The top layer of the pond receives oxygen from natural diffusion, wind mixing and algae driven photosynthesis. The lower layer is deprived of oxygen and becomes anoxic or anaerobic. Settleable solids accumulate and are digested on the bottom of the pond. The aerobic and anaerobic organisms

work together to achieve BOD reductions of up to 75%. The pond should be constructed to a depth of 1 to 2.5m and have a detention time between 5 to 30 days.

Following the anaerobic and the facultative ponds can be any number of aerobic (maturation) ponds to achieve a highly polished effluent. An aerobic pond is commonly referred to as a maturation, polishing, or finishing pond because it is usually the last step in a series of ponds and provides the final level of treatment. It is the shallowest of the ponds, usually constructed to a depth between 0.5 to 1.5m deep to ensure that the sunlight penetrates the full depth for photosynthesis. Because photosynthesis is driven by sunlight, the dissolved oxygen levels are highest during the day and drop off at night.

Whereas anaerobic and facultative ponds are designed for BOD removal, maturation ponds are designed for pathogen removal. Dissolved oxygen in the lake is provided by natural wind mixing and by photosynthetic algae that release oxygen into the water. If used in combination with algae and/or fish harvesting, this type of pond is effective at removing the majority of nitrogen and phosphorus from the effluent. To prevent leaching, the ponds should have a liner. The liner can be clay, asphalt, compacted earth, or another impervious material. To protect the pond from runoff and erosion, a protective berm should be constructed around the pond using the excavated material.

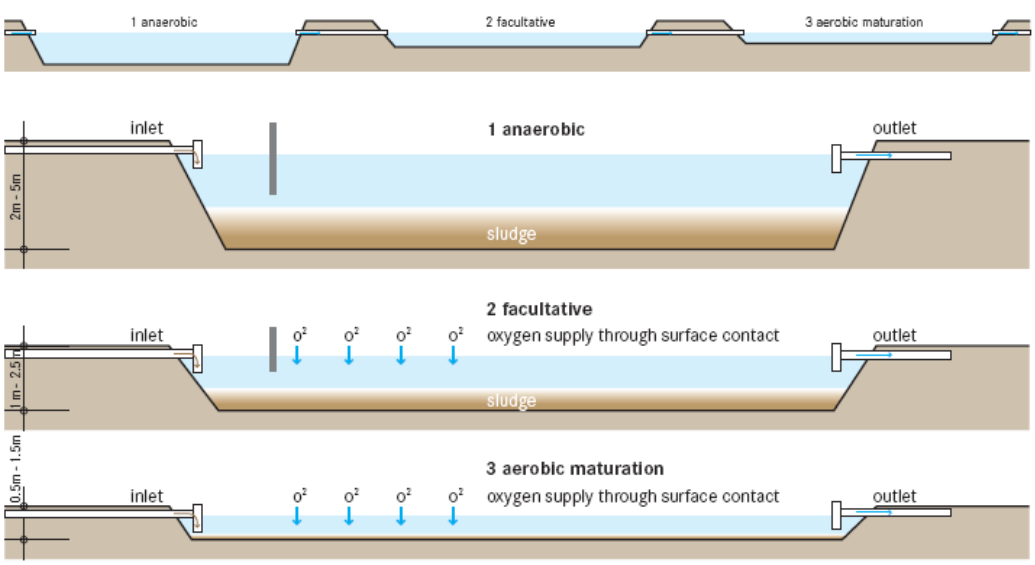


Fig G.1 Waste Stabilization Ponds (WSP)

Application level: Decentralised and Centralised

Centralised	Decentralised	Onsite
**	*	

Limitations: WSP can be applied in every type of climate although the efficiency will be affected in colder climates.

Maintenance To prevent scum formation, excess solids and garbage from entering the ponds, pre-treatment (with grease traps) is essential to maintain the ponds. The pond must be desludged once every 10 to 20 years. A fence should be installed to ensure that people and animals stay out of the area and excess garbage does not enter the ponds. Rodents may invade the berm and cause damage to the liner. Raising the water level should prompt rodents to evacuate the berm. Care should be taken to ensure that plant material does not fall into the ponds. Vegetation or macrophytes that are present in the pond should be removed as it may provide a breeding habitat for mosquitoes and prevent light from penetrating the water column.

Advantages

- High reduction in pathogens
- Can be built and repaired with locally available materials

- Construction can provide short-term employment to local labourers
- Low operating cost
- No electrical energy required
- No real problems with flies or odours if designed correctly

Disadvantages

- Requires expert design and supervision
- Variable capital cost depending on the price of land
- Requires large land area
- Effluent/sludge requires secondary treatment and/or appropriate discharge

Costs

The primary cost associated with constructing an anaerobic lagoon is the cost of the land, earthwork appurtenances, required service facilities, and the excavation. Costs for forming the embankment, compacting, lining, service road and fencing, and piping and pumps also need to be considered. Operating costs and power requirements are minimal.

Table G.2 Trickling Filter

Trickling filter-*Mechanical* Technology: *(Data Source: Adopted from EAWAG- A Compendium of Sanitation Systems & Technologies, 2008)*
Description: A Trickling Filter is a fixed bed, biological filter that operates under (mostly) aerobic conditions. Pre-settled wastewater is 'trickled' or sprayed over the filter. As the water migrates through the pores of the filter, organics are degraded by the biomass covering the filter material. The Trickling Filter is filled with a high specific surface area material such as rocks, gravel, shredded PVC bottles, or special pre-formed filter material. A material with a specific surface area between 30 and 900m2/m3 is desirable. Pre-treatment is essential to prevent clogging and to ensure efficient treatment. The pre-treated wastewater is 'trickled' over the surface of the filter. Organisms that grow in a thin bio film over the surface of the media oxidize the organic load in the wastewater to carbon dioxide and water while generating new biomass. The incoming wastewater is sprayed over the filter with the use of a rotating sprinkler. In this way, the filter media goes through cycles of being dosed and exposed to air. However, oxygen is depleted within the biomass and the inner layers may be anoxic or anaerobic. The filter is usually 1 to 3m deep but filters packed with lighter plastic filling can be up to 12m deep. The ideal filter material has a high surface to volume ratio, is light, durable and allows air to circulate. Whenever it is available, crushed rock or gravel is the cheapest option. The particles should be uniform such that 95% of the particles have a diameter between 7 and 10cm. Both ends of the filter are ventilated to allow oxygen to travel the length of the filter. A perforated slab that allows the effluent and excess sludge to be collected supports the bottom of the filter. With time, the biomass will grow thick and the attached layer will be deprived of oxygen; it will enter an endogenous state, will lose its ability to stay attached and will slough off. High-rate loading conditions will also cause sloughing. The collected effluent should be clarified in a settling tank to remove any biomass that may have dislodged from the filter. The hydraulic and nutrient loading rate (i.e. how much wastewater can be applied to the filter) is determined based on the characteristics of the wastewater, the type of filter media, the ambient temperature,

and the discharge requirements. This technology can only be used following primary clarification since high solids loading will cause the filter to clog. A skilled operator is required to monitor and repair the filter and the pump in case of problems. Compared to other technologies (e.g. WSPs), trickling filters are compact, although they are still are best suited for peri-urban or large, rural settlements.

The Conventional Trickling Filter process/technology offers the ability of a robust (shock loading inclusive), low energy intensity, low maintenance and operation costs, low skills requirement option for wastewater treatment. In areas where space is not a limiting factor and where occasional nuisance is not a serious consideration this technology can offer a reliable operation and consistent effluent quality. In practice the technology has been used in the past and is still used in places in Gauteng but has lost popularity on account of activated sludge systems. The benefits include nitrification and high degree of de-nitrification if operated properly. As a technology trickling filters are suitable for many situations detected in need of wastewater treatment in the study area. However before this technology can be recommended as a final technology choice more specific plant location and point discharges need to be known as well as the required effluent quality. This technology should be considered in all situations with full water borne sewerage and the number of people served is less than 100000.

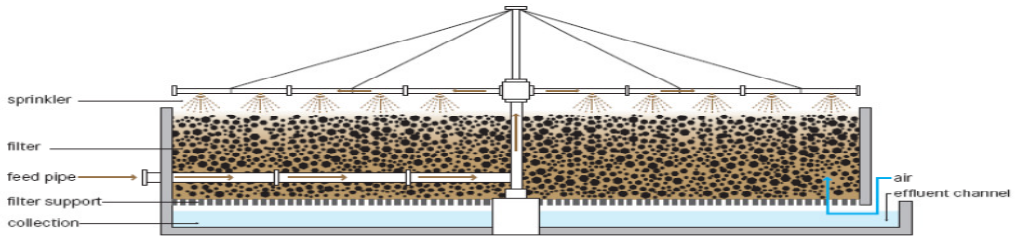


Fig G.2 Trickling filter

Application level: Decentralised and Centralised

Centralised	Decentralised	Onsite
**	*	

Limitations: A low-energy (gravity) trickling system can be designed, but in general,

a continuous supply of power and wastewater is required. Trickling Filters can be built in almost all environments, although special adaptations for cold climates are required.

Maintenance The sludge that accumulates on the filter must be periodically washed away to prevent clogging. High hydraulic loading rates can be used to flush the filter. The packing must be kept moist. This may be problematic at night when the water flow is reduced or when there are power failures.

Advantages

- Can be operated at a range of organic and hydraulic loading rates
- Small land area required compared to Constructed Wetlands

Disadvantages

- High capital costs and moderate operating costs
- Requires expert design and construction
- Requires constant source of electricity and constant wastewater flow
- Flies and odours are often problematic
- Not all parts and materials may be available locally
- Pre-treatment is required to prevent clogging
- Dosing system requires more complex engineering

Table G.3 Activated Sludge

Activated Sludge- ***Mechanical (Data Source: Adopted from EAWAG- A Compendium of Sanitation Systems & Technologies, 2008)***
Description: Activated Sludge is a multi-chamber reactor unit that makes use of (mostly) aerobic microorganisms to degrade organics in wastewater and to produce a high-quality effluent. To maintain aerobic conditions and to the keep the active biomass suspended, a constant and well-timed supply of oxygen is required. Different configurations of the Activated Sludge process can be employed to ensure that the wastewater is mixed and aerated (with either air or pure oxygen) in an aeration tank. The microorganisms oxidize the organic carbon in the wastewater to produce new cells, carbon dioxide and water. Although aerobic bacteria are the most common organisms, aerobic, anaerobic, and/or nitrifying bacteria along with higher organisms can be present. The exact composition depends on the reactor design, environment, and wastewater characteristics. During aeration and mixing, the bacteria form small clusters, or flocs. When the aeration stops, the mixture is transferred to a secondary clarifier where the flocs are allowed to settle out and the effluent moves on for further treatment or discharge. The sludge is then recycled back to the aeration tank, where the process is repeated. To achieve specific effluent goals for BOD, nitrogen and phosphorus, different adaptations and modifications have been made to the basic Activated Sludge design. Aerobic conditions, nutrient-specific organisms (especially for phosphorus), recycle design and carbon dosing, among others, have successfully allowed Activated Sludge processes to achieve high treatment efficiencies. Activated Sludge is only appropriate for a centralised treatment facility with a well-trained staff, constant electricity and a highly developed centralised management system to ensure that the facility is operated and maintained correctly. Activated Sludge processes are one part of a complex treatment system. They are used following primary treatment (that removes settleable solids) and before a final polishing step. The biological processes that occur are effective at removing

soluble, colloidal and particulate organic materials for biological nitrification and denitrification and for biological phosphorus removal. This technology is effective for the treatment of large volumes of flows: 10,000 to 1,000,000 people. Highly trained staff is required for maintenance and trouble-shooting. The design must be based on an accurate estimation of the wastewater composition and volume. Treatment efficiency can be severely compromised if the plant is under- or over-designed. An Activated Sludge process is appropriate for almost every climate.

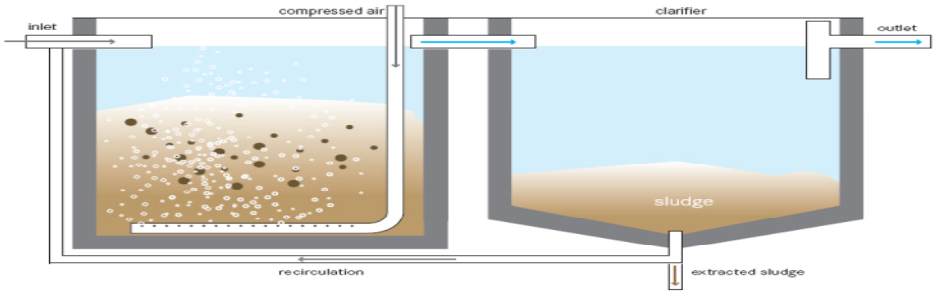


Fig G.3 Activated Sludge

Application level: Decentralised and Centralised

Suitability for centralised and decentralised systems:

Centralised	Decentralised	Onsite
**	*	

Maintenance The mechanical equipment (mixers, aerators and pumps) must be maintained constantly. As well, the influent and effluent must be monitored constantly to ensure that there are no abnormalities that could kill the active biomass and to ensure that detrimental organisms have not developed that could impair the process (e.g. filamentous bacteria).

Advantages

- Good resistance against shock loading
- Can be operated at a range of organic and hydraulic loading rates
- High reduction of BOD and pathogens (up to 99%)
- Can be modified to meet specific discharge limits

Disadvantages

- Prone to complicated chemical and microbiological problems
- Effluent might require further treatment/ disinfection before discharge
- Not all parts and materials may be available locally
- Requires expert design and supervision
- High Capital cost; high operation cost
- Constant source of electricity is required
- Effluent and sludge require secondary treatment and/or appropriate discharge

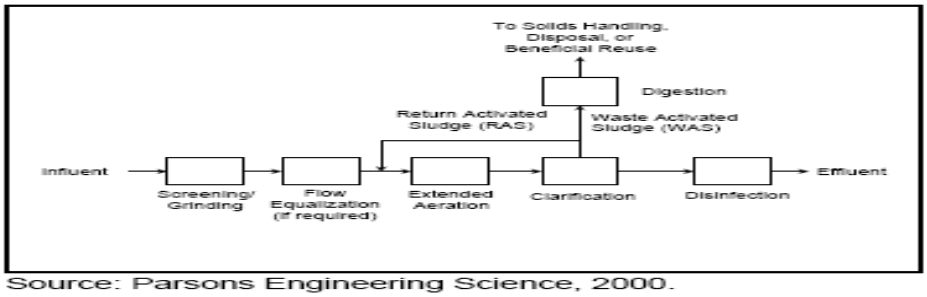
Table G.4 Package Plants

Package plants Technology: ***(Data Source: Adopted from EPA- Technology factsheets, 2000)***
Description: Package plants are pre-manufactured treatment facilities used to treat wastewater in small communities or on individual properties. According to manufacturers, package plants can be designed to treat flows as low as 0.002 MGD or as high as 0.5 MGD, although they more commonly treat flows between 0.01 and 0.25 MGD (Metcalf and Eddy, 1991). The most common types of package plants are extended aeration plants, sequencing batch reactors, oxidation ditches, contact stabilization plants, rotating biological contactors, and physical/chemical processes (Metcalf and Eddy, 1991). This research focuses on the first three, all of which are biological aeration processes. The extended aeration process is one modification of the activated sludge process which provides biological treatment for the removal of biodegradable organic wastes under aerobic conditions. Air may be supplied by mechanical or diffused aeration to provide the oxygen required to sustain the aerobic biological process. Mixing must be provided by aeration or mechanical means to maintain the microbial organisms in contact with the dissolved organics. In addition, the pH must be controlled to optimize the biological process and essential nutrients must be present to facilitate biological growth and the continuation of biological degradation. As depicted in above diagram, wastewater enters the treatment system and is typically screened immediately to remove large suspended, settleable, or floating solids that could interfere with or damage equipment downstream in the process. Wastewater may then pass through a grinder to reduce large particles that are not captured in the screening process. If the plant requires the flow to be regulated, the effluent will then flow into equalization basins which regulate peak wastewater flow rates. Wastewater then enters the aeration chamber, where it is mixed and oxygen is provided to the microorganisms. The mixed liquor then flows to a clarifier or settling chamber where most microorganisms settle to the bottom of the clarifier and a portion are pumped back to the incoming wastewater

at the beginning of the plant. This returned material is the return activated sludge (RAS). The material that is not returned, the waste activated sludge (WAS), is removed for treatment and disposal. The clarified wastewater then flows over a weir and into a collection channel before being diverted to the disinfection system.

Extended aeration package plants consist of a steel tank that is compartmentalized into flow equalization, aeration, clarification, disinfection, and aerated sludge holding/digestion segments. Extended aeration systems are typically manufactured to treat wastewater flow rates between 0.002 to 0.1 MGD. Use of concrete tanks may be preferable for larger sizes (Sloan, 1999). Extended aeration plants are usually started up using "seed sludge" from another sewage plant. It may take as many as two to four weeks from the time it is seeded for the plant to stabilize (Sloan, 1999).

Diagram:



Source: Parsons Engineering Science, 2000.

Fig G.4 Package plants

Application level: Decentralised & Centralised systems

Suitability for centralised and decentralised systems:

Centralised	Decentralised	Onsite
**	**	

Advantages

1. Plants are easy to operate, as many are manned for a maximum of two or three hours per day.
2. Extended aeration processes are often better at handling organic loading and flow fluctuations, as there is a greater detention time for the nutrients to be assimilated by microbes.

3. Systems are easy to install, as they are shipped in one or two pieces and then mounted on an onsite concrete pad, above or below grade.
4. Systems are odour free, can be installed in most locations, have a relatively small footprint, and can be landscaped to match the surrounding area.
5. Extended aeration systems have a relatively low sludge yield due to long sludge ages, can be designed to provide nitrification, and do not require a primary clarifier.

Disadvantages

1. Extended aeration plants do not achieve denitrification or phosphorus removal without additional unit processes.
2. Flexibility is limited to adapt to changing effluent requirements resulting from regulatory changes.
3. A longer aeration period requires more energy.
4. Systems require a larger amount of space and tankage than other "higher rate" processes, which have shorter aeration detention times

Table G.5 Living Machines

Living Machines: ***(Data Source: Adopted from EPA- Technology factsheets, 2000)***

Description: Ecological treatment methods are generally also decentralised systems. Most of them try to make use of natural purification processes that happen in the zones of interaction between water and soil or plants. Any flow that is treated in them undergoes primary treatment, which is usually screening and settlement. Living machines are a relatively new method of treating domestic wastewater. Their layout consists of a preliminary septic tank where sedimentation takes place. The water then enters, where required, a greenhouse, where the first phase of aerobic treatment takes place in a closed tank. The water then flows into open aerobic reactors. Floating on plant racks, macrophytes grow with their large root system submerged in the waste-water. In this phase, BOD and TSS are reduced and ammonia is nitrified. Oxygen is constantly bubbled into the reactors. Clarifiers then settle solids left in the effluent from the aerobic reactors. Denitrifcation takes place in the subsequent stage, the ecological fluidised beds. Live fish in the final effluent ensure an automatic quality control.

Diagram:

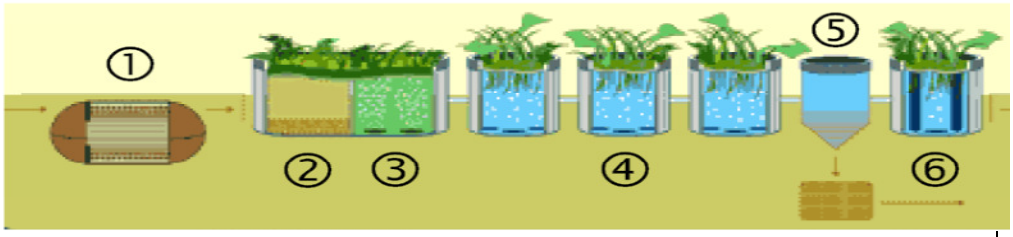


Fig G.5 Living Machines
COMPONENTS OF THE LIVING MACHINE: (1) ANAEROBIC REACTOR, (2) ANOXIC REACTOR, (3) CLOSED AEROBIC REACTOR, (4) OPEN AEROBIC REACTORS, (5) CLARIFIER, AND (6) "ECOLOGICAL FLUID BED"

Application level: Decentralised

Suitability for centralised and decentralised systems:

Centralised	Decentralised	Onsite
	**	**

Limitations: The Living Machine is well suited for treating both municipal and some industrial wastewaters. As with most treatment systems using plants, it can

require a larger footprint than more conventional systems, and its requirement for a greenhouse in more temperate climates can impact costs. However, its unique and aesthetically pleasing appearance makes it an ideal system in areas that oppose traditional treatment operations based on aesthetics (i.e., smell and appearance).

Maintenance: The routine operation and maintenance (O&M) requirements for Living Machines are similar to the requirements for a conventional wastewater treatment plant, with a few additional requirements. These additional requirements include cleaning the inlet/outlet structure; cleaning the screen and tank; removing and disposing sludge; and maintaining and repairing machinery. Other requirements are vegetation management, including routine harvesting to promote plant growth, and removal of accumulated plant litter. Additionally, it may be necessary to manage fish and snail populations, and control mosquitoes and flies (if applicable).

Advantages

- Capable of treating wastewaters to BOD5, TSS, and Total Nitrogen < 10 mg/L, Nitrate < 5 mg/L, and Ammonia < 1 mg/L.
- Offers a unique, aesthetically pleasing environment for treating and recycling wastewater. This may be helpful when attempting to locate the treatment system in areas where the public opposes traditional wastewater treatment operations for aesthetic reasons.

Disadvantages

- The Living Machine has only been shown to remove about 50 percent of influent phosphorous (with influents in the range of 5-11 mg/L). The removed phosphorus appears to be primarily associated with the incoming solids.
- The process requires a greenhouse for reliable operation in the cold weather of more temperate climates, adding to system costs.

Costs

Since the Living Machine is designed, marketed and trademarked by Living Machines, Inc., precise cost data are proprietary.

Table G.6 Aquaculture

Aquaculture: ***(Data Source: Adopted from EAWAG- A Compendium of Sanitation Systems & Technologies, 2008)***

Description: Duckweed and Aquaculture Ponds are an interesting modification of the conventional stabilization pond technology. The technology allows for intrinsic value recovery from wastewater and can offset costs of wastewater treatment and in some situations make a profit from wastewater treatment. The technology needs more detailed testing for South African conditions but should be considered as one of the feasible technology options for smaller communities (<50000 people). Aquaculture consists of large ponds in which different plants and fish live. The plants feed on the nutrients from either raw, screened sewage or secondary treated effluent. The fish in the pond feed on the plants and normally grow to full size in one vegetative season. They are then harvested and sold. Plants for human consumption can also be reared in aquacultures. Aquaculture is a good measure to directly recycle human waste.

Diagram:



Fig G.6 Aquaculture

Application level: Decentralised

Suitability for centralised and decentralised systems:

Centralised	Decentralised	Onsite
**	**	

Limitations Temperature (climate) is a major limitation since effective treatment is linked to the active growth phase of the vegetation. Herbicides and other materials toxic to the plants can affect their health and lead to poor treatment. Duckweeds are prized as food for waterfowls and fish and can be seriously depleted by these species. Winds may blow duckweed to the shore if wind screens

or deep trenches are not employed.

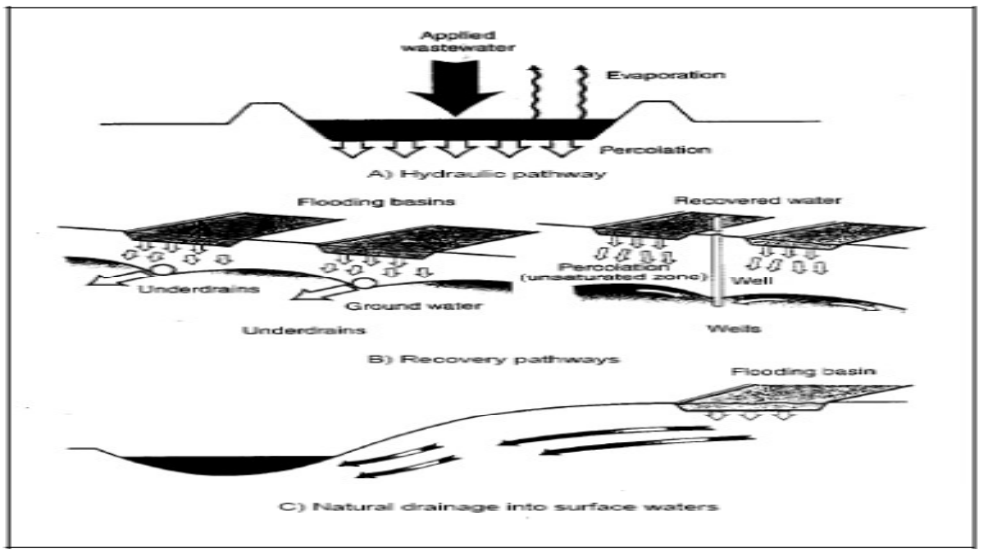
Advantages

- Aesthetically pleasing and provides animal habitat
- High reduction in BOD and solids; moderate pathogen removal
- Can be built and repaired with locally available materials
- Construction can provide short-term employment to local labourers
- No electrical energy required
- No real problems with flies or odours if used correctly

Disadvantages

- May facilitate mosquito breeding
- Long start up time to work at full capacity
- Requires large land area
- Requires expert design and supervision
- Moderate capital cost depending on land, liner, etc.; low operating costs

Table G.7 Rapid Infiltration

Rapid Infiltration (RI)- land Treatment Systems: ***(Data Source: Adopted from EPA- Technology factsheets, 2000)***
Description: Rapid Infiltration (RI), which is also known as soil aquifer treatment, is one of the three major land treatment techniques that use the soil ecosystem to treat wastewater. However, the RI process can treat a much larger volume of wastewater on a much smaller land area than other land treatment concepts. In RI systems, wastewater is applied to shallow basins constructed in deep and permeable deposits of highly porous soils. Wastewater application can be by flooding, or occasionally by sprinklers. Treatment, including filtration, adsorption, ion exchange, precipitation, and microbial action, occurs as the wastewater moves through the soil matrix. Phosphorus and most metals are retained in the soil while toxic organics are degraded or adsorbed. As wastewater percolates through the soil, it can be collected, or it can flow to native surface water or groundwater aquifers. Where the groundwater table is relatively shallow, the use of underdrains allows control of groundwater mounding and recovery of the renovated water. In areas with deeper groundwater, wells are used to recover the renovated water. This recovered water can be for irrigating crops or for industrial uses. This is known as "beneficial reuse." Water that is not recovered can recharge groundwater aquifers. The typical hydraulic pathways for water treated by RI are shown in the diagram.

Fig G.7 Rapid Infiltration (Source: Crites, *et al.,* 2000)

Application level: Decentralised & Centralised systems

Suitability for centralised and decentralised systems:

Centralised	Decentralised	Onsite
**	**	

Maintenance: The same maintenance requirements used at any earthen basin are applicable to RI systems. Special requirements for RI systems pertain to preserving the design infiltration capacity of the basins. The operator should perform daily inspections and record drainage time for the basins so that the infiltration rate can be tracked. Restoration of the infiltrative surface may be necessary when the infiltration rate decreases. Accumulated organic deposits are typically removed at least annually, and the infiltration surface is raked, disked or tilled to restore infiltration capacity. On a more extended interval, it may be necessary to remove the top few inches of soil to expose clean material. These maintenance activities should only occur when the basin bottom is dry to avoid soil compaction. Dikes and berms should also be monitored for signs of decay or erosion.

RI has excellent reliability. With proper operation and management, several systems in the North-eastern United States have operated continuously for more than 50 years without problems

Advantages

- Gravity distribution methods consume no energy.
- No chemicals are required.
- RI is a simple and economical treatment.
- The process is not constrained by seasonal changes.
- Effluent is of excellent quality.
- The process is very reliable with sufficient resting periods.
- RI provides a means for groundwater recharge, controlling groundwater levels, recovering renovated water for reuse or discharge to a particular surface water body, and temporary storage of renovated water in the aquifer.
- The process is suitable for small plants where operator expertise is limited.

Disadvantages

- As typically operated, RI systems will not usually meet the stringent nitrogen levels required for discharge to drinking water aquifers.
- Requires long term commitment of a significant land area for treatment, with minimal secondary benefits such as are possible with other natural treatment systems (i.e., crop/forest production, habitat enhancement, etc.).
- Requires annual removal of accumulated deposits of organic matter on the infiltration surfaces in the basins.
- May require occasional removal and disposal of the top few inches of soil to expose clean material.
- Clogging can occur when influent is received at high application rates from algal laden facultative lagoons and polishing ponds.

Costs

With suitable soil and hydrogeologic conditions, RI systems can produce a percolate that is essentially equal in quality to that produced by more conventional advanced wastewater treatment processes, at a fraction of the cost.

APPENDIX H SYSTEMATIC PROCEDURES ON MODEL USE

H.1 Purpose of the Model

The aim of the DSS developed in this research is to make use of Multi Criteria Decision Aid (MCDA) for the comparative evaluation and selection of wastewater treatment systems technology with respect to technical, environmental and social criteria in one step and then carry out a detailed economic analysis on the finite solution set as a second step. This multi criteria decision aid tool is to be used as a context-oriented planning tool by local governments and wastewater and water service authorities and/or providers. More, specifically this will assist experienced personnel to ensure the integration of economic, social and environmental considerations in decision-making at all levels in the wastewater sector. A major advantage of the DSS is that it provides a transparent interface between different stakeholders within the water sector. The DSS itself is easy to use once a certain degree of familiarity has been reached with its structure, input requirements and output format.

H.2 Scope

The model has been developed for application in the smaller municipalities for Gauteng province, which include small towns. The model should be applied to a specific local section or settlements within the municipalities. Since there is so much variation in social and economic needs within the areas; the overall understanding is that a differential wastewater management approach should be employed with tailor made solutions resulting for each municipality or certain areas within a municipality.

H.3 Limitations of the Model

The limitation of this model is that it considered the treatment technology part of the wastewater systems and did not consider the collection and storage, conveyance which usually account for 80-90% of the wastewater systems costs. This could have been ideal to do a full systems analysis and comparison using the model but the reason for focussing on the treatment apart from that that is where the risk from health and environmental impacts is high is that the full detailed data required for economic comparisons were not available. For the selection of the full wastewater system, a similar and structured selection process is then followed which utilises the same approach but a broader set of selection factors and criteria. This has to occur within the case specific situation due to particular case characteristics affecting the final system choice.

H.4 Protection against Incompatible Entries

The model provides a certain degree of protection against nonsensical data. Major incompatibilities will produce error messages and the model will not calculate the output.

H.5 Technical Specifications

DSS System is a Web based system developed on Microsoft Technologies. The front end is implemented using some of the latest development tools from Microsoft; including AJAX enabled C-Sharp development tools. The back end is driven by Microsoft SQL Server 2005.The model was initially developed using Excel for window and the user requires only a very basic knowledge of the Excel spreadsheet package.

H.5.1Technical Justification

The advantages of using the web based technology over other forms like disc or computer based technologies are as follows;

- No special configuration or changes are need on user's PCs, just requires a browser and every PC has one.
- Lower costs: less time spent talking to stakeholders over the phone, elimination of printed materials, authenticated users update their municipal details
- Centralised data is secure and easy to backup and manage.
- Updates can be made quickly and easily and are immediately available.
- Information is accessible to a wide audience anywhere in the world.
- Available 24 hours a day, 7 days a week.
- Online training can be completed at user's own time and pace.
- Stakeholders located at different locations, on the road or even abroad, all have direct access to current information.

H.6 Basic Methodology

The users of the DSS should generally undertake the following steps.

H.6.1 Stage 1 Alternatives Determination

Using the algorithm developed select feasible range of technologies-Derive the range of sanitation/wastewater technology options which can be utilised in the context of the area in question. The iterative process is shown in Chapter 5 Fig 5.1 of the main thesis. This framework enables one to come up with relevant site specific alternatives which are context based and appropriate to the area based on the water supply levels since wastewater production is a function of the water supply. The output of this is a technology database which can be used to select the appropriate technologies for analysis.

H.6.2 Development of Technology Database

In order to make the selection much easier this research constructed a technology database derived from the algorithm as shown in figure 5.2 and also highlighted in Appendix G. There are many wastewater treatment technologies available for centralised and decentralised systems. Choosing from the large range of a set of centralised and decentralised systems can be complex and time consuming, which may cause the municipal authorities to disregard viable options they are not familiar with. The database helps to provide information and on the listed technologies which can help municipal officials in the comparative analysis of the technologies.

H.6.3 Stage 2 Defining Pertinent Criteria

There are two main steps in the second stage of the MCDA assessment. MCDA has specific application as a decision-making tool in steps 1 and 2.

1. The identification and selection of criteria/indicators.
2. The development of a weighting system on the selected set.

H.6.3.1 Step 1: Establish an initial set of Criteria

This is done through literature review and input from the municipal and provincial authorities. It is of paramount importance to understand the critical sustainable criteria for the area understudy. In this case, stakeholders examine the initial set of indicators and discuss the importance of each indicator and modify the initial set if necessary.

A ranking exercise using a set of questionnaires in Appendix C1 is used and criteria are accepted or rejected over the average value score obtained from the ranking. The screening of criteria is done on the basis of the scale shown in Table H.1.After ranking the initial set of criteria on a scale of 1 to 10 the criteria are accepted based on the arbitrarily scale score agreed upon by the members. This involves administering questionnaires to relevant stakeholders within the municipality and depending on internal agreements on the cut off score for the

criteria to be accepted or rejected. Criteria with a low score are then discarded as they are deemed less important. The final list is presented to the stakeholders. If the stakeholders are satisfied, then list of criteria is adopted. If the stakeholders are not satisfied then the process can be repeated. The ranking is solicited using Questionnaire 1 in appendix C1.

Table H.1 Criteria Classification

Classification of Criteria	**Score Range**	**Decision**
Highly Significant	10	Accept
Significant	7-9	Accept
Fairly Significant	5-6	Accept/Reject
Insignificant	<5	Reject

Meaningful use of the model requires that information is accurate, and it is therefore essential that experienced municipal official be involved in the review and processing of data generated through use of the questionnaires. The list of criteria accepted is then termed sustainable criteria and will be the one used in comparative analysis of the technologies or systems. The criteria classification scale is an arbitrary scale which is not part of the model but provides input into the model. The scale must be adjusted to meet the local context specifics of the area under consideration.

H.6.4 Step 2 Development of a Weighting System

A relatively simple approach to eliciting weights is the swing weight approach. For quantitative criteria, the number alone would be sufficient, while for qualitative criteria, the levels need to be described in words. The weights are calculated using equation H.1 as shown in Table H.2. The same procedure in

calculation of the main criteria weights is extended to the individual criterion under the three main criteria in order to come up with an individual weight of every criterion regarded for the evaluation.

H.6.4.1 Main Criteria Weighting

Weighting of the main criteria is done to reflect the relative importance of the main criterion with respect to one another. The main criteria are ranked and rated using questionnaire in Appendix C2. The swing method is used to come up with suitable weights for the criteria. The results are then analysed using excel spread sheet to come with relative weights of each criteria based on the equation 4.1

$$W_i = pi / \sum_{i=1}^{m} pi \qquad \text{Eqn (H.1)}$$

Table H.2 Main Criteria Weights

CRITERIA	RANKED WEIGHTS	NORMALISED WEIGHTS
TECHNICAL	100	0,4
ENVIRONMENTAL	80	0,3
SOCIAL	80	0,3
SUM	260	1,0

The procedure is that when percentage figures derived from questionnaires are entered in the main criteria weights the systems does an automatic calculation and gives the overall weights for the main criteria as shown in Table H.2. The sub criteria for technical, social, and environmental weighting systems follows the same process as for the main criteria as shown in Table H.3. The system then calculates the individual overall weight coefficients for all the sub criteria which are a product of the main criteria weight and the sub criteria weight of the main criteria. The assessment of the technology in terms of its overall performance is against the overall individual weights of all the criteria are the ones used in the evaluation of the technologies

Table H.3 Technical Weights Determination

CATEGORY	MAIN CRITERIA	SUB CRITERIA	Ranking	Normalised category weight coefficients (%)	Overall Individual weight coefficients (%)
Technical	Performance	BOD removal TSS removal Nitrogen Removal Phosphorus removal Fecal Coliforms removal	100	27,8	10,68
	Reliability		*95*	26,4	10,15
	Ease of construction		80	22,2	8,55
	Adaptability		*85*	23,6	9,08
			360	100,0	0,4

H.6.5 Stage 3 Scoring & General Assessments Methodology

The goal of this step is to find a way of evaluating the overall performance/ sustainability of wastewater technologies and express it as a score. A scoring system that adequately reflects the performance of the wastewater technology being assessed is the key to any evaluation system.

H.6.5.1 Step 1 Scoring the System

A questionnaire administered to the decision makers/service providers is shown in Appendix D. The responses derived from the questionnaire are input into the DSS for analysis. The DSS uses a scale of 1-5 to generate a score from a set of questions/statements. Arithmetic mean is used to aggregate the standardised value obtained in questions/statements involved in DSS questionnaires using the expression below:

$$a_j = \frac{1}{m} \sum_{i=1}^{n} X_{ij} \qquad \text{Eqn (H.2)}$$

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)

H.6.5.2 Step 2 Matching score to Evaluation scale

The result obtained by summation of all questions/statements is then aggregated to obtain standardised outcome score on the scale 0 to 10 for the technical, social and environmental criteria. The final score on a scale of 0 to 10 is derived from the following equations;

If the Target for an indicator is Maximum score, then

$$\text{Score} = (d_{ave} - d_{low})/d_{max} - d_{low})*10 \qquad \text{Eqn (H.2)}$$

If the Target for an indicator is Minimum score, then

$$\text{Score} = |(d_{ave} - d_{low})/d_{max} - d_{low}) - 1|*10, \text{ where} \qquad \text{Eqn (H.3)}$$

$a_j = d_{ave}$ is the average score derived from eqn (H.2)

d_{low} is the lowest value over the range of scale considered which is equal to 1

d_{max} is the maximum value over the range of scale considered which is equal to 5

H.6.6 Stage 4 Manually Input of Score

The scores derived from the computations procedure outlined in section H.6.5.2 are manually entered in the DSS as shown in Table H.4.

Table H.4 Scores

Technologies	Technical				Environmental		Social				
	T1	T2	T3	T4	C1	C2	S1	S2	S3	S4	S5
Activated sludge	7	7	6	6	5	7	8	10	8	10	8
Trickling filter (biofilters)	7	7	6	6	6	7	8	10	5	9	8
Rotating Biological Contactors	8	4	8	5	5	8	6	10	8	10	8
Aerated lagoons	8	6	5	6	6	9	8	10	8	10	8
Anaerobic lagoons	7	8	7	3	8	9	5	6	5	10	8
Facultative ponds	7	5	7	4	8	9	8	8	8	10	8
Recirculating biological filter (RBF)	9	9	8	6	8	8	8	5	8	5	10
Oxidation ditches	9	9	8	6	8	8	8	3	8	5	10
Sequence batch reactor	9	9	8	6	8	8	8	5	8	5	10
Constructed wetlands	8	7	6	7	8	9	4	4	8	7	6
Living machines	8	6	4	5	8	10	6	7	5	4	10
Aquaculture	9	8	9	6	6	9	6	6	10	8	4
Slow infiltration	8	10	8	9	8	9	7	8	8	9	8
Rapid Infiltration	8	10	8	9	9	9	7	8	8	9	10
Overland Flow	9	10	8	8	8	9	7	8	8	9	8

H.7 Stage 5 Evaluation using Weighted Sum Method

The Weighted Sum Method involves computation through maximising the expected utility function, H_j, as in the following:

$$H_j = \sum_{i=1}^{m} w_i v_{ij} \qquad \text{Eqn (H.4)}$$

where m is the number of criteria of alternative j, v_{ij} is the value of jth alternative with respect to the ith criterion, and w_i is the weight of importance assigned to criterion i with the constraints of $w_i \geq 0$ and

$$\sum_{i=1}^{m} w_i = 1 \qquad \text{Eqn (H.5)}$$

Table H.5 Aggregate Score

Technologies	Technical				Environmental		Social					Sum
	T1	T2	T3	T4	C1	C2	S1	S2	S3	S4	S5	
Activated sludge	61,20	55,82	42,74	40,87	98,62	121,79	48,72	58,12	46,15	54,70	51,28	680,01
Trickling filter (biofilters)	62,74	55,82	42,74	40,87	110,95	131,16	48,72	58,12	30,77	51,28	51,28	684,44
Rotating Biological Contactors	69,57	35,52	55,56	36,32	98,62	140,53	40,60	58,12	46,15	54,70	51,28	686,98
Aerated lagoons	65,98	45,67	34,19	40,87	123,27	168,64	48,72	58,12	46,15	54,70	51,28	737,60
Anaerobic lagoons	60,68	65,97	47,01	18,16	147,93	159,27	32,48	33,90	30,77	54,70	51,28	702,16
Facultative ponds	61,71	40,60	47,01	31,78	147,93	168,64	48,72	43,59	46,15	54,70	51,28	742,11
Recirculating biological filter	80,51	71,05	51,28	45,41	147,93	140,53	48,72	29,06	46,15	27,35	68,38	756,37
Oxidation ditches	80,51	71,05	51,28	45,41	147,93	149,90	48,72	14,53	46,15	27,35	68,38	751,21
Sequence batch reactor	80,51	71,05	51,28	45,41	147,93	140,53	48,72	29,06	46,15	27,35	68,38	756,37
Constructed wetlands	67,01	55,82	42,74	49,95	160,26	168,64	28,42	24,22	46,15	37,61	39,89	720,69
Living machines	72,14	45,67	29,91	36,32	147,93	187,38	40,60	38,75	30,77	23,93	68,38	721,78
Aquaculture	76,92	65,97	59,83	45,41	123,27	168,64	36,54	33,90	61,54	41,03	28,49	741,54
Slow infiltration	72,56	81,20	51,28	63,57	147,93	168,64	44,66	48,43	46,15	51,28	56,98	832,69
Rapid Infiltration	72,56	81,20	55,56	63,57	172,58	159,27	44,66	48,43	46,15	51,28	68,38	863,64
Overland Flow	73,33	81,20	55,56	59,03	160,26	159,27	44,66	48,43	46,15	51,28	56,98	836,15

The scores derived from use of the equations are based on theoretical values, which were formulated using a combination of literature studies and assessments by the researcher in collaboration with Gauteng Provincial local government officials as well as Witwatersrand University postgraduate students for the Wastewater Engineering course.

H.8 Stage 6: 1st Ranking of Technology

The overall results from the calculation are ranked through a bar chart as shown in Chapter 5 in Fig 5.10 in the main thesis, with the most sustainable technologies

having a higher percentage score. The scores were expressed as percentages of the highest possible score. Table H.6 shows the scale used for analysis and for acceptance for the possible sustainable solutions.

$$SI = \frac{H_j * 100}{H_{\max}} \qquad \text{Eqn (H.6)}$$

Where SI is the sustainability index measure as a percentage

H_j is the overall score for the technology after evaluation based on all criteria

H_{max} is the highest possible score for a technology based on all the mentioned criteria.

Table H.6 Sustainability Index Classification

Classification of Choice	Sustainability index (%)	Sustainability Ranking
Excellent	80 - 100	Highly Sustainable
Very Good	70 - 80	Sustainable
Good	60 – 70	Partially Sustainable
Fair	40 - 60	
Poor	<40	Unsustainable

The key output provided by the model/DSS is the technology shortlist.

H.9 Stage 7: Undertake a Sensitivity Analysis

The results of the ranking can never be completely objective because of the weighting procedure, but confidence in the results can be increased by carrying out a sensitive analysis. This is done by looking at the effects on ranking caused by changes in the weighting. The criteria most open to subjective interpretation is selected and the weights of the criteria are slightly changed, recalculated and the final scores are summed up and re-ranking of the technologies is done. Comparisons between the ranking order for different scoring and weighting scenarios indicated the level of confidence that can be given to the results. Minimal changes in ranking order indicate a high degree of confidence in the

results. Conversely, wide variations in ranking will indicate that the results should be treated with care.

H.10 Stage 8 Detailed Economic Analysis

The final output after the sensitivity analysis needs to be assessed in terms of the economic costs of the technologies. This stage utilises the same procedures as outlined in stages H.3 to H.9. Using MCDA methodology. The economic evaluation will then rank the shortlisted technologies. The next step is to present the chosen scenarios/technology options, together with the sensitivities of the key parameters, to the political representatives and responsible authorities. These should then choose the most appropriate technology for further or detailed investigation.

H.11 Model Requirements

The minimum number of respondents to questionnaires needed to make the methodology developed and the tool implemented a reliable instrument to support effective decision making is 50. This figure is derived from social statistics analysis literature in order to eliminate bias in the decision making and to increase the confidence in the results derived from the decision support system.

The following stakeholders should be considered if the model is to give meaningful results which can be implemented. The stakeholders will include the following; social scientist, economist, scientist, engineer, community representatives, municipal officials, Provincial authorities, DWAF, CMA and District management authorities. The stakeholders' team must consist of at least 40 team members representing expertise in each of the disciplines. Effort should be made to utilise the best expertise available, both with respect to the discipline and site concerned. It is also important to include different perspectives on the teams (e.g. academics, consultants and NGOs).