

**Development of an Impact Assessment Methodology and
Decision Making Tool to Assist in the Evaluation of Site
Suitability for On-site Sanitation Systems**

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Thesis submitted for the degree Doctor of Philosophy
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School of Environmental Sciences and Development

At the Potchefstroom Campus of the North West University

November 2006

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ACKNOWLEDGEMENTS

It is my desire to acknowledge the following organisation and persons who contributed significantly towards finishing this thesis.

Africa Geo-Environmental Services (Pty) Ltd for the support and opportunity to write this thesis, and especially my colleagues for their continual support and encouragement.

My promoter, Prof IJ van der Walt from the University of the North West. His guidance and helpful suggestions, especially during the final stages of the thesis is greatly appreciated.

My parents, family and friends for their interest, inspiration and continuous prayers.

My husband Koos, for his patience during the completion of this thesis. I could not have achieved this without his support and love. It is therefore with great appreciation and love that I want to dedicate this thesis to him.

My Lord and Saviour Jesus Christ, whose presence, guidance and mercy in my life helped me, accomplished this task.

**DEVELOPMENT OF AN IMPACT ASSESSMENT METHODOLOGY AND DECISION MAKING
TOOL TO ASSIST IN THE EVALUATION OF SITE SUITABILITY FOR ON-SITE SANITATION
SYSTEMS**

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ABSTRACT

Groundwater plays an important role in water supply to rural communities. This statement is supported by the survey conducted at clinics within the Limpopo Province where the majority of aquifers in the area can be classified as Sole Source aquifers, supplying 50 % or more of domestic water in the absence of any reasonable alternative. The water quality study also concluded that the impact from on site sanitation on the groundwater system is significant given that 44 % of water samples of clinics with their own water supply classified as either poor or dangerous quality according to DWAF criteria and poses a significant health risk to susceptible individuals.

Groundwater quality should therefore be protected with an emphasis on prevention as in most cases groundwater pollution is difficult to reverse and remediation is often a lengthy and expensive exercise. Although South Africa has all the legal tools to promote sustainable development, financial considerations are usually the driving force behind technology

selection and not social or environmental aspects.

The aim of this research is to develop an environmental impact assessment methodology and decision support framework that will aid in the selection of the most appropriate on site sanitation technology for a given area integrating environmental, economical and social criteria. The decision support framework developed in this study had a strong stakeholder component, involving stakeholders in the decision making process from the conception of the project through to the resolution of actions. Providing objective information about the performance of options, coupled with an opportunity to participate in the decision-making process, increases the awareness and commitment of the community.

Field testing of the decision support framework produced good results and sensible recommendations were made with regard to alternative selection.

Key words: Sanitation, sustainability, alternative technology, decision support framework, groundwater.

**ONTWIKKELING VAN 'N IMPAK ONDERSOEK METODOLOGIE EN BESLUITNEMINGS
RAAMWERK VIR DIE EVALUERING VAN DIE GESKIKTHEID VAN SANITASIE SISTEME**

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OPSOMMING

Grondwater speel 'n baie belangrike rol in water voorsiening vir landelike gemeenskappe. Die stelling word ondersteun deur die waterkwaliteits ondersoek wat gedoen is by klinieke in die Limpopo Provinsie waar die meerderheid van water vir huishoudelike gebruik afkomstig is vanaf grondwater. Waterkwaliteitsresultate het ook aangetoon dat die impak van sanitasie sisteme wel 'n beduidende impak het op die kwaliteit van grondwater. Vier en veertig persent van watermonsters vanaf klinieke, is as ondrinkbaar geklassifiseer.

Grondwaterkwaliteit moet daarom beskerm word met 'n klem op voorkoming. Alhoewel die Suid Afrikaanse wetgewing voorsiening maak vir volhoubare ontwikkeling, is finansiele oorwegings gewoonlik die deurslaggewende faktor in besluite wat geneem word.

Die doel van die studie is om 'n omgewingsimpakmetodologie en besluitnemingsraamwerk te ontwikkel vir die evaluering van die geskiktheid van sanitasie sisteme. Die voorgestelde metodiek het ten doel om omgewings-, ekonomiese en sosiale faktore te integreer om 'n optimale oplossing te vind vir die sanitasie problem. 'n Pragmatiese benadering word voorgestel met aktiewe deelname van die publiek. Die implementering van die

impakmetodologie en besluitnemingsraamwerk het sinvolle resultate gelewer met betrekking tot die mees geskikte sanitasie tegnologie.

Sleutelwoorde: Sanitasie, volhoubaarheid, alternatiewe tegnologie, besluitnemings raamwerk, grondwater.

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List of abbreviations

AI	Artificial intelligence
BPEO	best practical environmental option
CDC	Centre for Disease Control
CWSS	Community water supply and sanitation
DALY	Disability Adjusted Life Years
DR	Desirable range
DWAF	Department of Water Affairs and Forestry
ECA	Environmental Conservation Act
EDSS	Environmental decision support systems
EPA	Environmental Protection Agency
FRP	filterable reactive phosphorus
GDP	Gross Domestic Product
GNP	Gross National Product
GRIP	Groundwater Information Project
HACCP	Hazard assessment critical control point
HAV	Hepatitis A Virus
HIA	Health Impact Assessment
ISD	Institutional and Social Development
MAE	Mean annual evaporation
MAP	Mean annual precipitation
mbdl	meters below datum level
MEP	Minimum evaluation procedure
MIB	More is better
MIW	More is worse
MODSF	Multiple objective decision support framework
NRC	National Research Council
NGDB	National Groundwater Database
NWRS	National Water Resource Strategy
O&M	Operation and Maintenance
PFU	Plaque forming units
PHAST	Participatory Health and Sanitation Transformation
PP	Public Participation
PSE	Purified sewage effluent
SANEX	Sanitation expert system
SSPRA	Site Sanitation Planning and Reporting Aid
TBL	Triple Bottom Line
TDS	Total dissolved solids
THM	trihalomethanes
TWQR	Target Water Quality Range
UDR	Undesirable range
VIP	Ventilated Improved Pit Toilet
WATSAN	Water and sanitation
WEIS	Water and Environmental Information System
WHO	World Health Organization
WHPA	Well head protection area

CHAPTER 1

1 INTRODUCTION

“Nowadays people know the price of everything and the value of nothing...” Oscar Wilde

1.1 General

Since the UN Earth Summit 1992 in Rio de Janeiro, Brazil, numerous discussions have been held on environmental pollution, exploitation and limitation of natural resources all over the world. The intake capacity and overloading of the natural environment with emissions and waste are reaching a critical point, strengthened by rapid urbanisation, fast population growth and migration into urban centres. The effects are manifold, but the most severely affected are the poorest in society, especially women and children in developing countries who suffer most from water related diseases and the damaged environment (Mara, 2003).

The main burdens are the consequence of inadequate drinking water sources and lack of sanitation facilities, which causes health and environmental problems of which water pollution is the most significant. Worldwide, one in five persons do not have access to safe and affordable drinking water and every second person do not have access to safe and sufficient sanitation (Mara, 2003).

The World Health Organization stated that globally around 1.1 billion people do not have access to improved water supply sources, whereas 2.4 billion people do not have access to any type of improved sanitation facility. Approximately 2 million people die every year due to diarrhoeal diseases; most of them are children younger than five years of age. One point three million children under the age of five die each year (i.e. one diarrhoeal disease child death every 25 seconds). Children under the age of five years form only 10 percent of the world’s population, yet they bear at least 40 percent of the total burden of disease. The most affected are the populations in developing countries, living in extreme conditions of poverty, normally peri-urban dwellers or rural inhabitants (World Health Organization, 2002).

Introduction

There is a worldwide recognition that sustainability can only be achieved by a combined attention to water supply, sanitation and hygiene. The lack of provision of adequate and appropriate sanitation facilities in developing communities has direct and serious effects on the quality of surface and ground water resources and subsequently on human health (DWAF, 2004). Although South Africa has all the legal tools to promote sustainability in the water and sanitation sector, financial considerations are usually the driving force behind technology selection and not social or environmental aspects.

Environmental site assessments are restricted to a first order approach and the only variables investigated are distance from the nearest water supply borehole (rule of thumb of 200 m), soil characteristics and depth to water table. Health impact assessments are not adequately addressed since the general belief is that the vadose zone is sufficient in retaining and absorbing micro-organisms and that the risk posed by nitrates is over estimated (Jackson, 1998). From the cited literature it is however evident that soil and rock are imperfect traps for microbial pathogens released in sewage to the shallow subsurface via leaky sewers, septic tanks or pit latrines. This is evident from both widespread detection of microbial pathogens in groundwater (Goss *et al.*, 1998; Hancock *et al.*, 1998; Abbaszadegan *et al.*, 1999; Macler and Merkle, 2000) and outbreaks of water borne disease that were derived from the consumption of sewage-contaminated water.

The public are presented with few sanitation options, and very limited information on the implications of their choices (Howard *et al.*, 2000). In most instances, it is the site engineer or builder who decides which technical options are feasible, and illustrates them by constructing demo toilets which tend to be variations on the theme of Ventilated Improved Pit (VIP) toilets. Household choices are usually made on the basis of the appearance and affordability of the superstructure, rather than the merits of the underlying sanitation technology.

The cost in addressing diarrhoeal disease in South Africa represents about 20 % of the respective provincial and national health budgets. Furthermore, the total cost of diarrhoea is equivalent to at least 1% of the South African Gross Domestic Product (GDP) (R3.4 billion). A study by Van Ryneveld *et al.* (2001) indicated that additional water treatment costs will amount to R83 million/annum for surface water and R238 million/annum for groundwater within the catchment of the Vaal Barrage, downstream of Vaal Dam due to increased pollution from sanitation

Introduction

systems. Water quality in some river systems has deteriorated to such an extent that conventional purification processes cannot treat the water to acceptable standards (Rota, 2004) thus giving rise to further increases in cost. It has been reported by Hutton and Haller (2004) that the costs and benefits of water and sanitation improvements at the global level showed that all water and sanitation improvements were found to be cost-beneficial. In developing regions the return on a US\$1 investment was in the range of US\$5 to US\$28. The main contributor to benefits was the saving of time associated with better access to water supply and sanitation services and economic benefits of avoiding diarrhoeal disease. Unfortunately, cost benefit analyses are not conducted during the initial planning phases of sanitation implementation and the secondary benefits in choosing the appropriate sanitation system are not assessed.

The current approach in South Africa is re-active and not pro-active. Although the National Water Act (NWA) and National Environmental Management Act (NEMA) give effect to principles such as “best practical environmental option”, “precautionary approach”, and “duty of care” they are not taken in consideration when it comes to sanitation selection and implementation. The general view is that where excessive pollution is evident from sanitation systems, one can abandon the borehole and move the water source to a less polluted area or alternatively treat the water to drinking standards. The problem with these two approaches is that South Africa is already classified as a water-stressed country, having resources that cater for less than 1700 m³/year a person.

1.2 Problem statement

Most of the communities in the more arid parts of our country rely solely on groundwater for potable water supply. Groundwater quality should therefore be protected with an emphasis on prevention as in most cases groundwater pollution is difficult to reverse and remediation is often a lengthy and expensive exercise. Currently on site sanitation systems are installed with limited or no consideration for impacts on the environment. It is also stated in DWAF’s groundwater protocol and literature pertaining to the South African situation, that the impact of on-site sanitation systems is over estimated. There is however no scientific proof available, which may support this statement. The need therefore exists for an impact assessment methodology as well as a decision-making framework, which will aid in technology selection for on site sanitation

systems, based on environmental, economic and social criteria.

1.3 Aim and Objectives

The aim of this research is to develop an environmental impact assessment methodology and decision support framework that will aid in the selection of the most appropriate on site sanitation technology for a given area. Specific objectives of the study include:

1. Review of the literature to form an understanding of the various factors that may influence the selection of a specific sanitation technology. These factors include:
 - a. Status quo situation in South Africa with regard to service provision
 - b. Legislative requirements
 - c. Technology options
 - d. The effect of on-site sanitation disposal on human health and the environment
 - e. Importance of groundwater as a resource
 - f. Social preferences and requirements
 - g. Environmental protection methodologies
2. Assess and review existing decision support frameworks and methodologies
3. Assess the magnitude of the impact of on site sanitation systems on the groundwater system and contributing factors
4. The development of a multiple objective decision support framework (MODSF) for sanitation selection.

1.4 Structure of this document

The document is divided into five main sections:

- The first section (Chapter 2) gives a summary on the literature pertaining to sanitation and water provision in South Africa, factors affecting sustainability, legislative requirements, impacts of on site sanitation disposal on the environment and human health, factors influencing environmental protection and the social aspects with regard to sanitation selection.

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- The second section (Chapter 3) includes the results of a detailed sanitation survey conducted at 274 clinics within the Limpopo Province. The main objective of the survey was to determine the impact of on site sanitation disposal on the groundwater quality and to determine the contributing factors giving rise to pollution.
- The third section (Chapter 4) introduces the decision support framework and impact assessment methodology and discusses each of its components.
- The fourth section (Chapter 5) includes a case study against which the decision support framework was tested.
- In the last section (Chapter 6), conclusions are drawn and recommendations made.



CHAPTER 2

2 LITERATURE REVIEW

2.1 Water supply and sanitation in South Africa

In South Africa, as in most developing countries, rapid urbanisation has outstripped investments of municipal governments in infrastructure and services especially in the residential areas with a predominance of poorer households. The result has been an increase in people living in overcrowded and informal settlements. People in these settlements live in substandard housing with often inadequate water supply, sanitation and other necessities. Population growth creates water shortages not only by adding to the number of consumers, but also by increasing population density beyond the level that nearby water supplies can serve. Enteric infections, particularly due to bacterial and viral pathogens, are readily transmitted under these circumstances (Levine and Levine, 1994).

Prior 1994, it was estimated that 12 million people in rural areas had inadequate access to basic water supply services and that 21 million people did not have access to a basic level of sanitation.

Basic water supply in South Africa is defined as 25 litres per person per day, within 200 meters of the home and of acceptable quality (DWAF, 2003a). Basic sanitation is defined as a ventilated improved pit latrine (VIP) or equivalent. During a situation assessment, conducted by the Palmer Development Group (1995), the following was concluded:

- Approximately 95 % of the 21 million rural and peri-urban residents in South Africa lack properly designed and constructed sanitation facilities.
- About 90% of rural schools (some 5 million pupils), and 50 % of the approximately 1100 rural clinics do not have adequate sanitation facilities.
- Over 50 % of rural people were without a safe and accessible water supply

Addressing the water supply and sanitation backlog was one of the priorities of the government elected in 1994.

Literature Review

The following key targets were set to provide a water supply and sanitation to the poorest of the poor in rural areas and to contribute to poverty eradication (DWAF, 2003a) and include:

- The elimination of the water and sanitation service backlog over a period of 10 years;
- Each individual to have at least 25 litres of water per day within 200 meters of their home;
- Each household to have sanitation in the form of at least a ventilated pit latrine.

The Community Water Supply and Sanitation (CWSS) program was established to achieve the targets. Their mandate was to:

“Ensure, through programme support to all stakeholders including local government, that all South Africans have access to sustainable, effective, equitable and economical water supply and sanitation services.”

During the last few years considerable progress has been made in addressing the levels of under-servicing. Within seven years of the CWSS program, the number of people without access to safe, potable water has been halved. In terms of sanitation, the government has committed to clearing the sanitation backlog within the next ten years (DWAF, 2003 a). The highest priority is given to those communities that face the greatest health risk due to inadequate sanitation.

As of February 2002, 66% of the total population in the country who have access to water infrastructure is benefiting from the “Free Basic Water” policy. Twenty-six million people have currently access to 6000 litres of free water per household per month. This policy was implemented to ensure equitable access to sufficient water, as a social right in terms of the constitution (DWAF 2003a).

The CWSS Programme also provides a household grant for a basic sanitation system. In most cases this results in a bucket system or inadequate pit latrine being replaced with a Ventilated Improved Pit Latrine (VIP) (DWAF 2003a).

2.2 Towards Sustainability

The introduction in 1998 by the Department of Water Affairs and Forestry of the National Water Act (Act 36 of 1998) has contributed to the fundamental reform of legislation relating to the protection, use development, conservation, management and control of the country's water resources. The Act as a whole, gives effect to the Constitutional right of access to water and the environmental right ensuring protection and conservation, thus assisting South Africa to take a further step towards achieving integrated environmental management and a first world environmental management system. Principles relevant to the achievement of sustainable development are given effect in most of South Africa's legislation and policies and include the principles of "polluter pays", "cradle-to-grave", "precautionary approach", "waste avoidance and minimisation" and "best practicable environmental option (BPEO)".

Sustainable development was first described by the Brundtland Commission in 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987).

Since the Brundtland Commission, many alternative definitions of sustainability have been proposed and diverse interpretations of the concept made. Many of these are based upon the "three pillar" or "triple bottom line" (TBL) concept. Whereas the Brundtland Commission presented a two-pillar model reflecting environment and development concerns, the three-pillar TBL model separates development issues into social and economic factors, emphasising that "material gains are not sufficient measures or preserves of human well-being" (Gibson, 2001).

The term "sustainable development" was adopted by the Agenda 21 program of the United Nations. The 1995 World Summit on Social Development further defined this term as "the framework for our efforts to achieve a higher quality of life for all people," in which "economic development, social development and environmental protection are interdependent and mutually reinforcing components". The 2002 World Summit on Sustainable Development expanded this definition identifying the "three overarching objectives of sustainable development" to be (1) eradicating poverty, (2) protecting natural resources, and (3) changing unsustainable production and consumption patterns (Pope *et al.*, 2004).

Some people now consider the term "sustainable development" as too closely linked with continued material development, and prefer to use terms like "sustainability", "sustainable

Literature Review

prosperity" and "sustainable genuine progress" as the umbrella terms. Despite differences, a number of common principles are embedded in most charters or action programs to achieve sustainable development, sustainability or sustainable prosperity. These include (Hargroves and Smith, 2005):

- Dealing cautiously with risk, uncertainty and irreversibility
- Ensuring appropriate valuation, appreciation and restoration of nature
- Integration of environmental, social and economic goals in policies and activities
- Equal opportunity and community participation
- Conservation of biodiversity and ecological integrity
- Ensuring inter-generation equity
- Recognising the global dimension
- A commitment to best practice
- No net loss of human capital or natural capital
- The principles of continuous improvement
- The need for good governance

The provision of sanitation facilities is a complex task and is dependent on many different variables which may influence sustainability and include affordability on the part of both the users and the service providers, willingness of the users to pay for both the capital development and maintenance of systems, technical suitability and capacities for operation and maintenance (O&M).

In the past users were largely excluded from the planning and decision-making process and technical issues (topography, distance to water and existing infrastructure) remained the only consideration. Cultural norms and the perceptions and preferences of the users have seldom been integral to decision making. Failure to successfully integrate all the variables into the planning of sanitation projects and in selecting sanitation technologies provides the background to many failed attempts at sanitation delivery. The World Health Organization (2000) defined a service as being sustainable when:

- It is functioning and being used;

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- It is able to deliver an appropriate level of benefits (quality, quantity, convenience, comfort, continuity, affordability, efficiency, equity, reliability and health);
- It continues over a prolonged period of time;
- Its management is institutionalised (community management, gender perspective, partnership with local authorities);
- Its operation, maintenance and replacement costs are covered at local level;
- It can be operated and maintained at local level with limited but feasible external support (technical assistance, training and monitoring) and
- Does not affect the environment negatively

As described in Figure 1, sustainability with regard to sanitation relies on four interrelated factors: (a) a legal and institutional framework (b) technical factors, (c) environmental factors and (d) community factors.

The technical factors are: technology selection; complexity of technology; its capacity to respond to a demand and a desired service level; its impact on the environment; the technical skills needed to operate and maintain a system; the availability, accessibility and cost involved (World Health Organization, 2000).

The community factors are: availability of technical skills to operate and maintain a service; capacity and willingness to pay, participation of all social groups in the community; the need felt for an improved service; socio-cultural aspects related to water; and behaviour regarding health and sanitation (World Health Organization, 2000). The intersection between the technical circle and the community circle indicates the level of ownership and responsibility of communities towards the service. Ownership and responsibility are key prerequisites for sustainable operation and maintenance.

The environmental factors are: the quality of the water source; its quantity and continuity. The intersection between the environmental circle and the community circle represents the way the community will manage water resources and especially the impact on the environment of community behaviour in terms of sanitation and management of water used. All these factors evolve within a legal and institutional framework. At the national level there must be clear policies and strategies towards sustainable development (World Health Organization, 2000).

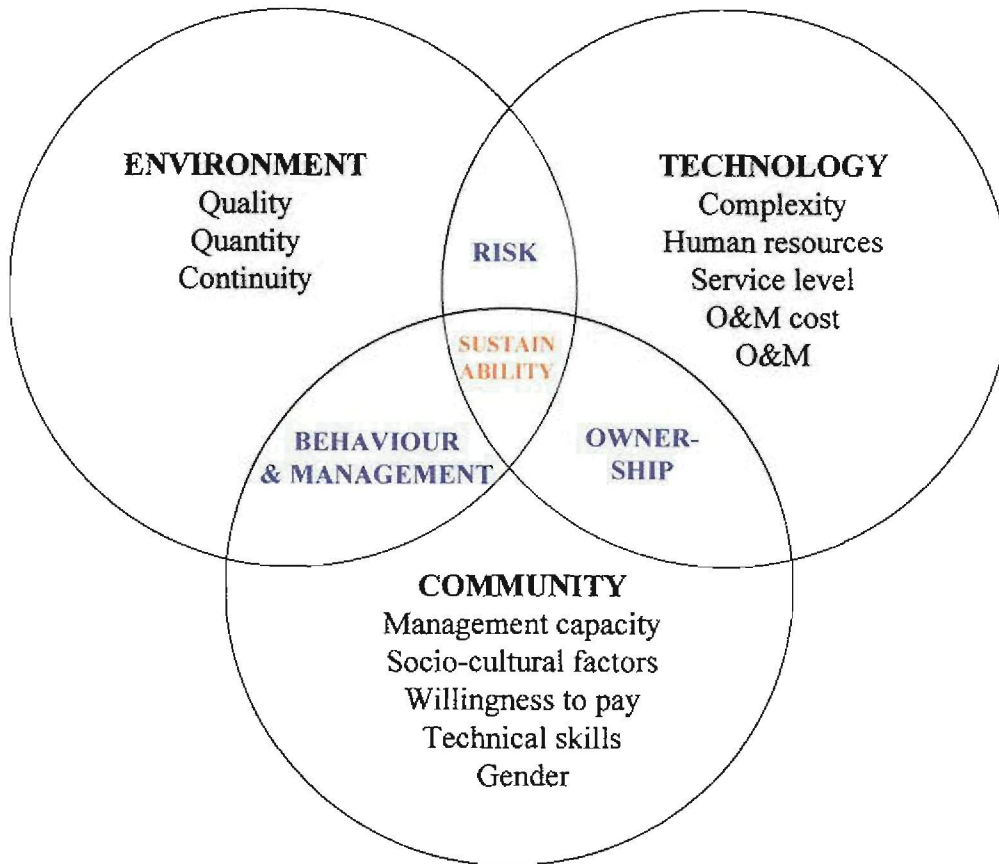


Figure 1: Factors influencing sustainability (World Health Organization, 2000)

2.3 Legal and institutional framework

The Constitution of the Republic of South Africa (Act 108 of 1996) was published in 1996 and assigned the local government the responsibility for providing water and sanitation services to all. The Constitution states that everyone has the right to an environment that is not harmful to his or her well-being with sufficient water and adequate sanitation. It also states that everyone has the right to have the environment protected for the benefit of present and future generations through legislation that prevents pollution and ecological degradation, promotes conservation and secures ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Literature Review

A number of strategic goals and objectives under the overarching goal of sustainable development are outlined in the National Environmental Management Act (NEMA) (Act 107 of 1998) and the National Water Act (NWA) (Act 36 of 1998). In both NEMA and the NWA, these include an effective and co-ordinated institutional framework and legislation, sustainable resource use and impact management; holistic and integrated planning and management; public participation and partnerships in environmental governance; environmental education and empowerment and information management for sustainable development (Glazewski, 2000; Sampson, 2001). In these Acts, sustainable development becomes a legal binding principle. Key legislation with respect to water and sanitation is briefly discussed below:

The National Water Act (Act 36 of 1998) legislates the way in which the water resource is protected, used, developed, managed, conserved and controlled. The NWA focuses on the principles of sustainability and equality. These principles take into account:

- the basic human needs of present and future generations,
- the need to protect water resources,
- the need to share water resources with other countries,
- the need to promote social and economic development through the use of water and
- the need to protect aquatic ecosystems.

The NWA impose a duty on anyone who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent it from occurring, continuing or recurring. In this, the Act requires that the impact of any development be properly assessed and evaluated, and that the transportation of pollutants by water be prevented.

Pollution is defined in the NWA as the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it:

- less fit for any beneficial purpose for which it may reasonably be expected to used or
- harmful or potentially harmful
 - to the welfare, health or safety of human beings
 - to any aquatic or non-aquatic organisms
 - to the resource quality

Literature Review

- to property

The National Water Resource Strategy (NWRS) was developed to provide the implementation framework for the National Water Act (Act 36 of 1998). The NWRS is based on integrated water resource management, taking into account the availability of surface and groundwater, water use, groundwater and surface water quality, and environmental and social considerations. Surface and groundwater are viewed as an integrated whole, as are aspects of water quality and quantity.

A policy and strategy for groundwater quality management in South Africa has been published by the Department of Water Affairs and Forestry (DWAF, 2000) within the general framework of the National Water Resource Strategy. The groundwater strategy provides the framework within which detailed management procedures can be developed and implemented. Principles that guide the implementation of this strategy include self-regulation, pollution prevention, integrated environmental management, equity, sustainability, the polluter pays, and public participation. Groundwater protection is based on a precautionary approach (DWAF, 2000). All groundwater are assumed vulnerable to damage, unless it can be shown otherwise (DWAF, 2000). In terms of damage to aquifers by waste disposal, the Department based its regulatory response upon the importance and vulnerability of the aquifer. The Department therefore placed a general ban on waste disposal and other polluting activities within 200 meters of the recharge zone for major aquifers and sole source aquifers (DWAF, 2000). According to the policy and strategy document, the Department will also seek to promote the development and implementation of cleaner sanitation and waste disposal practices in rapidly developing areas. The use of pit latrines, septic tanks and soakaways will be discouraged in urban, peri-urban and high population density rural settlement situations. It has also been stated that inappropriate land use around wellheads will be discouraged and regulated or prohibited where necessary (DWAF, 2000).

In the light of the fact that sanitation systems are being installed on an ongoing basis and the need for some policy/guidelines with regard to environmental impact of these systems, DWAF has developed a groundwater protocol (DWAF, 2003b). One of the key elements of the groundwater protocol is that it provides a simple basis for distinguishing between instances of higher risk and instances of lower risk of groundwater pollution, and sets out responsibilities and procedures for investigation of each level of risk. While the protocol does not fully resolve the question of whether on-site sanitation can be used in any particular instance, it does give a framework within

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which such decisions can be made (DWAF, 2003b).

The National Environmental Management Act (Act 107 of 1998) regulates co-operative environmental governance by establishing principles for decision-making matters affecting the environment. The preamble to the Act describes the method for the implementation of sustainable development. It also defines the term as meaning the integration of social, economic and environmental factors into planning, implementation and decision making so as to ensure that the development serves present and future generations.

Principles relevant to the achievement of sustainable development are given effect, and include the principles of “polluter pays”, “cradle-to-grave”, “precaution” and “waste avoidance and minimisation”. As with the NWA, the NEMA imposes a duty on everyone who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent it occurring, continuing or recurring. Measures should include:

- investigate, assess and evaluate the impact on the environment;
- cease, modify or control any act, activity or process causing the pollution or degradation of the environment;
- contain or prevent the movement of pollutants or the causing of degradation;
- eliminate any source of the pollution or degradation or;
- remedy the effects of the pollution or degradation.

A national environmental management standard has also been prescribed in the National Environmental Management Act (Act 107 of 1998). This is known as the Best Practicable Environmental Option (BPEO), which is defined as involving a “selection of the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as in the short term”.

The Water Services Act (Act 108 of 1997) makes provision for municipalities to undertake their role as water services authorities and to look after the interest of the consumer. It also clarifies the role of other water services institutions, especially water services providers and water boards. It defines the minimum standard for basic sanitation services as:

“a toilet which is safe, reliable, environmentally sound, easy to keep clean, provides privacy and protection against the weather, well ventilated and prevents the entry and exit of flies and other

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disease-carrying pests.”

The Act also makes provision for the quality of potable water and stipulates that:

“should the comparison of the results as contemplated in sub regulation (3) indicate that the water supplied poses a health risk, the water services institution must inform the Director-General of Department of Water Affairs and Forestry and the head of the relevant Provincial Department of Health and it must take steps to inform its consumers-

- that the quality of the water that is supplied poses a health risk;
- of the reasons for the health risk;
- of any precautions to be taken by the consumers; and
- of the time frame, if any, within which it may be expected that water of a safe quality will be provided.”

A range of municipal legislation has been developed and implemented since 1994. These include amongst other the Local Government Demarcation Act (Act 117 of 1998), and the Municipal Structures Amendment Act (Act 33 of 2000).

The National Health Act (Act 61 of 2003) promotes the protection, improvement and maintenance of the health of the population. One of the objectives of the Act is to protect, respect, promote and to fulfil the rights of the people of South Africa to an environment that is not harmful to their health and well-being.

The White Paper on Basic Household Sanitation (DWAF, 2001) emphasises the provision of a basic level of household sanitation to those areas with greatest need. It focuses on the safe disposal of human waste in conjunction with appropriate health and hygiene practices. It is premised on ten policy principles:

- development should be demand driven and community based
- basic services are a human right
- ‘some for all’ rather than ‘all for some’
- equitable regional allocation of development resources
- water has an economic value
- the user pays

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- integrated development
- environmental integrity
- sanitation is about health
- *sanitation is a social responsibility*

The White Paper prioritises the provision of at least basic sanitation services - which it defines as VIP toilets - to all before embarking on higher levels of servicing, and to approach sanitation as an integrated demand-driven development issue, requiring the active support of a wide range of government departments and, most importantly, of the user communities themselves. The White Paper addressed technology choice explicitly (DWAF, 2001). Commenting on the tendency to regard sanitation choice as the exclusive preserve of engineers, it stressed the need to consider “numerous factors ... in a transparent manner in close contact with prospective consumers”. It suggested a preliminary list of factors that need to be addressed:

- affordability
- institutional requirements
- environmental impact
- social issues
- water supply service levels
- reliability
- upgradability
- physical site-specific issues
- use of local resources
- settlement patterns

2.4 Technology

In South Africa the most commonly used sanitation technologies are waterborne sewerage at one end of the scale and pit toilets at the other. There are some intermediate technologies, such as septic tanks, but it is a fact that everybody aspires to the top of the range article despite implications such as high water usage, high operation and maintenance costs, and the advanced

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technology and institutional capacity required for removal, treatment and disposal of the excreta.

Ventilated improved pit (VIP) toilets have unfortunately also acquired the stigma of being a poor man's solution to the sanitation problem (Austin and Van Vuuren, 2001).

Many community sanitation schemes have been successfully implemented utilising VIP toilets. However, others have been problematic, often due to poor design and construction practices or to social factors such as lack of community buy in, or a combination of these. Sufficient attention is not always given to factors such as environmental impact, social issues, water supply levels, reliability or institutional capacity (Austin and Van Vuuren, 2001). The result has often been a legacy of poorly planned and inadequately maintained systems provided by well-intentioned but short sighted authorities and developers (Austin *et al.*, 2005).

South Africa's Gross National Product (GNP) classifies it as partly developed and partly undeveloped. It is an unequal economy with large discrepancies in wealth between rich and poor. Some of its inhabitants have a high level of service, while others have very little or none at all. The combination of these factors has brought about resistance to the use of onsite sanitation, centred on the following issues (Fourie and Van Reyneveld, 1994):

- A perception that the use of on site sanitation implies second class
- A perception that there is plenty of money in the country for a high level of service
- A disbelief that waterborne sewerage costs as much as it does
- A perception that waterborne sewage is a robust system, whereas it is in fact a fragile system that is sensitive to misuse and use of inappropriate cleansing materials.
- A perception that on site sanitation is unhealthy, that it does not work as well as full waterborne sewerage, and will cause disease and
- Concerns that on-site sanitation may pollute the country's scarce water resources

Winblad (1996a and 1996b) maintains that sanitation approaches based on flush toilets, sewers and central treatment plants cannot solve the sanitation problem. Nor can the problem in high-density urban areas be solved by systems based on various kinds of pit toilets. Selecting the most appropriate technology requires a thorough analysis of all factors including cost, cultural acceptability, simplicity of design and construction, operation and maintenance, and local availability of materials and skills (World Health Organization, 2000). According to Dudley

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(1996), conventional sanitation options may be suited to certain situations, but in other circumstances where both water and space are scarce there is a need for permanent emptiable toilets which do not require water. When limits are placed on other variables, for example money and depth to water table, the circumstances where options such as sewers and pit toilets are viable become fewer, while the need for permanent, emptiable, waterless toilets grow.

Within the South African context, a number of alternative sanitation systems to waterborne sanitation have emerged which, in theory, fulfil accepted health and system norms. The question of what constitutes adequate sanitation has been defined in the White Paper on Basic Household Sanitation (DWA, 2001), as follows:

“The Ventilated Improved Latrine (VIP), if constructed to agreed standards and maintained properly, provides an appropriate and adequate basic level of sanitation service. Adequate basic provision is therefore defined as one well constructed VIP latrine (in various forms, to agreed standards) per household”.

VIP toilets correctly engineered and implemented, are a good means of providing sanitation in areas where financial factors preclude the provision of a higher level of service. These systems are not without their problems, however. Geotechnical conditions, such as hard rocky ground sometimes make the choice of this technology inappropriate. In other cases, non-cohesive soils will require a pit to be fully lined in order to prevent collapse of the structure. Pits should preferably also be avoided in areas with shallow water tables, especially in aquifers with high hydraulic conductivity, where rapid transmission of pollutants is possible (Austin *et al.*, 2005).

Ecological sanitation (ecosan) is established as an accepted technology in many countries. One of the major challenges of the ecosan technology is to find ways of reducing the health risks attached to the handling of faeces. Handling of excreta, especially faeces, also remains a social taboo in some communities. Implementation practices for ecosan projects presently suffer from the same shortcomings as conventional sanitation projects, in that the approaches used, coordination between implementing agencies, skills building, training, hygiene awareness, etc. are not given sufficient attention. The operation and maintenance of urine diversion toilets is a crucial issue, and it is thus essential that proper training programs be provided to ensure project sustainability (Stewart Scott, 1998; Austin *et al.*, 2005).

Technologies for the treatment of water borne sewage in small communities can be grouped in

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the following systems (Joy *et al.*, 2003):

- On site systems: one of many types of technologies in which the waste water is treated and returned to the environment at the location where it is generated (ie without the use of community-wide sewers or centralised treatment). Most commonly a septic system or a single home, but can be a more advanced treatment facility.
- Cluster and Communal Systems: Small systems connecting small neighbourhoods of homes (typically less than 100) using alternative collection systems with a central facility to treat wastewater. Effluent disposal may be subsurface or direct surface discharge after treatment.
- Decentralized systems: An on site cluster system that is used to treat and dispose of relatively small volumes of wastewater, generally from individual or groups of dwellings and businesses that are located relatively close together.

Examples of treatment systems include aerobic treatment units, trickling filters, lagoons and constructed wetlands, activated sludge plants and membrane separation plants. Australian experience has shown that sequencing batch reactors, which are fill and draw type reactor systems involving one or more reactors, can provide one of the best options for small communities compared with the more traditional lagoon and soil filter technologies (Joy *et al.*, 2003).

Operation and maintenance (O&M) are the two words that appeared in the answers of many sector professionals and community workers when they were asked about what could be done to improve the performance, efficiency and sustainability of the rural water supply and sanitation services in developing countries (WHO, 2000). It is well known that O&M has been neglected in the past, or been discussed and introduced only after a project was completed. This neglect or delay in applying proper operation and maintenance has adversely affected the credibility of the investments made, the functioning of the services, the well-being of rural populations, and the development of further projects (Joy *et al.*, 2003).

However, the importance of O&M has gained considerable visibility over the past few years, and it appears that policy-makers and project designers are now more conscious of the direct links between improved O&M procedures and the sustainability of water supply and sanitation services (WHO, 2000). Professionals in the sector has realized that O&M in not just a technical issue, but has social, community, gender, financial, institutional, political, managerial and

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environmental aspects as well. Operation and maintenance must be organized and planned at both national and local levels, and should be managed at the community level with appropriate support from the local authorities and the private sector (WHO, 2000).

Operation and maintenance in South Africa can still be described as crises maintenance and can be defined as maintenance that is undertaken only in response to breakdowns and/public complaints, leading to poor service levels, high O&M costs, faster wear and tear of equipment, and users dissatisfaction. The objective will be to move towards preventative maintenance which can be defined as maintenance activities undertaken in response to pre-scheduled systematic inspection, repair and replacement, leading to continuity in service level, O&M costs spread over time, user satisfaction and willingness to pay.

Linking technology choice with operation and maintenance is a key factor for sustainability; the resulting choice depends on the use of appropriate criteria and the selection process (WHO, 2000).

2.5 Community Factors

The literature is virtually unanimous in stating that the final choice of sanitation technology should lie with the people who will use it and who will be responsible for operating and maintaining it. Comprehensive literature on how planning/implementing agents facilitate this process of decision-making in low-cost sanitation programmes has been written in the last decade (Wood *et al.* 1998; Palerm, 1999a; WHO, 2000, Howard *et al.*, 2000; Pearson *et al.*, 2001; Swartz and Ralo, 2004). The key themes that run through the literature include the importance of facilitating the involvement of all sectors of the community, with particular reference to the poorest households and women, in information generation, prioritisation, planning, organizing and evaluating. Acceptance of improved facilities, changes in behaviour and effective operation and maintenance are not achievable without participation. The methods used in facilitation should empower the users and provide a context for continuous capacity-building.

People do not always have the same perceptions and vision of a problem since they belong to different cultures, and have different priorities in their working or living environments. People have evolved different ways of thinking about waste, which in turn affects behaviour and also affects the way messages about health effects or sensible re-use will be received. Experience has shown that many sanitation projects adopted interventions and technologies that were selected

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with poor assessment of the demand for sanitation. In these instances there was hardly any communication between the future users and the project planners (Dunstan and Associates, 1998; Bility and Onya, 2000). The social, gender, cultural and religious aspects were not taken into sufficient consideration. Table 1 gives a summary on the outcome of studies that were conducted amongst users of different systems within four areas.

Table 1: Responses from users of different sanitation systems within four study areas

Reference	Study area	Sanitation system	Conclusions
(Dunstan, 1998)	Soshanguve TT, an Independent Development Trust development of an informal settlement	On-site, low flush system installed on every stand	<ul style="list-style-type: none"> The system was disliked mainly by women, due to the extra workload it imposes. The main objective to this system was that it did not function properly and that people need to drain the toilets by themselves. The women indicated that their expectations were unfulfilled and that there are no extra benefit in comparison to their former pit latrines. The women also felt that they were excluded in decisions regarding the choice of the sanitation system. The drainage of the toilets was a big problem. The service was privatised and was consequently unaffordable to the community who were not consulted beforehand.
	Ga Mmotla, a peri-urban settlement about 20 km north from Soshanguve in the Eastern District of the North West Province	Unimproved pit latrines	<ul style="list-style-type: none"> Unsafe structures cause fears of falling into the pit, especially by the elderly, disabled and children. Children were therefore discouraged to use the toilet. Children's faeces are not considered harmful. Toilets were characterised by flies and bad smells. Personal hygiene was poor with many cases of skin sores being treated at the local clinic. People preferred electricity as a greater need than improved sanitation.
	Ivory Park, a settlement in Midrand	Variety of on-site systems	<ul style="list-style-type: none"> All systems (one dry and two that used water in the flush systems) were malfunctioning and therefore disliked in varying degrees by the community. The toilets were mostly foul smelling and poorly kept. The tank toilets were not regularly evacuated by the Council. It was also reported that suction tanks were emptied into the river that runs through Ivory Park. The residents expected their toilets to be upgraded to waterborne systems in the near future. The level of payment for services was reportedly poor at only 4%. The prevailing culture of non payment made it impossible to hold realistic discussions on what people would or should be prepared to pay.

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Reference	Study area	Sanitation system	Conclusions
Bility and Onya (2000)	Primary school children in the Northern Province and Western Cape	Pit toilets Flush toilets	<ul style="list-style-type: none"> The sanitation facilities at all schools are in a poor state of repair. The learner to toilet ratio was very high and led to non-functional flush toilets or full pit toilets. As a result learners from both sexes tended to avoid using the toilets, with the males choosing to urinate outside of the toilet. The females tried to only urinate at home or find a far away area of veld or community toilet. Some females also expressed a fear of lack of privacy when using the school toilets. Another common theme across all schools, but more prevalent in the rural areas, is the fear of various reptiles and insects. Snakes, lizards, scorpions, mosquitoes and flies were most commonly depicted in relation to reasons for not using toilets. Smaller learners are afraid of falling into the toilet, and in many cases children fear "pinkie-pinkie", a make-belief creature that allegedly harms children. From the survey the most common health problems included diarrhoea, scabies, nutrition related conditions, vomiting, sores, ring worm, colds/flu and bilharzia.

In three research areas (Soshanguve, Ivory Park and Ga-Mmotla) people were dissatisfied with their sanitation systems. They believe that they have inferior, second rate systems in comparison to those enjoyed by urban people. There was a strong sense of frustration with malfunctioning on-site systems and a feeling that only on-site flush systems would meet the community's needs. The communities reported poor or non-consultation processes at the time of installation of the systems and women felt particularly excluded (Dunstan and Associates, 1998). Children (Northern Province and Western Cape) were generally afraid of using the toilets (insects, snakes and falling into the pit) and lack of privacy was the main concern amongst the female learners. Most of the systems at the schools were in disrepair, non functional and not adequate for the number of learners (Bility and Onya, 2000).

The following principles of best-practice with regard to public participation have been described in the literature:

- Public participation (PP) must take place early in the decision-making process, when alternatives are still open, and ideally from the screening and scoping stages (Palerm, 1999a).

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- Public participation must be inclusive, integrating a wide range of stakeholders and taking particular account of minorities. Palerm (1999a) concluded that stakeholder inclusion does not make planning expensive or inconclusive and increases problem definition and innovation diversity.
- Public participation must be a two-way communication affair where there is a dialogue between the developer and the public oriented to reach consensus (if possible) and where mutual learning takes place (Videira *et al.*, 2003).
- In order for PP to be effective, it must be accompanied by real opportunities of access of information as well as provision of key information (Palerm, 1999b)
- Effective PP should empower stakeholders, i.e. give them a real opportunity to influence the decision-making process (Deelstra *et al.*, 2003)
- EIA processes must be transparent and decisions accountable. Where decision is not justified, trust is lost and decision lose legitimacy (Palerm, 1999b).

The Department of Water Affairs and Forestry has adopted the PHAST (Participatory Health and Sanitation Transformation) methodology recommended by the World Health Organization, in helping communities to improve their environments and to manage their water and sanitation facilities (Wood *et al.*, 1998).

The aim of the PHAST methodology is to provide accessible tools for extension workers to enable community participation in low cost sanitation programmes. The methodology is based on the principle that self-esteem is critical to development of these capabilities (Wood *et al.*, 1998). A range of tools has been developed that are visual, easy to understand and allow for the expression of different responses and concerns. PHAST techniques enable groups and individuals to express, share and analyse the complex and diverse realities of their conditions, to gain confidence to plan and act.

PHAST methodologies have the potential to resolve a number of issues that previously were not appropriately dealt with between planning and delivery (Howard *et al.*, 2000). This can be illustrated by the following example:

In most sanitation projects, three to five demonstration toilets are built before sanitation delivery takes place to demonstrate locally-appropriate technical options. For example, several permutations of a VIP would be built – models with a ‘zinc’ superstructure, block spiral and

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cement blocks; a ‘Phungalutho’; a double pit VIP; and, if local demand and affordability levels warranted it, a septic tank and soakaway as well. The purpose of these demo toilets is to allow householders to physically inspect, cost and assess their options, based on working models. This brings up the question about what process of pre-selection and decision-making led to the construction of those particular technology options. Whose decision was it to exclude other possible options, such as a urine diversion system, an aqua-privy or any one of a range of proprietary systems?

Demonstration toilets are frequently built long before community members (as opposed to a handful of Project Steering Committee members) have the information needed to identify and weigh their options, and short-list a number of locally-appropriate technical options suitable for demonstration. Frequently it is the site engineer or builder who decides which technical options are feasible, and illustrates them by constructing demo toilets. Household choices are usually made on the basis of the appearance and affordability of the superstructure, rather than the merits of the underlying sanitation technology. Householders are presented with few choices, and very limited information on the implications of their choices (Howard *et al.*, 2000).

By contrast, PHAST offers people a number of techniques to explore and appraise their choices. A field report from a Namaqualand case study illustrates the potential of tools known as the sanitation ladder and the modified matrix for decision-making. In particular, PHAST methodologies allow for a range of technical options that are potentially feasible in a given settlement to be explored on the basis of locally credible information – information that residents themselves have provided and endorse (Breslin *et al.*, 1998).

2.6 The environment – health and environmental protection

The most significant impacts with regard to poor sanitation are ground- and surface water pollution, which in turn affects human and aquatic health negatively.

Available global evidence suggests that the two most important ways in which environmental quality has a negative impact on the health of the poor is through water and indoor air pollution. Respiratory infection and diarrhoeal diseases are the two biggest causes of death among the poorest 20 % of the world's countries as ranked by national Gross Domestic Product (GDP) per capita. Every 15 seconds a child dies because of water related diseases. Hundreds of millions of children do not attend school because of ill health, lack of sanitation facilities, or the amount of time they spend fetching water for their communities (Morris, 2004).

The global impact of waterborne disease is reflected by data such as those released by the World Health Organisation (WHO) according to which every year there are 1.7 million deaths related to unsafe water, sanitation and hygiene, mainly through infectious diarrhoea. The vast majority of these deaths are among children under five years of age (Prüss and Havelaar, 2001). An estimated 4 billion cases account for over 82 million Disability Adjusted Life Years (DALY's), representing 5.7 % of the global burden of disease and placing diarrhoeal diseases as the third highest cause of morbidity and sixth highest cause of mortality (Prüss and Havelaar, 2001).

In South Africa, diarrhoeal diseases rank as the fifth most important cause of mortality in the entire population, after HIV/AIDS, homicide/violence, tuberculosis and road traffic accidents (Editorial, 2003). Diarrhoeal diseases account for 10.2 % (10 786) deaths in the under 5-age group (Bradshaw *et al.*, 2002; Bradshaw *et al.*, 2003).

The mortality rate associated with diarrhoeal diseases is relatively low. The mortality rate do, therefore, not reflect the large number of infected individuals who suffer from clinical manifestations that range from mild discomfort to severe illness, with far-reaching socio-economic implications (Pegram *et al.*, 1998).

2.6.1 Waterborne diseases – microbiological aspects

Contaminated drinking water supplies are a major source of waterborne diseases world wide. In the United States, the concept of waterborne diseases was poorly understood until the late 19th century. During the Civil War (1860 – 1865), encamped soldiers often disposed of the waste

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upriver, but drew drinking water from downriver. This practice resulted in widespread dysentery. In fact, dysentery, together with typhoid fever was the leading cause of death among soldiers of all armies until the 20th century (Rusin *et al.*, 2000). In 1890, more than 30 people out of every 100 000 in the United States died of typhoid. By 1907, water filtration was becoming more common in most US cities and in 1914 chlorination was introduced. Because of these new practices, the national typhoid death rate in the United States dropped from 36 to 5 cases per 100 000 people between 1900 and 1928 (Rusin *et al.*, 2000).

The transmission of disease by drinking water was confirmed for the first time in 1876 by John Snow. He associated cholera infections with drinking water derived from a hand pump in Broad Street, London. The pioneering discovery was made possible largely by the easy diagnosis of infected individuals. For many years to come, waterborne diseases were almost exclusively associated with bacterial pathogens (Grabow, 1996). More recently, epidemiological data began to reveal that pathogens other than bacteria, notably viruses, are also transmitted by water. The typical example was the hepatitis A virus (Grabow, 1996).

The possible health outcomes associated with exposure to waterborne pathogens are diverse, ranging from no infection to asymptomatic infection, mild to severe illness or mortality. Some of these organisms are opportunistic pathogens that pose little or no threat to healthy adults, but can cause disease in sensitive populations (Committee Report, 1999).

Typically, investigations of health outcomes associated with waterborne pathogens focus on gastrointestinal illness. However, waterborne pathogens can also cause infections in other organs or systemic illness such as hepatitis, aseptic meningitis, typhoid fever, and respiratory infections. Some of these infections have chronic sequelae that are often overlooked in discussions about waterborne disease (Committee Report, 1999).

Table 2 gives an overview of Feachem's environmental classification of excreta-related diseases (Feachem *et al.*, 1983; Mara 2003). Water borne pathogens are categorized into four main groups of organisms namely viruses, bacteria, protozoa and helminths (Committee Report, 1999).

Most pathogenic waterborne agents of concern are enteric organisms such as Shigella, Norwalk like viruses and Cryptosporidium that infect and multiply in the gastrointestinal tract of humans. These agents are excreted by faeces and are transmitted by the ingestion of faecally contaminated water or food. Faeces from infected individuals may contain as many as 10⁶ PFU (plaque

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forming units) of enteroviruses per gram of faeces and 10^{10} rotaviruses per gram (Tyrrell and Kapikian, 1982).

Table 2: Organisms associated with water borne transmission (Feachem et al., 1983)

Category	Environmental transmission features	Major examples of infection	Environmental transmission focus
I: Non Bacterial feaco-oral disease	Non Latent Low to medium persistence Unable to multiply High infectivity No intermediate host	Viral: Hepatitis A and E, Rotavirus diarrhoea, Norovirus diarrhoea Protozoan: Amoebiasis, Cryptosporidiosis, Giardiasis Helmintic: Enterobiasis, Hymenolepiasis	Personal Domestic Wastewater
II Bacterial Feaco-oral disease	Non latent Medium to high persistence Able to multiply Medium to low infectivity No intermediate host	Campylobacteriosis Cholera Pathogenic E. coli infection Salmonellosis Typhoid Yersiniosis	Personal Domestic Wastewater Crops
III Geohelminthiasis	Latent Very persistent Unable to multiply No intermediate host Very high infectivity	Ascariasis Hookwork infection Strongyloideiasis Trichuriasis	Peri-domestic Wastewater Crops
IV Taeniasis	Latent Persistent Able to multiply Very high infectivity Cow or pig intermediate host	Taeniasis	Peri-domestic Wastewater Fodder crops
V Water based helminthiasis	Latent Persistent Able to multiply High infectivity Intermediate aquatic hosts	Schistosomiasis Clonorchiasis Fasciolopsiasis	Wastewater Fish Aquatic species Aquatic vegetables
VI Excreta related insect-vector disease		Bancroftian filariasis transmitted by Culex quinquefasciatus	Wastewater
VII Excreta related rodent vector disease		Leptospirosis	Wastewater

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The continued occurrence of waterborne disease outbreaks demonstrates that contamination of drinking water with pathogenic bacteria, viruses and parasites still poses a serious health risk when treatment is inadequate. Soil and rock are good but imperfect traps for microbial pathogens released in sewage to the shallow subsurface via leaky sewers, septic tanks or pit latrines. This is evident from both widespread detection of microbial pathogens in groundwater (Goss *et al.*, 1998; Hancock *et al.*, 1998; Abbaszadegan *et al.*, 1999; Macler and Merkle; 2000) and outbreaks of water borne disease that derive from the consumption of sewage-contaminated water.

Although soil does serve as a natural filter that limits microbial transport, its retention capabilities are obviously limited as evidenced by a number of outbreaks discussed below (Newby *et al.*, 2000).

Specific examples include outbreaks of hepatitis A (Bloch *et al.*, 1990; Bowen and McCarthy, 1983; De Serres *et al.*, 1999), Norwalk-like viruses (Barwick *et al.*, 2000; Beller *et al.*, 1997; Häfliger *et al.*, 2000), viral gastroenteritis, cholera, typhoid fever and giardiasis that have all been traced to groundwater contamination.

Approximately 20 – 25 % of the groundwater sources of the United States are contaminated with microbial pathogens, including more than 100 types of viruses (Macler, 1995). Low concentrations of sewage-derived microbial contaminants have been observed in sandstone aquifers underlying the cities of Birmingham and Nottingham in central England (Powell *et al.*, 2003). Depth specific monitoring of sewage-derived microorganisms over a period of 15 months revealed penetrations depths of up to 90 m below surface. Incidence of microbial contamination with depth coincided strongly with heterogeneities in the sandstones (e.g. fissures).

During 1997 – 1998, seventeen outbreaks associated with drinking water have been reported in the United States of which 88.2 % were linked to groundwater. These outbreaks caused an estimated 2038 persons to become ill. Ten of the seventeen outbreaks were of known etiology of which 60 % were caused by parasites and 40 % by bacteria (CDC, 1996).

In a study on the microbial contamination of groundwater sources in New South Wales in Australia, both hepatitis A virus (HAV) and Norwalk virus were detected in boreholes. Hepatitis A virus levels were found to be as high as 60 particles per 100 ml. Importantly, these aquifers did not contain any bacterial faecal indicators, emphasizing the questionable reliability of bacterial indicators in groundwater (Jiwan and Gates, 1998).

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Coxsackieviruses have emerged as an important waterborne enteric pathogen. In a study of viruses in raw sewage and treated effluent in Puerto Rico, 95 % of the enteroviruses detected were coxsackie B5 viruses (Dahling *et al.*, 1989). Other studies have reported that approximately 30 % of isolates from untreated waste water were Coxsackie B2, B4 and B5 viruses, with an estimated concentration of 35.8 to 172.8 cytopathic units per liter (Krikelis *et al.*, 1985). This group of viruses is relatively resistant to conventional treatment processes and has been detected in treated drinking water (Vivier *et al.*, 2004). Coxsackie viruses have been associated with myocarditis, paralytic disease, aseptic meningitis, encephalitis and insulin-dependent diabetes (Wagenknecht *et al.*, 1991).

Giardia cysts and Cryptosporidium oocysts were detected in raw and drinking water supplies used by unserved rural communities in the Groblersdal/Marble Hall and in the Hammanskraal/Moretele areas (Du Preez and Gericke, 1999). The sampling sites included protected boreholes, raw unprotected water and treated water. The findings of this study showed that raw and treated water, at the majority of the sites, were contaminated with cysts and oocysts. Protozoan parasites were detected in all three protected boreholes as well as in treated tap water. No correlation was observed between the incidence of Cryptosporidium/Giardia and indicator organisms (Du Preez and Gericke, 1999).

Untreated water sources, used for drinking purposes by developing communities in South Africa, were analysed for enteric viruses (Grabow, 2004). Borehole samples from Bloemfontein, Fort Hare, Umgeni and Venda were sampled and analysed for indicator organisms and enteric viruses. Fifty to seventy-five percent of samples tested positive for viruses of which enteroviruses were detected most frequently (Grabow, 2004). Risk assessment results indicated risk of infections of between 0.065 and 0.1, which exceeded the risk of one infection per 100 000 consumers per year, proposed by the Environmental Protection Agency (EPA) as an acceptable risk for drinking water.

A study was conducted by Nevondo and Cloete (1999) to determine the quality of drinking water supplies in the Dertig/Lefathlheng village in Hammanskraal. Samples were collected from groundwater, rainwater and river water and analysed for chemical and microbiological constituents. Faecal coliform counts greater than 20 per 100 ml were detected in all the samples, suggesting that the general quality of the water is unacceptable and may result in an increased

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risk of infection to susceptible individuals (Nevondo and Cloete, 1999). Various pathogenic bacteria were also identified from the different water sources. The results of chemical analysis were below the Department of Water Affairs and Forestry's guideline for acceptable drinking water.

In August 2000, South Africa was experiencing one of the worst cholera epidemics in the country's recent history. Initial reports of the cholera outbreak came from the largely rural and impoverished communities on the outskirts of the Ngwelezane Township, near Empangeni. Since August 2000 to February 2002, cholera has infected 113,966 people and claimed 259 lives in KwaZulu Natal (Nevondo and Cloete, 2001). The source of the epidemic was traced to the uMhlatuze River, also in the northern part of the KwaZulu-Natal Province. However, by the end of the year 2000, the northern Kwa Zulu-Natal cholera outbreak had replicated itself in eight of South Africa's nine provinces (Nevondo and Cloete, 2001). With HIV/AIDS at a pandemic scale in South Africa, the added contagion of cholera becomes fatal although it is a curable disease. A doctor at Ngwelezane hospital estimated 40% of the cholera deaths to be AIDS related.

In 1995/96, a *Shigella dysenteriae* type 1 epidemic in KwaZulu Natal, which can also be traced to surface water contamination, resulted in thousands of observed cases with many hundreds of deaths (CDC, 1996).

2.6.2 Waterborne diseases – chemical aspects

The South African Initiative on the World Commission on Dams report listed some 50 eutrophic dams in which nutrients are present in such excess that dissolved oxygen content of the water reduces to the point that living organisms begin to die (Rota, 2004). Water quality in some river systems has deteriorated to such an extent that conventional purification processes cannot treat the water to acceptable standards (Rota, 2004). Impacts of eutrophication, can be summarised as follows (Van Ryneveld *et al.*, 2001):

- Increased cost of water treatment (increased use of chemicals and shorter filter run);
- Formation of trihalomethanes (THMs) (carcinogenic and cannot be removed by conventional drinking water treatment processes);
- Taste and odour problems in drinking water caused by blue-green algae;

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- Extensive anaerobic hypolimnia in lakes with the resultant adverse effects on lake biota such as oxygen-dependent organisms and lake chemistry such as increased concentrations of iron and manganese;
- Aesthetic problems associated with massive growth of algae and aquatic macrophytes or both, and when these decay;
- Interference with the recreational uses of water bodies such as swimming, boating, fishing and waterskiing;
- Skin irritations in swimmers;
- Loss of livestock as a result of algal toxins produced by certain algae;
- Fish deaths in saline lakes due to toxin producing algal blooms;
- Adverse effects on adjacent real estate development.

Excessive nutrients (specifically nitrates) cause problems in themselves in that high nitrates can cause health problems for young infants, especially when contaminated groundwater is used in formula milk. Nitrate can occur naturally in surface and groundwater at a level that does not generally cause health problems. High levels of nitrate in groundwater often result from improper borehole construction, borehole location, overuse of chemical fertilizers, septic systems, or improper disposal of human and animal waste (CDC, 2003). Microbial action in soil or water decomposes wastes containing organic nitrogen first into ammonia, which is then oxidised to nitrite and nitrate. Because nitrite is easily oxidised to nitrate, nitrate is the compound predominantly found in ground- and surface waters. Nitrate toxicity causes methemoglobinemia and infants younger than 4 months of age are at particular risk of nitrate toxicity from contaminated water. Pregnant women may also be more sensitive to the induction of clinical methemoglobinemia by nitrites or nitrates at or near the 30th week of pregnancy (CDC, 2003). It has also been reported that nitrates can pass through the mother's milk and affect babies directly (CDC, 2003). Links between high nitrate levels and gastric cancer, congenital deformities, and headaches have also been reported (Jackson, 1998).

The Centre for Disease Control and Prevention in the USA has recommended that persons who use drinking water that contains nitrate levels > 10 mg/L should have alternative sources of drinking water or appropriate treatment of existing supplies (CDC, 2003).

2.6.3 Environmental Protection

In recent years, a variety of mathematical and numerical models have been used to assess the vulnerability of an aquifer (or water body) to pollution by estimating time of arrival of pollutants percolating through the vadose zone from the ground surface to the water table (Taylor *et al.*, 2004). However, times-of-arrival estimates do not always represent reality. This can result from incorrect assumptions made with regard to the dynamics of pollutant transport and groundwater flow, known and unknown interactions of leachate arising from land-use activities within the unsaturated and saturated zone, as well as the possible presence of “short-cut” phenomena which could significantly accelerate infiltration to groundwater not only in limestone aquifers, but also in sandstone aquifers. In arid areas, the grade of consolidation and fissuring of the soil and the unsaturated zone can further reduce the accuracy of such time-of-arrival estimates (Zoller *et al.*, 2003).

Microbial transport studies in several hydrogeological environments are presented in Table 3. Apart from indicating rapid microbial transport, relative to the average linear velocity of groundwater flow, these studies show that the difference in flow velocities is intensified in fractured or fissured rock compared with alluvial sands and gravels where matrix dominated flow is expected (Taylor *et al.*, 2004).

Table 3: Field observations of rapid microbial transport (Taylor *et al.*, 2004)

Hydro-geological Environment	Evidence of rapid microbial transport
Alluvial sands and gravels	Horizontal transport of poliovirus and PRD-1, MS-2 coliphages (30 – 40 m per day) slightly faster than bromide (22.5 – 30 m per day) over 7.5 m. Horizontal transport of T7 bacteriophage (132 m per day) faster than naphionate dye (63 m per day) over 64.4 m. Horizontal transport of f2 bacteriophages slightly faster (x 1.6 – 1.9) than bromide over 1 – 3 m. Horizontal transport of stained, indigenous bacteria (32 m per day) slightly faster than bromide (25 m per day).
Glacial till (fissured)	Vertical transport of PRD-1 coliphage (7.4 m per day) >10 times faster than chloride (0.7 m per day) over 2 m. Horizontal transport of PRD-1 and MS-2 phage (2.5 – 5 m per day) > 35 times faster than bromide (0.01 – 9.01 m per day) over 4 m.
Chalk (fissured)	Horizontal transport of bacteriophages more rapid (2.4 km per day) than bulk groundwater flow over 366 m.
Granite (fractured)	Horizontal transport of <i>Bacillus stearothermophilis</i> more rapid (1m per day) than bulk groundwater flow over 29 m. Horizontal transport of <i>E coli</i> (90 m per day); 9 times faster than bromide (11 m per day) over 12.5 m.

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The results of field studies is supported by numerical modelling which shows that, as the heterogeneity of porous media increases, microbial (and colloidal) transport can be facilitated to the extent that the arrival of these tracers precedes that of conservative tracers (Rehmann *et al.*, 1999; Sun *et al.*, 2001). In karst and sand aquifers where larger pore sizes reduce the impact of size exclusion, microbial tracers have been observed to move at velocities similar to conservative tracers (Pieper *et al.*, 1997).

An important difference noted between the transport of microbial and conservative tracers is that a very low proportion (often <1%) of the applied microbial tracer is recovered (Pieper *et al.*, 1997). The majority of microbial tracer is trapped by filtration or adsorption, dispersed in the subsurface or inactivated between the source and receptor (Newby *et al.*, 2000). At input concentrations of between 10^6 and 10^{11} particles per gram of faeces excreted by an infected individual (Rusin *et al.*, 2000), <1% still constitutes a significant health risk to consumers. Ingestion of low quantities (< 10^2) of microbial pathogens, particularly enteric viruses, can result in acute disease. This is particularly relevant for low-income countries where the global burden of disease and mortality that result from unsafe water supplies and inadequate sanitation and hygiene are greatest (Ezzati *et al.*, 2002).

Transport of microbes and other contaminants occurs within the pore spaces of a soil or subsurface material and is mainly influenced by the following factors:

- Microbial filtration. One mechanism by which microbial transport is limited is by physical straining or filtration of cells by small pores (Newby *et al.*, 2000). Filtration becomes an important mechanism when the limiting dimension of the microbe is greater than 5 % of the soil particles. Thus, for a sandy soil with particle diameter of 0.05 to 2 mm, filtration will have a relatively small impact on the retention of bacteria of diameter approximately 0.3 – 2 μm . However, if a soil contains a significant portion of silt or clay particles (0.2 – 50 μm), filtration will be a major mechanism of bacterial cell removal (Newby *et al.*, 2000). In contrast, filtration has however little effect on movement of particles less than 50 nm in diameter such as viruses (Figure 2).

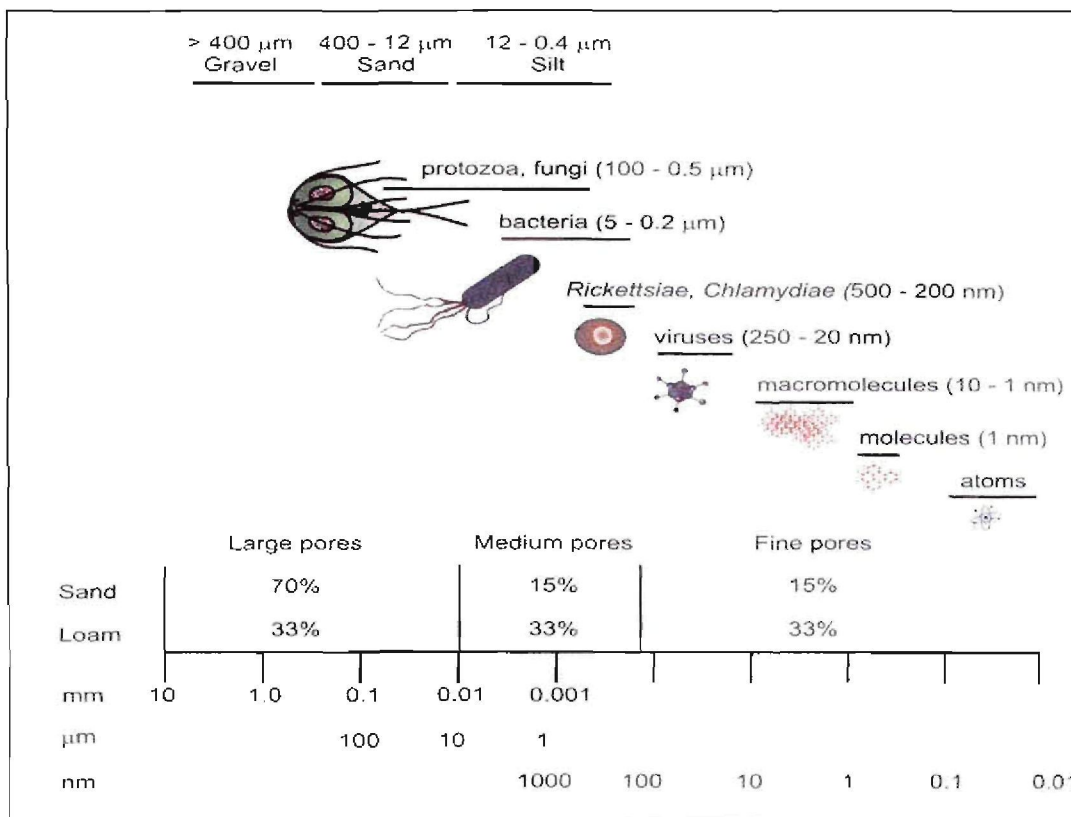


Figure 2: Factors influencing microbial transport (Newby et al., 2000)

- **Physiological state.** The physiological state of microbial cells is one factor that plays a significant role in determining their size. Under starvation conditions, bacteria typically decrease in size to 0.3 μm or even smaller and shed their glycocalyx or capsule layer (Newby et al., 2000). This may increase their transport potential, because both cell size and surface properties are changed.
- **Microbial adhesion.** The key cell surface factors affecting adhesion are charge and hydrophobicity. The adhesion of microbes to soil particles and vadose zone materials requires an initial interaction between the cell and a particle surface and may include diffusion, convective transport, or active movement of the cell. Diffusion is a result of Brownian motion and allows random interactions of cells with surfaces. The effective rate of diffusion is in the order of 40 μm /hr. Convective transport is primarily due to water movement and can be several orders of magnitude faster than diffusive transport. Once contact between a cell and a particulate surface has been made, adhesion

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can take place (Newby *et al.*, 2000). Adhesion is a physiochemical process and is controlled by a balance of: electrostatic interactions, hydrophobic interactions and van der Waals forces.

- Impact of pH and temperature on microbial transport. The survival of sewage-derived microorganisms in groundwater remains poorly resolved, but depends in part, on environmental conditions such as pH and temperature (Yates *et al.*, 1985). The pH of the matrix solution within a porous medium does not seem to have a large effect on microbial transport. However, viral transport can vary greatly depending on the pH of the porous medium solution. Difference in charges on the surfaces of viruses can be expressed in terms of the isoelectric point (pI). The pI is the pH at which the net charge on a particle is zero. For bacteria the pI usually ranges from 2.5 to 3.5, so the majority of cells are negatively charged at neutral pH. The pI of viruses on the other hand range between 3.9 and 8.2, depending on the virus type as well as the particular strain (Yates *et al.*, 1985).

A number of methods have been described in the literature to protect the environment and include well head protection areas (WHPA), source water protection with hazard assessment critical control point analysis, groundwater vulnerability mapping and land use zoning. These methods are discussed in more detail in the following sections.

2.6.3.1 Wellhead protection areas

Strategies to protect groundwater sources from microbial contamination rely upon effective, natural attenuation of sewage-derived micro-organisms by soil and rock over set distances, known as “setback distances” or wellhead protection areas (WHPA), between wells or springs and potential sources of contamination. Wellhead protection areas have been widely adopted in high-income countries (USEPA, 1991; Adams and Foster, 1992) and promoted in middle and low-income countries (Cleary and Cleary, 1991).

The methods by which wellhead protection areas around abstraction wells of setback distances between groundwater sources and potential sources of contamination are delineated, vary from simple analytical methods to deterministic and stochastic numerical models of groundwater flow (USEPA, 1991; Ervers and Lerner, 1998). These methods are based on two fundamental principles:

1. Pathogen survival in groundwater is known and

2. Micro-organisms are transported at the average linear velocity of groundwater flow.

However, Taylor *et al.* (2004), stated that these assumptions are both invalid since the knowledge on survival of pathogenic microorganisms and standard indicator bacteria in the subsurface are limited (Taylor *et al.*, 2004). Survival times of 30 to 50 days have been presumed for microbial pathogens and incorporated in protection strategies (Gosselin *et al.*, 1997; Adams and Foster, 1992). These survival times are based on pathogenic bacteria such as *E coli* and are unrepresentative of viruses, which have a greater survival rate and lower infective doses (Taylor *et al.*, 2004). Uncertainty in pathogen survival in the subsurface has a significant impact on the size of WHPAs and setback distances. For example, applications of viral decay constants of 0.29 and 0.1 day⁻¹ for groundwater temperatures of 15 and 10°C respectively, result in estimated setback distances in alluvial sand and gravel aquifers of between 80 and 325 m (Robertson and Edberg, 1997).

The second assumption is unsupported by the bulk of evidence from studies of contaminant transport using microbial tracers and surveys of microbial groundwater quality. Rapid transport of microbial tracers in groundwater (faster than average linear velocity of groundwater flow) is observed in a wide range of hydrogeological environments (Table 3). The wide detection of sewage derived pathogens at depth in groundwater suggests aquifer penetration rates by microorganisms that are in the order of days to weeks rather than years that would be expected for bulk of recharging waters (Taylor *et al.*, 2004).

2.6.3.2 Source water protection

The World Health Organisation (WHO) is concerned about the shortcomings of conventional indicator organism tests for the end-point analysis of treated drinking water supplies to the extent that a new strategy for water quality control is recommended. Conventional indicator tests do not only have shortcomings for viruses, but also for other pathogens, notably protozoan parasites. The WHO therefore recommended that end-point analyses of treated drinking water supplies be abandoned and replaced by a strategy for water quality control based on the principles of HACCP (Hazard Assessment and Critical Control Points) (Havelaar, 1994; WHO, 1997). This approach is strongly recommended by the WHO. A number of countries, including Australia, are making sound progress on the introduction of HACCP strategies in the policies for water quality control

and safety.

Source water protection is founded on the “precautionary principle”. Prevention is an essential feature of effective drinking water quality management. Preventive strategies are those actions and activities that are required to eliminate hazards or reduce their impacts to acceptable levels and are based on best practise management. Ensuring the safety of a water supply entails a wide-range program of protection, treatment and monitoring with barriers to the entry and transmission of contaminants (particularly microorganisms) (Rob *et al.*, 2005). Catchment management and source water protection provides the first barrier for the protection of water quality. Best practise management of land use and water resources in catchments is essential to a safe water supply (Edzwald and Kelley, 1998). Whether water is drawn from surface catchments or underground sources, it is important that the characteristics of the local catchment or aquifer be understood and the activities that could lead to water pollution be identified and managed (Rob *et al.*, 2005).

2.6.3.3 Groundwater vulnerability mapping

Groundwater vulnerability maps are designed to show areas of greatest potential for ground-water contamination on the basis of hydrogeological and anthropogenic (human) factors. The maps are developed by using computer mapping hardware and software called a geographic information system (GIS) to combine data layers such as land use, soils, and depth to groundwater. Usually groundwater vulnerability is determined by assigning point ratings to the individual data layers and then adding the point ratings together when those layers are combined into a vulnerability map. Probably the most widely used groundwater vulnerability mapping method is DRASTIC, named for the seven factors considered in the method: Depth to groundwater, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media and Hydraulic Conductivity of the aquifer (Aller *et al.*, 1985).

The DRASTIC model was originally developed as an easy-to-use tool for aquifer vulnerability assessment encompassing diverse hydrogeologic settings based on vulnerability index. The DRASTIC vulnerability index is useful at a regional scale, to prioritise areas into high, moderate and low vulnerability regions, which would be followed up by detailed field investigations. The model is rigid in the assignment of ratings and weights to the model parameters. However, for better addressing of local issues for refined representation of local hydrogeological settings, researchers envisaged several modifications of the original DRASTIC model. The modifications

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were in the form of using additional parameters, removal of certain parameters and usage of different ratings and weights for the parameters (Piscopo 2001; Al-Adamat *et al.* 2003; Thirumalaivasan *et al.* 2003).

2.6.4 Economic Factors

The installation of sanitation systems in South Africa is mainly influenced and driven by economical factors rather than environmental, social or health considerations. The most cost-effective sanitation systems are being installed in rural areas without considerations for the Best Practicable Environmental Options, as specified in the NEMA, NWA and Groundwater Policy. There is also no consideration of secondary costs resulting from poor or inadequate sanitation technology. These may include costs associated with loss of a resource (groundwater), water treatment costs, medical costs of treatment of an epidemic (eg. cholera), and losses in agricultural exports.

For example, in Peru, more than 1000 people died from cholera and losses in agricultural exports and tourism revenues were estimated at close to US\$1 billion. In 1991, polluted water from Amman's poor sewerage works and industrial effluents severely damaged 6000 hectares of land downriver used for irrigating vegetable crops. In Columbia, cleaning up the Bogota River would cost an estimated US\$1.4 billion. In Shanghai, the cost of moving intakes upstream, because of pollution, is US\$300 million, while in Lima, upstream pollution has increased treatment costs by 30 percent (World Bank, 1996).

A study was conducted by Pegram *et al.* (1998) to determine the cost of diarrhoea and epidemic dysentery in KwaZulu Natal and South Africa. They used the cost of illness (COI) approach. This approach is based on the estimation of the direct and indirect costs associated with illness, which need resources to be redirected away from other beneficial uses (Pegram *et al.*, 1998). Direct costs may include the costs of medical resources used in treatment of the disease, including costs of self-treatment and government expenditure; transport to health services and household costs to accommodate the needs of the affected person. Indirect costs may include loss of economic opportunities caused by illness or death, due to reduced productivity of the family care providers both in the long and short term. Social costs include both short- and long term quality of life reductions associated with the pain and suffering from illness or death caused by the disease (Pegram *et al.*, 1998). Estimates of the costs associated with the short-term

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impacts on lost productivity, direct health care costs and transport associated with health-care are presented in Table 4. The results indicate that the direct health costs of diarrhoea have the most significant impact on the estimated costs – accounting to approximately 90 % of the total estimated cost (Pegram *et al.*, 1998). This cost represents about 20 % of the respective provincial and national health budgets. The study concluded that up to 15 % of the South African health budget may be spent on addressing diarrhoeal disease. Furthermore, the total cost of diarrhoea is equivalent to at least 1 % of the South African GDP (R3.4 billion). Estimates of the costs associated with the short-term impacts on lost productivity, direct health care costs and transport associated with health care are presented in Table 4.

Table 4: Summary of diarrhoeal costs in Kwazulu –Natal and South Africa (Pegram *et al.*, 1998)

	South Africa	Kwazulu - Natal	
	Diarrhoea	Diarrhoea	SD1 Dysentery
Productivity cost (R m./yr)	325	75	6
Health costs (R m./yr)	3 000	700	112
Transport costs (R m./yr)	40	8	2
Total costs (R m./yr)	3375	785	120
Average Household cost (R/yr)	380	430	67

There is a need to translate the environmental impact of sanitation systems (and on-site sanitation in particular) into financial terms so as to enable a comparison of these systems, which includes not only the cost of the construction, operation and maintenance of the systems, but also the costs of their respective environmental and health impacts. Van Ryneveld *et al* (2001) have developed a methodology to assign a financial cost to pollution from sanitation systems with particular reference to Gauteng. The study indicated that additional treatment costs will amount to R83 million/annum for surface water and R238 million/annum for groundwater within the catchment of the Vaal Barrage, downstream of Vaal Dam due to increased pollution from sanitation systems (Van Ryneveld *et al.*, 2001).

A study conducted by Hutton and Haller (2004) on the costs and benefits of water and sanitation improvements at the global level showed that all water and sanitation improvements were found to be cost-beneficial. In developing regions the return on a US\$1 investment was in the range of

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US\$5 to US\$28. The main contributor to benefits was the saving of time associated with better access to water supply and sanitation services and economic benefits of avoiding diarrhoeal disease (Table 5).

Table 5: Economic benefits arising from water and sanitation improvements

Beneficiary	Direct economic benefits of avoiding diarrhoeal disease	Indirect economic benefits related to health improvements	Non-health benefits related to water and sanitation improvement
Health sector	Less expenditure on treatment of diarrhoeal disease	Value of less health workers falling sick with diarrhoea	More efficient management of water resources and effects on vector bionomics.
Patients	Less expenditure on treatment of diarrhoeal disease and less related costs Less expenditure on transport seeking treatment Less time lost due to treatment seeking	Value of avoided days lost at work or school Value of avoided time lost of parent/ caretaker of sick children Value of loss of death avoided	More efficiently managed water resources and effects on vector bionomics.
Consumers			Time savings related to water collection or accessing sanitary facilities. Labour-saving devices in household. Switch away from more expensive water sources. Property value rise. Leisure activities and non-use value.
Agriculture and industrial sectors	Less expenditure on treatment of employees with diarrhoeal disease	Less impact on productivity of ill health workers	Benefits to agriculture and industry of improved water supply, more efficient management of water resources-time saving or income generating technologies and land use changes.

2.7 Towards sustainability – integrating the environment, technology, social aspects and the economy

The previous section dealt with the individual components that influence sustainability with specific reference to the legal framework, technology choices, environmental considerations and economical aspects. In order for sanitation delivery in South Africa to be sustainable, all these aspects need to be integrated and evaluated holistically.

The aim of integrated assessment is articulated by Post *et al.*, (1997) as:

“It aspires to describe – from the perspective of an identified problem or proposed project – the relations between the human communities concerned, their economic organization and their actual resource base. It qualifies, quantifies, and as far as possible, values the effect of proposed and alternative interventions on the three (economic, social and natural) subsystems and their intersystem relations. It attempts to identify beneficial interventions and to fully expose unavoidable trade-offs.”

The integration of environmental, social and economic considerations is an example of what Scrase and Sheate (2003) call integration among assessment tools. As with sustainability, the term “integration” can be interpreted in different ways. Scrase and Sheate (2003) define 14 meanings of the term “integration”, with at least three being directly related to the concerns of impact assessment.

If the respective assessment processes (environmental, social and economic impacts) are not integrated effectively, then this form of “integrated” assessment is reduced to three separate impact assessments, each generating data relating to the potential environmental, social and economic impacts of the proposal or initiative. The three sets of data must then be “integrated” in some way after it has been collected in order to reach a decision as to whether or not the initiative is acceptable within a sustainability context.

This raises a substantive limitation, which is related to trade-offs between the different (social, environment and cost) categories. Fuller (2002) summarises these concerns by suggesting that “where trade-offs between the economy and the environment are seen as legitimate in the pursuit of sustainability, sustainability assessment could be regarded as a means for economic requirements to override those of the environment or the social context” as is currently the practice in South Africa with regard to sanitation provision. In most instances, the emphasis is

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on addressing economic priorities first and then compensating the losers and repairing the environment (Mahoney and Potter, 2004).

A tension that remains unresolved in the Triple Bottom Line (TBL) approach, is the integration between and across the three dimensions i.e. environment, social and economy. Mahoney and Potter (2004) proposed the use of Health Impact Assessments (HIA) to unite the elements of the TBL approach, through a common focus on health, providing a cross-cutting connection or link. With the environmental dimension, HIA can provide a specific mechanism through the application of standard impact assessment tools for identifying impacts on the environment, and in particular, on human health. With the social dimension, HIA can provide a mechanism for determining the impacts of policies on people's health and well being (Mahoney and Potter, 2004).

George (2001) suggested that an objective-based approach is more likely to result in (win-win) outcomes between the three pillars of sustainability, and is therefore less likely to generate conflicts and trade-offs. This would require agreement on a broad set of objectives reflecting the needs of all stakeholders at the commencement of the process. An example of objective-led integrated assessment is the UK Department of the Environment, Transport and Regions (DETR) process requiring that regional plans be subject to "sustainable appraisal" defined as:

"...a systematic and iterative process undertaken during the preparation of a plan or strategy, which identifies and reports on the extent to which the implementation of the plan or strategy could achieve the environmental, economic and social objectives".

The authors pointed out that most applications of integrated assessment processes in practice, even objective-led processes attempt to define sustainability in terms of TBL objectives and therefore tend to limit themselves to measuring whether or not a proposal represents a positive or negative contribution to sustainability.

It was argued by Pope *et al.*, (2004) that EIA-driven integrated assessment methods tends to focus on minimizing negative impacts and reducing unsustainable practices, but fails to address the concept of sustainability as a societal goal. Objective-led integrated assessment was found to be far more compatible with the concept of sustainability, since it assesses the contribution of a proposal to objectives, rather than against baseline conditions. They proposed the process of assessment for sustainability, which requires a clear definition of sustainability and

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corresponding criteria against which the assessment can be conducted. The process is based on a principle-based criteria for sustainability that avoid the problems of the TBL approach (Pope *et al.*, 2004). In order to provide an example of principle-based criteria, Table 6 presents the sustainability principles that have been developed for Western Australia and the criteria for sustainability assessment that have been derived from these principles (Pope *et al.*, 2004). The criteria listed is however very generic and insufficiently defined to form the basis of an assessment for sustainability process. The next step in the process of defining criteria for the purposes of assessment would be to operationalize the criteria in Table 6 specifically for the assessment at hand.

Table 6: Western Australian sustainability principles and criteria (Pope *et al.*, 2004)

Principles	Criteria
Long-term economic health. Sustainability recognize the needs of current and future generations for long-term economic health, innovation, diversity and productivity of the earth.	Provides both short and long-term economic gain.
Equity and human rights. Sustainability recognizes that an environment needs to be created where all people can express their full potential and lead productive lives and that significant gaps in sufficiency, safety and opportunity endanger the earth.	Increases access, equity and human rights in the provision of material security and effective choices.
Biodiversity and ecological integrity. Sustainability recognizes that all life has intrinsic value and its interconnected and that biodiversity and ecological integrity are part of the irreplaceable life support systems on which the earth depends.	Improves biodiversity and ecological integrity and builds life support systems.
Settlement efficiency and quality of life. Sustainability recognizes that settlements need to reduce their ecological footprint (i.e less material and energy demands and reduction in waste) while they simultaneously improve their quality of life (health, housing, employment, community).	Reduces ecological footprint while improving quality of life.
Community, regions, "sense of place" and heritage. Sustainability recognizes the significance and diversity of community and regions for the management of the earth, and the critical importance of "sense of place" and heritage in any plans for the future.	Build up community and regions, "sense of place" and heritage protection.
Net benefit from development. Sustainability means that all development, and particularly development involving extraction of non-renewable resources, should strive to provide net environmental, social and economic benefit to future generations.	Provides conservation benefits and net social-economic benefit.
Common good from planning. Sustainability recognizes that planning for the common good requires equitable distribution of public resources (like air, water and open space) so that ecosystem functions are maintained and a shared resource is available to all.	Increase common good resources.
Precaution. Sustainability requires caution, avoiding poorly understood risks of serious or irreversible damage to environmental, economic or social capital, designing	Ensures there are acceptable levels of risk with adaptation process for the worst-case scenarios.

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Principles	Criteria
for surprise and managing adaptation.	
Hope, vision, symbolic and iterative change. Sustainability recognizes that applying these principles as part of a broad strategic vision for the earth, can generate hope in the future, and thus it will involve symbolic change that is part of many successive steps over generations.	Brings change and a sense of hope for the future as it is linked to a broader strategic vision.

2.8 Sanitation Decision Support Systems

In the last few decades, mathematical/statistical models, numerical algorithms and computer simulations have been used as the appropriate means to gain insight into environmental management problems and provide useful information to decision-makers. Most of these efforts were however focused on problems that could be assigned to the first level of complexity. Consequently, many complex environmental problems have not been effectively addressed by the scientific community (Poch *et al.*, 2004). Environmental decision support systems (EDSS) have been developed to deal with more complex systems. The range of environmental problems to which EDSS have been applied is wide and varied, ranging from water management to aspects or risk assessment (Poch *et al.*, 2004).

These systems are built by integrating several artificial intelligence methods, geographical information system components, mathematical or statistical techniques, and environmental ontologies (Figure 3). How a particular EDSS is constructed will vary depending on the type of environmental problem and the type of information and knowledge that can be acquired (Poch *et al.*, 2004). Artificial Intelligence seeks to develop systems that attempt to mimic human intelligence without claiming an understanding of the underlying processes. The common advantage of these methods is that they are tolerant of imprecision, ambiguity, uncertainty and partial truth. Artificial Intelligence is a general term covering a number of methods such as evolutionary algorithms (EA), genetic programming, artificial neural networks, cellular automata (CA) and fuzzy systems (Malczewski, 2004). The use of AI tools and models provide direct access to expertise and their flexibility makes them capable of supporting learning and decision-making processes. This confers EDSSs the ability to deal with complex problems, in which the experience of experts provides valuable help for finding a solution to the problem (Poch *et al.*, 2004).

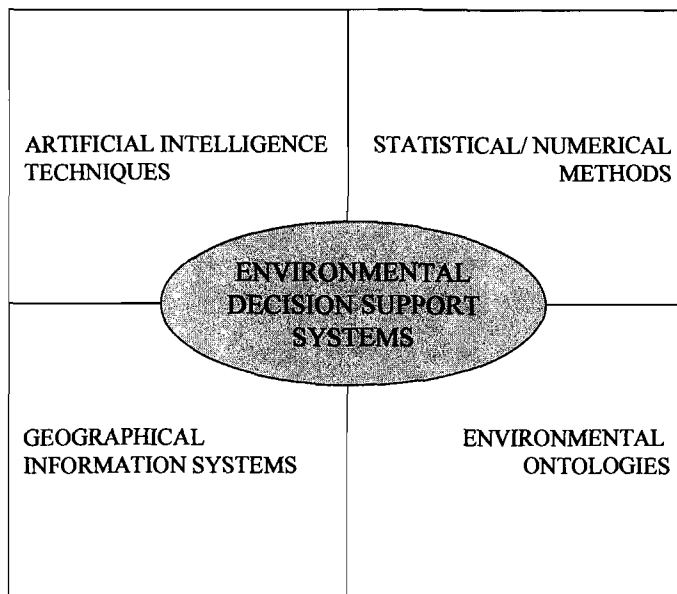


Figure 3: EDSS conceptual components (Poch et al., 2004)

There are two broad approaches to decision-making in the water and sanitation (WATSAN) sector outlined in the available literature: structured decision-making, and collaborative decision-making, using community-based methods. Structured decision making falls broadly into two information formats, which are often used in combination i.e tables and algorithms (Howard *et al.*, 2000).

Tables summarize the attributes and requirements of the various sanitation technical options. Decision-makers start with a particular technology, and work backwards to see which is appropriate for a given site. Potential options are initially excluded on the basis of technical reasons. Social factors are then considered on the basis of consultation with the community. The information gathered would result in the exclusion of some of the remaining options, and finally cost considerations would narrow down the field to the choices available.

With algorithms, questions are outlined in a flow-chart, generally characterized by yes/no options. Responses lead to a recommendation for a particular technology. This recommendation is then assessed in the light of other variables not accommodated by the algorithm. Algorithms that have been developed for sanitation selection are detailed in Table 7 and include the Sanitation Expert System (SANEX) and the Site Sanitation Planning and Reporting Aid (SSPRA).

Table 7: Advantages and disadvantages of sanitation technology selection

	Environmental considerations	Public Participation	Technology Selection	Financial consideration	Integration with water supply planning	Address site specific mitigation measures	Address high income group	Make provision for water-borne sanitation	Addresses Health Impacts
SANEX	*	*	***						
SSPRA	**	**	**	*	*			*	*

***Aspect covered in detail

** Aspect covered, but not in detail

* Aspect not explicitly stated, but could be interpreted to include

SANEX– the Sanitation Expert System is a decision support system for evaluating sanitation projects, aimed at ‘the special circumstances present in developing countries’. The software was developed by Thomas Loetscher, a chemical engineer based at the University of Queensland in Australia (Loetscher and Keller, 2002). Sanitation technology selection is approached in two sequential stages in the software:

- A screening stage during which questions relating to the community are asked (e.g. location, community profile, demographics and pollution control activities.); and
- A comparison stage during which questions relating to operation, costing and construction are asked.

From a software point of view, SANEX is well laid out, clearly presented with structured logic, easy to use and with a range of supplementary information tools. The software algorithm applies over 40 evaluation criteria (technical, socio-cultural and financial) to approximately 80 sanitation alternatives, which range from simple latrines to conventional off-site treatment.

The SANEX model also has a number of limitations. Sanitation is regarded as an issue of infrastructure provision, rather than a complex amalgam of attitudes, awareness, behaviour and amenities, in which personal hygiene behaviours, rather than latrine types, are key. Environmental and health aspects are not addressed adequately; the software focuses mainly on low cost on-site systems with no consideration for water availability and planning. Off-site systems are only addressed partially.

Loetscher’s definition of ‘sustainability’ as ‘the likelihood that a project will provide satisfactory service during its design life’, reduces good sanitation to a function of technology, and fails to address the range of human variables that underpin or undermine its value or effectiveness. A

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facility may be technologically robust and well suited to the physical circumstances of a given environment; however, if users do not like the technology and do not use it, or do not use it in the way it was designed to be used, any other formulations of sustainability are irrelevant.

The Site Sanitation Planning and Reporting Aid (SSPRA), developed by Howard *et al.*, (2000) assess socio-economic, environmental, technical, financial, and political factors in the sanitation technology selection process. The SSPRA takes the user through a logical series of steps each of which depends on the completion of the step before the user is guided to a decision at the end of the process. The main limitations to the program include the following:

- Technology selection is limited to VIPs, LOFLOS, Septic tank Systems and Full Waterborne Systems. No alternatives are provided in the decision-making tool.
- Environmental Assessment are only addressed partially.
- The willingness of residents to contribute to Operation and Maintenance (in the Operation and Maintenance Index) is only calculated in terms of a financial contribution.
- Criteria (environment, cost etc) are evaluated separately with no integration of the TBL components.
- The environmental assessment focuses only on groundwater and not surface water.

2.9 Summary

Although South Africa has all the legal tools to promote sustainable development, financial considerations are usually the driving force behind technology selection and not social or environmental aspects. The public are presented with few sanitation options, and very limited information on the implications of their choices (Howard *et al.*, 2000). In most instances, it is the site engineer or builder who decides which technical options are feasible, and illustrates them by constructing demo toilets which tend to be variations on the theme of VIPs. Household choices are usually made on the basis of the appearance and affordability of the superstructure, rather than the merits of the underlying sanitation technology.

Environmental site assessments are restricted to a first order approach and the only variables investigated are distance from the nearest water supply borehole (rule of thumb of 200 m), soil characteristics and depth to water table. Health impact assessments are not adequately addressed

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since the general belief is that the vadose zone is sufficient in retaining and absorbing micro-organisms and that the risk posed by nitrates is over estimated (Jackson *et al.*, 1998). From the cited literature it is however evident that soil and rock are imperfect traps for microbial pathogens released in sewage to the shallow subsurface via leaky sewers, septic tanks or pit latrines. This is evident from both widespread detection of microbial pathogens in groundwater (Goss *et al.*, 1998; Hancock *et al.*, 1998; Abbaszadegan *et al.*, 1999; Macler and Merkle, 1999) and outbreaks of water borne disease that were derived from the consumption of sewage-contaminated water. The cost in addressing diarrhoeal disease in South Africa represents about 20 % of the respective provincial and national health budgets. Furthermore, the total cost of diarrhoea is equivalent to at least 1% of the South African GDP (R3.4 billion). A study by Van Ryneveld *et al.* (2001) indicated that additional water treatment costs will amount to R83 million/annum for surface water and R238 million/annum for groundwater within the catchment of the Vaal Barrage, downstream of Vaal Dam due to increased pollution from sanitation systems. Water quality in some river systems has deteriorated to such an extent that conventional purification processes cannot treat the water to acceptable standards (Rota, 2004) thus giving rise to further increases in cost. It has been reported by Hutton and Haller (2004) that the costs and benefits of water and sanitation improvements at the global level showed that all water and sanitation improvements were found to be cost-beneficial. The main contributor to benefits was the saving of time associated with better access to water supply and sanitation services and economic benefits of avoiding diarrhoeal disease. Unfortunately, cost benefit analyses are not conducted during the initial planning phases of sanitation implementation and the secondary benefits in choosing the appropriate sanitation system not assessed.

The current approach in South Africa is re-active and not pro-active. Although the NWA and NEMA give effect to principles such as “best practical environmental option”, “precautionary approach”, and “duty of care” they are not taken in consideration when it comes to sanitation selection and implementation. The general view is that where excessive pollution is evident from sanitation systems, one can abandon the borehole and move the water source to a less polluted area or alternatively treat the water to drinking standards. The problem with these two approaches is that South Africa is already classified as a water-stressed country. Furthermore, monitoring of community water supply boreholes in South Africa is limited and relies on the detection of indicator organisms. From the literature it is evident that the conventional indicator

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organisms have major shortcomings when it comes to the detection of viruses. Viruses are also reportedly more resistant to conventional treatment and have been detected in treated drinking water at concentrations that exceeded acceptable risks.

The question remains how can this resource be protected for future generations and what methodologies can be followed to reach the ultimate goal of sustainability? A number of methods have been described in the literature to protect the environment and include delineation of well head protection areas (WHPA), implementation of source water protection zones with hazard assessment critical control point analysis, groundwater vulnerability mapping, land use zoning and environmental decision support systems. Of these methods, environmental decision support systems proved the most promising since they are tolerant of imprecision, ambiguity, uncertainty and partial truth.

Sustainability can only be achieved when the three pillars of sustainability (social, economy and environment) are truly integrated. If the respective assessment processes (environmental, social and economic impacts) are not integrated effectively, then this form of “integrated” assessment is reduced to three separate impact assessments, each generating data relating to the potential environmental, social and economic impacts of the proposal or initiative. The three sets of data must then be “integrated” in some way after it has been collected in order to reach a decision as to whether or not the initiative is acceptable within a sustainability context. This raises a substantive limitation, which is related to trade-offs between the TBL categories. Methodologies that have been suggested to integrate the three dimensions include health risk assessments, objective-based assessments or assessment for sustainability, which requires a clear definition of sustainability and corresponding criteria against which the assessment can be conducted.

CHAPTER 3

3 ON SITE SANITATION: ARE WE EXAGGERATING THE IMPACTS?

“When the well is dry, we know the value of water”, Benjamin Franklin, 1753

3.1 Introduction

For large parts of South Africa on-site sanitation remains the only viable option. Not all such practices lead to groundwater pollution, but in the wrong hydrogeological and environmental conditions, the effect on groundwater quality can be significant (Tredoux, 2004). On site sanitation is generally a cost-effective approach and any pollution management strategy has to contend with realistic on-site sanitation options. The impacts of low impact point sources are often overlooked. However, where many of these point sources occur, their cumulative impact may be significant.

Nitrate pollution of groundwater from sanitation systems has tended to be overlooked or downplayed in many of the policies and strategies relating both to water supply and sanitation and to water quality management in South Africa (Tredoux, 2004). Doubts have been expressed about the true severity of the nitrate impacts from this source, but little data have been collected to prove the opposite. In the short term health impacts from pathogens, are a far more pressing issue and most recommended mitigation measures revolve around providing sufficient separation between sanitation systems and water supply points to ensure that bacterial contamination cannot migrate to the point of groundwater abstraction (Tredoux, 2004). As evidenced by the cited literature in Chapter 2, soil and rock are good but imperfect traps for microbial pathogens released in sewage to the shallow subsurface. This is evident from both widespread detection of microbial pathogens in groundwater (Goss *et al.*, 1998; Hancock *et al.*, 1998; Abbaszadegan *et al.*, 1999; Macler and Merkle; 1999) and outbreaks of water borne disease that derive from the consumption of sewage-contaminated water (Bloch *et al.*, 1990; Bowen and McCarthy, 1983; De Serres *et al.*, 1999, Barwick *et al.*, 2000; Beller *et al.*, 1997; Häfliger *et al.*, 2000).

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The role of water in transmitting microbial illness to humans has frequently been overlooked compared with other transmission paths. An outbreak of cryptosporidiosis in Milwaukee in 1993 where 50 % of the population were infected cost US\$25 billion US, (NRC, 1999) leading regulatory authorities and large water treatment plants around the world to carefully consider waterborne pathogenic organisms.

Microbial quality is almost exclusively determined by the presence/absence of total coliforms, faecal coliforms and/or *E coli* despite the fact that most pathogenic microbes have much greater resistance to disinfectants or can more easily contaminate and survive in groundwater (viruses). Vivier *et al* (2004) reported virus detection in 24 % of treated water samples, which meet all specifications for treatment disinfection and counts of indicator organisms. All treated samples had heterotrophic plate counts of <100/ml, and no total or faecal coliforms/100 ml suggesting adequate treatment and safe water. Eighteen percent of these viruses were identified as enteroviruses.

Most waterborne pathogenic bacteria can cause gastrointestinal illness, but can also cause more severe illness. For example *E coli* 0157:H7 can cause bloody diarrhoea and hemorrhagic colitis as well as haemolytic uremic syndrome. In mid May 2000, a waterborne outbreak caused by *E coli* 0157:H7 was detected in the rural town of Walkerton Ontario. By the time the outbreak was brought under control in mid-June more than 2300 cases and 7 deaths had been reported (USEPA, 2000).

The USEPA (2000) divides viruses into two separate classes, those that have low-to-moderate infectivity, with severe health effects (Type B viruses, causing for example myocarditis), and those that have high infectivity, but relatively mild health effects (Type A viruses, typically causing gastroenteritis). The illnesses caused by Type B viruses can be extremely costly to treat. Rotavirus has been used as the model organism for Type A viruses and echovirus have been used for Type B viruses. Secondary exposures from these group of viruses are also a concern. It has been estimated that for every child with a waterborne disease, an additional 0.55 people (Type A) and 0.35 people (Type B) will become ill (USEPA, 2000).

The general view in South Africa is that where excessive pollution is evident from sanitation systems, one can abandon the borehole and move the water source to a less polluted area or alternatively treat the water to drinking standards. The problem with this approach is that South

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Africa is a water-stressed country. If Vegter's (2001) groundwater use growth is accepted at 3.4 % per annum and if the Exploitation Potential is correct, then the Limpopo Province is at the brink of groundwater over-abstraction. The reason for this is that there is approximately $725 \times 10^6 \text{ m}^3$ per annum exploitable groundwater in Limpopo, derived from the Harvest Potential value multiplied with an average Exploitation Factor of 50 % and the use is at $550 \times 10^6 \text{ m}^3/\text{a}$ (Haupt, 1995). Therefore if the groundwater-use growth rate of 3.4 % (Vegter, 2001) is correct, the demand will equal the supply in 2014. In the context of the above it is disturbing that the following statements are made at conferences, workshops and in the literature:

- “groundwater is not sacrosanct!” WRC, 2006-02-09”.
- “...it is often better to have groundwater polluted than the immediate domestic environment” WRC 2006.
- “on site water plus off site sanitation is often technically infeasible, and much more expensive than off site water (standpipes) plus on-site sanitation” WRC, 2006.
- “the risk of groundwater pollution is NEVER sufficient reason to change the sanitation system” – Jackson, 1998.

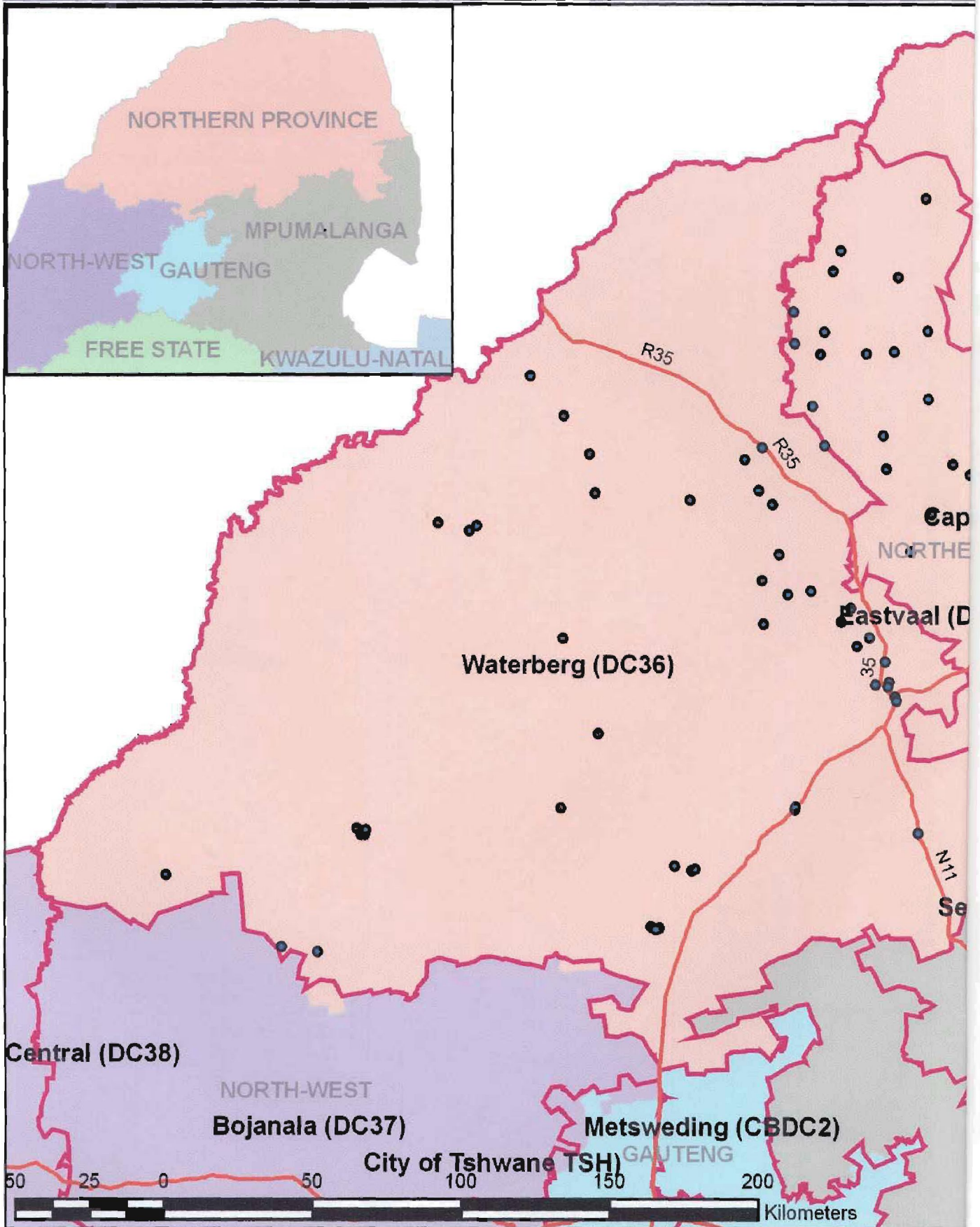
The objective of this study was to assess the groundwater quality (in terms of macro-chemical and microbiological constituents) at health facilities within the rural areas of the Limpopo Province and to attempt to identify environmental and physical factors that may aggravate the deterioration in water quality due to sanitation systems.

3.2 Materials and Methods

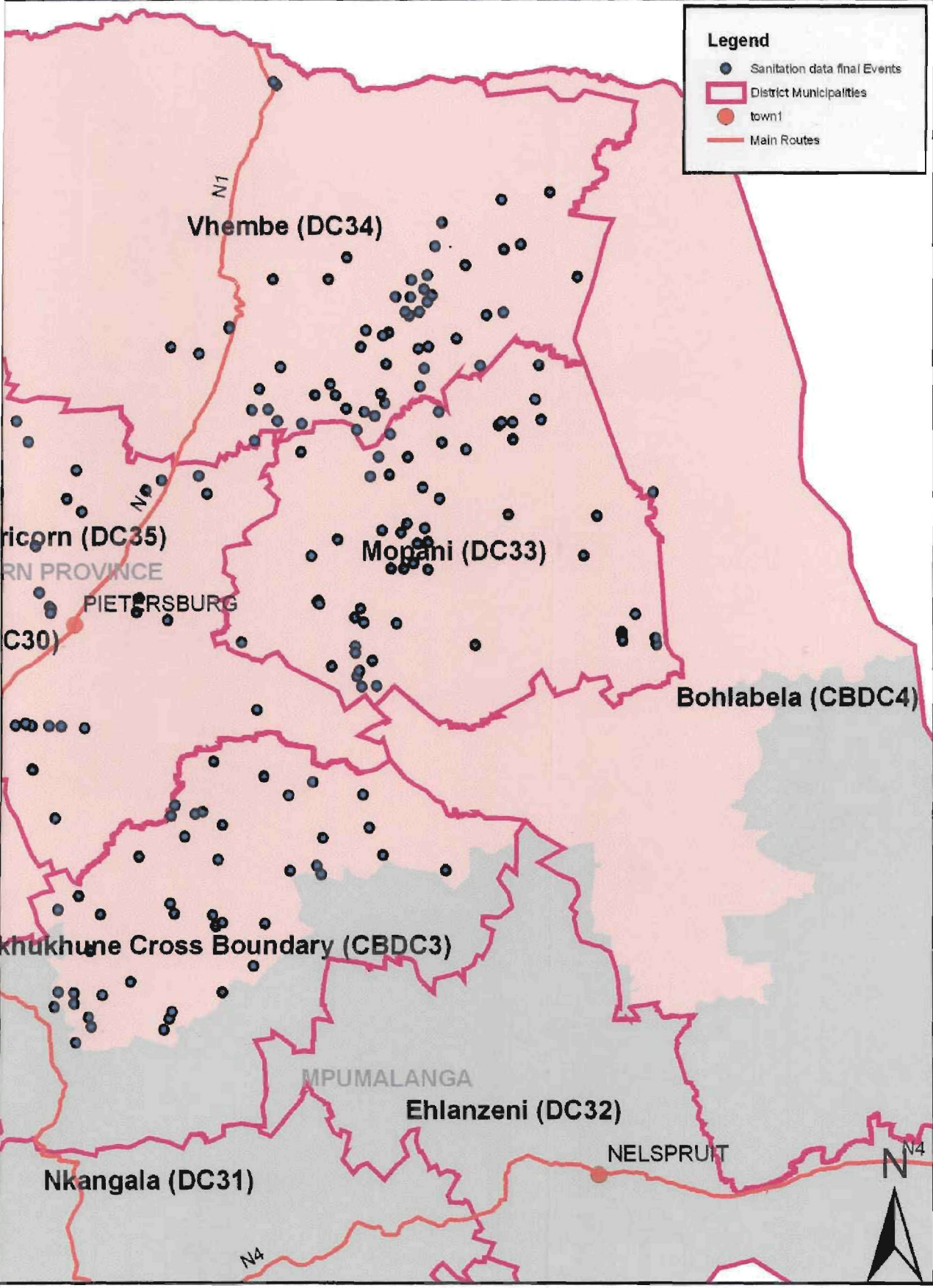
3.2.1 Study area

Two hundred and seventy four clinics were visited within the Capricorn, Vembe, Sekhukhune, Mopani and Waterberg district municipalities of the Limpopo Province between March 2006 and July 2006. The location of the health facilities are detailed in Figure 4. Most of these clinics are reliant on groundwater for domestic and general purposes, whether from a community source or on site boreholes.

Figure 4 : Region



nal Locality Map



On site sanitation: are we exaggerating the impacts?

3.2.2 Desktop study

Regional geological-, and geohydrological information was obtained from the following sources prior to the site assessment:

- Published geological-, geohydrological- and topographical maps.
- Results of previous geotechnical investigations conducted in the vicinity of the site (Africa Geo-Environmental Services (Pty) Ltd).
- Local data from the Groundwater Information Project (GRIP) and the National Groundwater Database (NGDB).

3.2.3 Sample collection and preservation

Groundwater samples were taken at the point of use at each of the facilities. The sampling procedure for groundwater was done according to the protocol compiled by Weaver (1992). Field measurements of pH, electrical conductivity and temperature were recorded at each site using a Hannah Instrument (HI 98130). Unfiltered samples were collected in cleaned 1L polyethylene bottles for major cation and anion analysis. Water samples for microbiological analysis were collected in sterile glass bottles supplied by the laboratory. The samples were kept cold and dispatched to ERWAT laboratory (chemical analysis) and VET laboratory (microbiological analysis) within 24 hours from sampling. Samples were analysed for physical (pH and Total Dissolved Solids and total hardness), chemical (fluoride, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, ortho-phosphate) and microbial parameters (Total Coliform bacteria, *E coli* and coliphages) using standard methods.

3.2.4 Hydrocensus Survey

The hydrocensus survey was conducted between March 2006 and July 2006 within a 100 m radius from the facilities to document current surface- and groundwater usage, the status of existing on site sanitation systems, cleansing material used, willingness to perform operation and maintenance and an assessment of the most and least preferred sanitation options.

3.3 Results

3.3.1 Desktop study

The average annual rainfall varies both spatially and temporally, and is further influenced by topographic effects. This means that available groundwater resources vary both in terms of quantity and quality. Recharge cycles are also influenced by climatic variability. The region is affected by hydrological drought conditions as a result of low and infrequent rainfall and the high potential evapotranspiration rate. Monthly evaporation data were obtained from station no 677802A5 in Polokwane (1957 – 1987). The maximum evaporation was measured during October with an average rate of 259 mm per month. The average annual precipitation of the area varies between 344 mm (Cromford Station) and 502 mm (Armoede Station). The standard deviation is 121 mm/year, and 123 mm/year for the two stations respectively, which indicates that the rainfall has a high variability. Most of the rainfall occurs in the summer months between November-March with dry conditions in the winter.

Most of the communities and clinics in the study area rely exclusively on groundwater as a source of drinking water. The rivers in the study area are non-perennial and flow only for short periods after heavy rain events. According to the South African Aquifer System Management Classification system (Parsons, 1995), the aquifers in the study area are generally classified as *Sole Source Aquifer Systems*, which can be defined as:

“an aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.” (Parsons, 1995).

Based on yield, the majority of aquifers in the study area can be classified as low potential aquifer systems except along geological structures such as fault zones and dykes (Botha, 1999). Geology associated with the lower potential aquifers is the Waterberg Group Sandstone (Waterberg Area), Nelspruit and Halfway House Granites (Mopanie and Southern Vembe) and Soutpansberg Quartzite (Southern Vembhe). DWAf data indicate that only 10 % to 20 % of boreholes will yield more than 2 L/s. The majority of boreholes (60 %) will have yields less than 1 L/s.

A major aquifer was delineated within the central part of Capricorn and Southern Vembe and is associated with the alluvial deposits along the primary river channels and weathering and

On site sanitation: are we exaggerating the impacts?

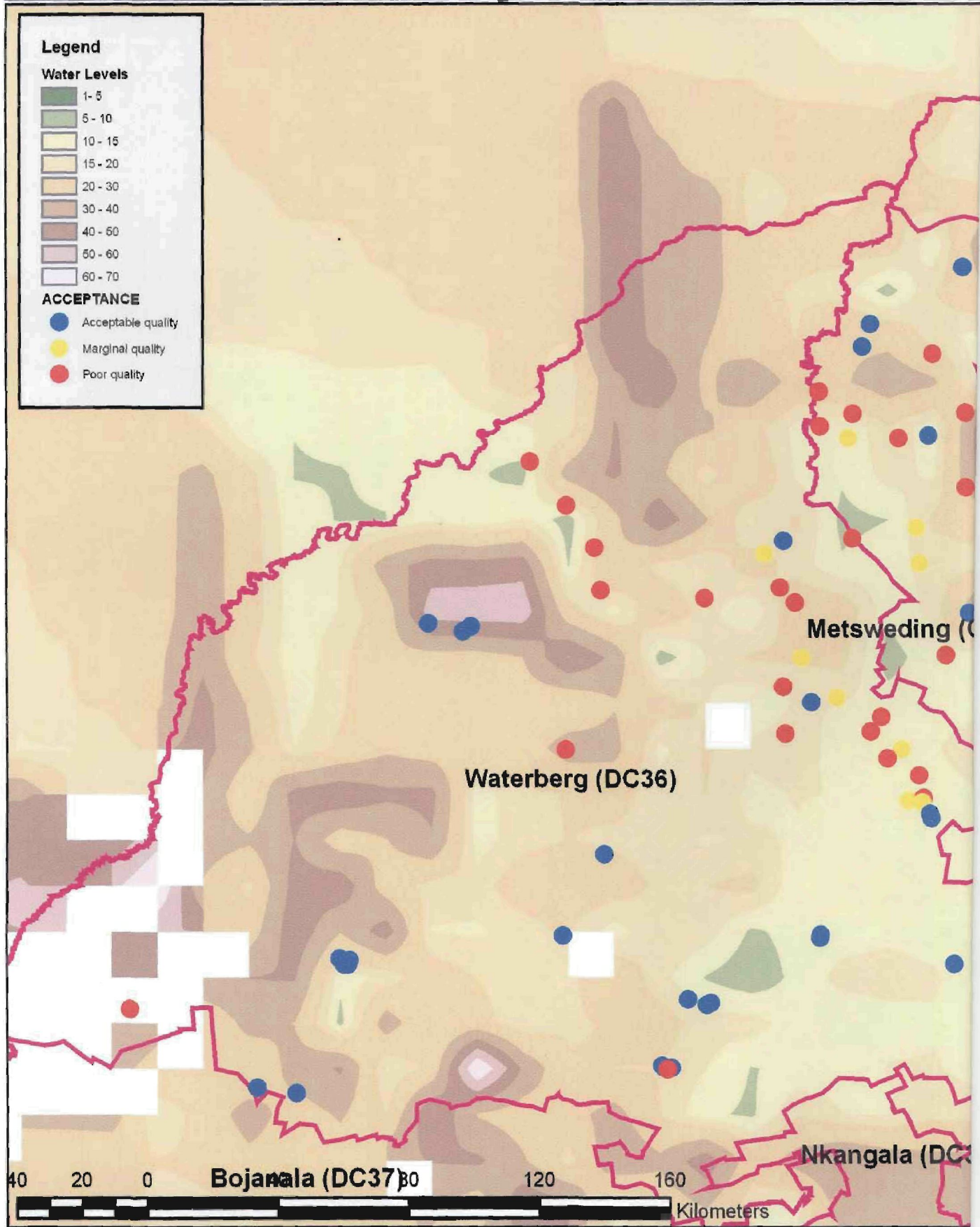
fracturing of the Hout River Gneiss. Significant groundwater abstraction is associated with structural variation in the geology which has resulted in zones of fracturing and deeper weathering. The deeper weathering allows for more infiltration, and has a greater effective porosity. Sixty percent of boreholes within this zone yield more than 2 L/s. According to Parsons (1995) a major aquifer can be defined as:

“highly permeable formations usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m)”

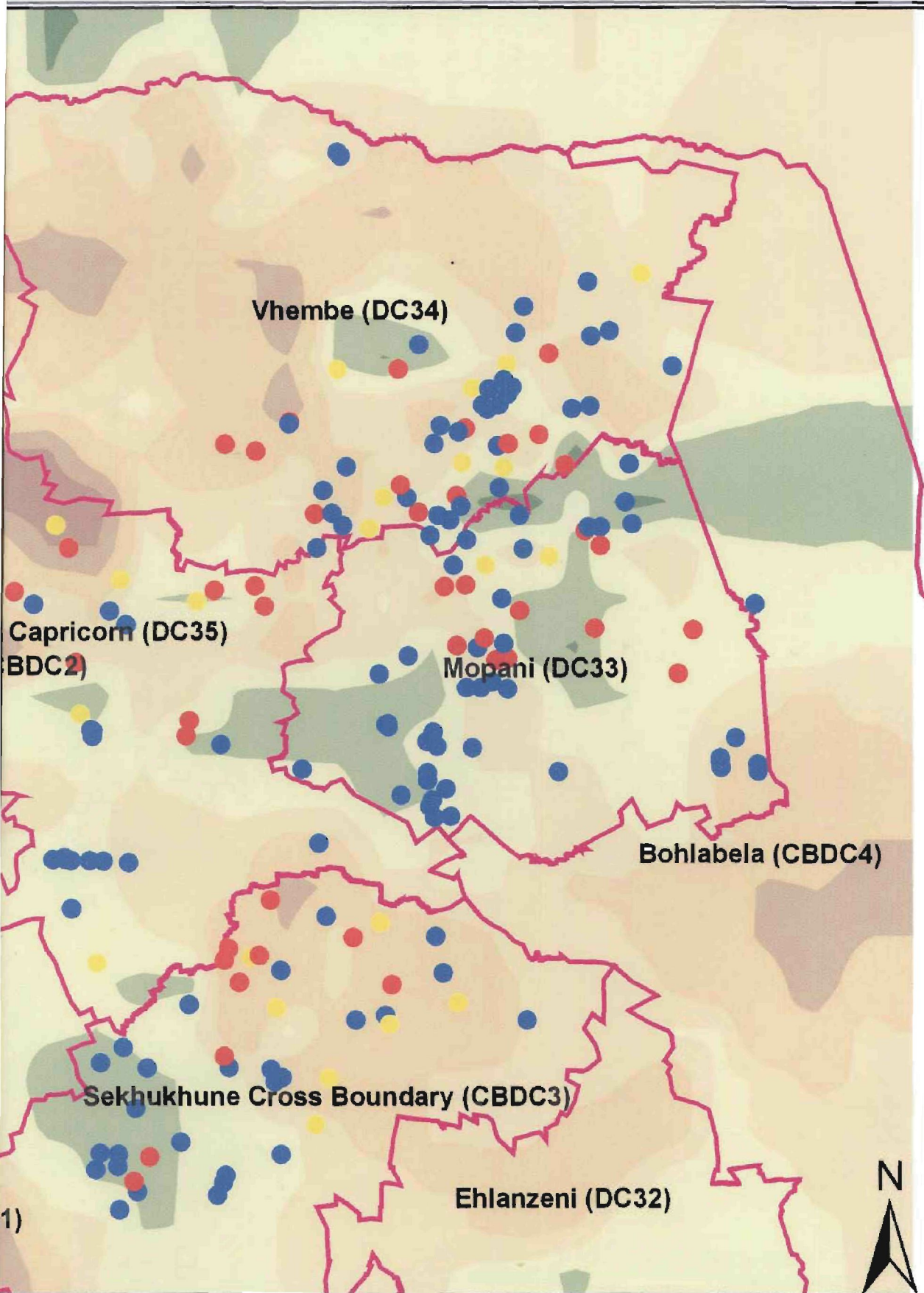
The second significant aquifer is identified within the central area of the Capricorn area and is associated with the regional dolomites in the vicinity of Lebowakgomo and the interconnected fractured material associated with the Zebediela fault systems intersecting the Capricorn and Sekhukhune areas. By the location, nature and extent of these fault systems, a vast area of relatively porous material is interconnected, making this a significant source of groundwater.

Since the majority of boreholes were locked at the time of survey, regional water levels from the GRIP and NGDB databases were used to compile a water contour map of the study area using Kriging (Figure 5).

Figure 5 : Region



al Water Levels



3.3.2 Hydrocensus Results

The results of the surveys are detailed in Annexure A and can be summarised as follows:

- Of the 266 clinics surveyed, 49 % have their own water source (borehole) for domestic purposes (Figure 6). Of these, 63 % are located within the clinic yard while 37 % are located outside the yard, but still within 100 m from the clinic. Water is mainly used for potable water, sanitation, washing and irrigation. At 21 % of the facilities the water supply was reported to be irregular and unreliable. Approximately 90 % of facilities with their own water supply do not treat the water prior to consumption.

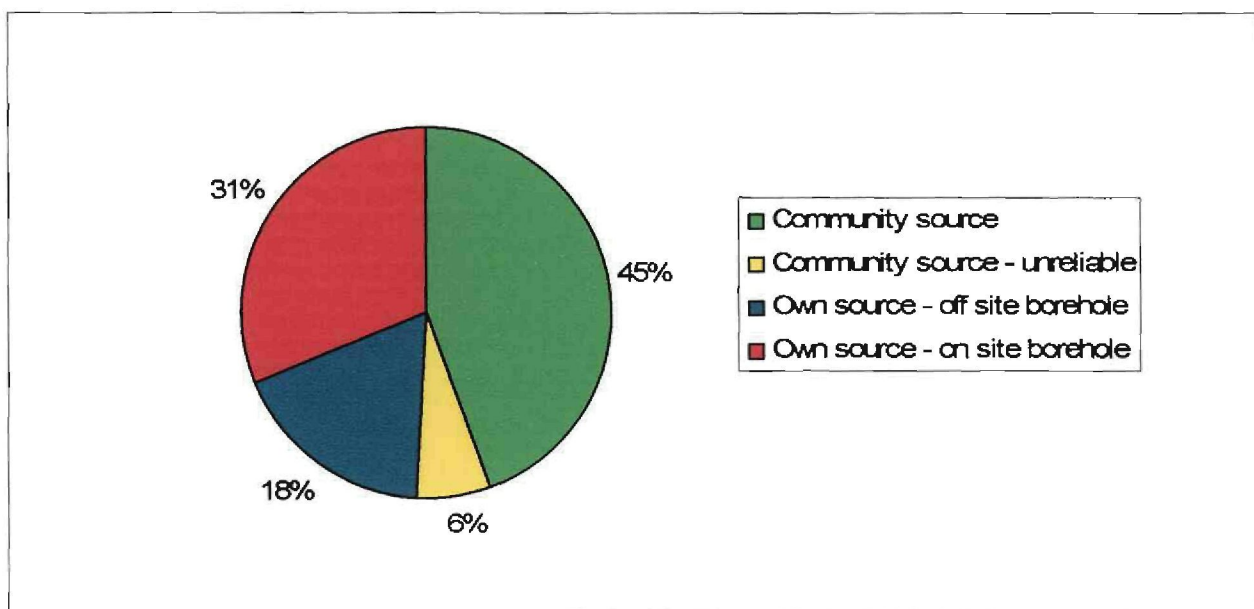


Figure 6: Water supply distribution at the clinics

- Primary sanitation infrastructure at the different facilities, constituted pit latrines (15 %), VIP's (23 %), Eco toilets (3 %), Septic tanks with soakaways (34 %), conservancy tanks (4%), on site waterborne systems (7%), and off site waterborne systems (13 %) (Figure 7). One percent of the clinics reported that they do not have any form of sanitation.

On site sanitation: are we exaggerating the impacts

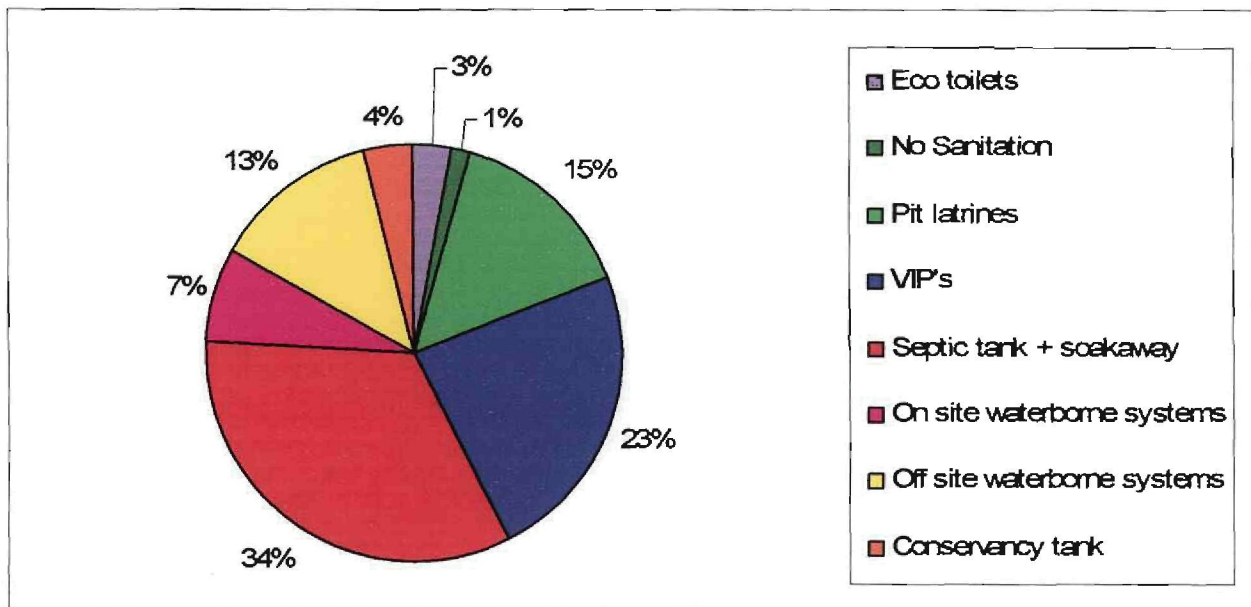
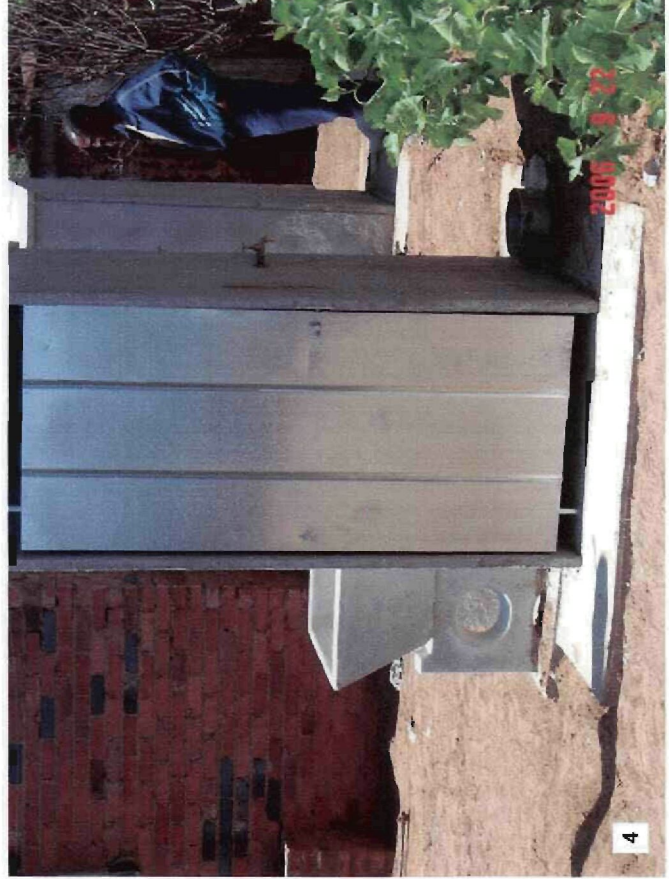
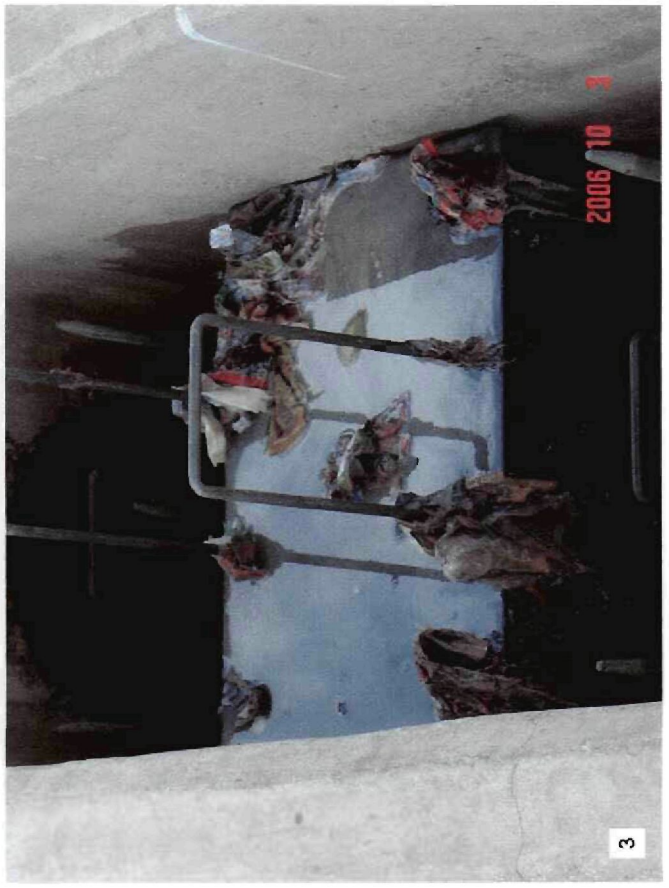
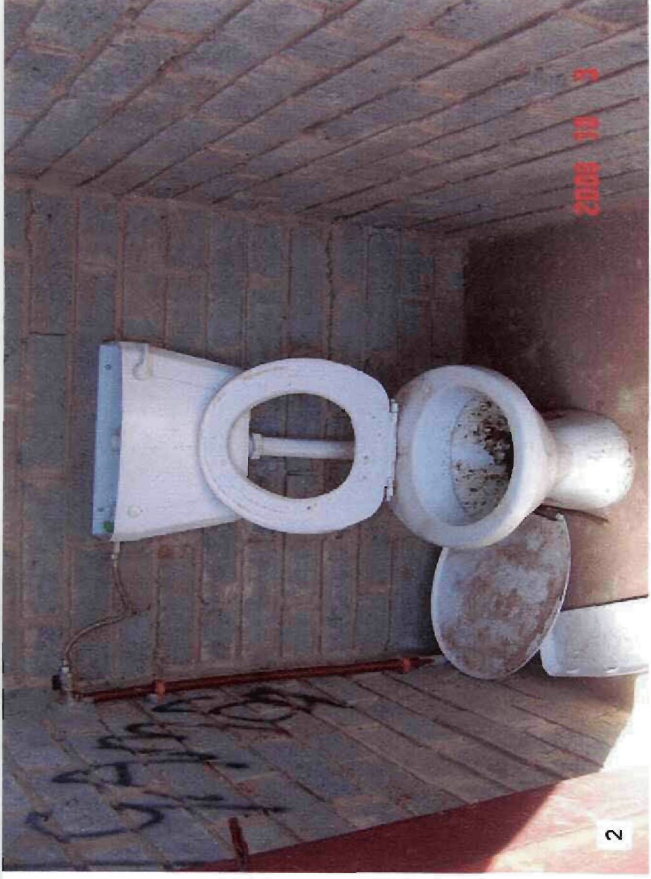


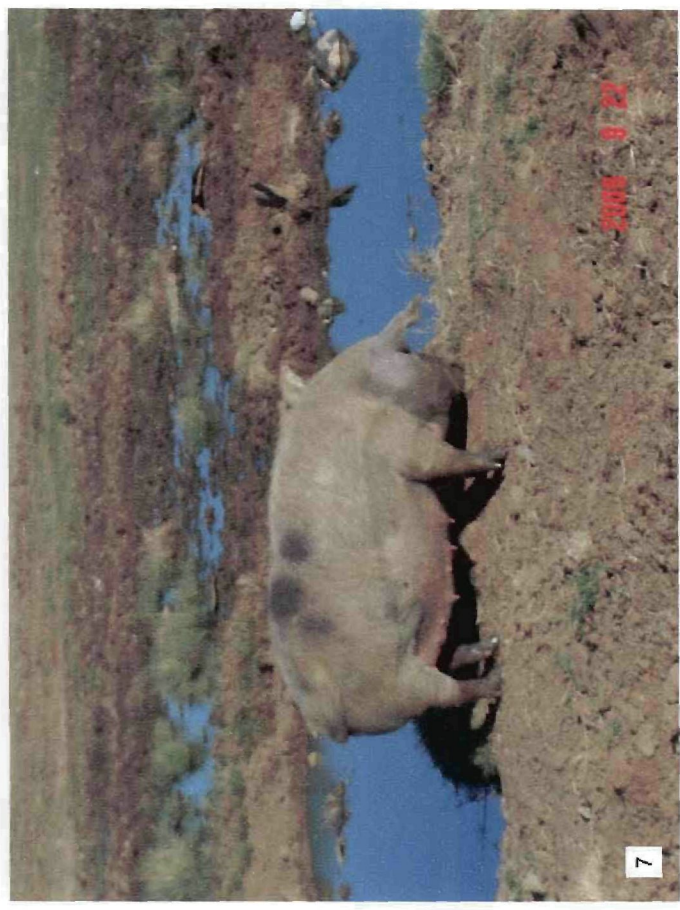
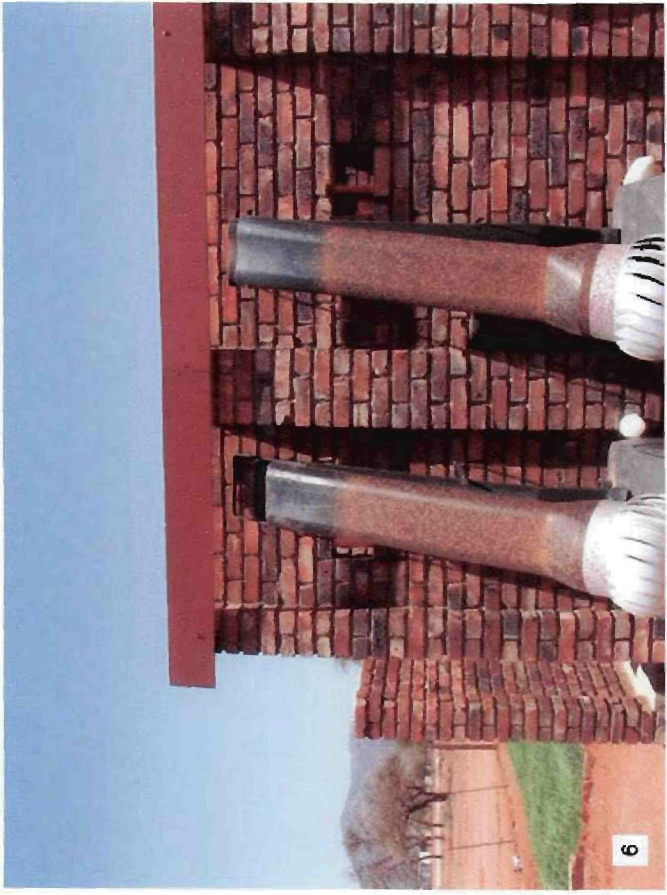
Figure 7: Sanitation technology distribution at the clinics

- Twenty two percent of these facilities were in a poor state of repair due to lack of operation and maintenance. Problems reported ranged from overflowing placenta pits and toilets to broken doors. Operation and maintenance problems occurred more frequently at facilities with waterborne sewage i.e. leaking pipes, not enough water to flush toilets, overflowing pits etc. as depicted in Photos 1 – 8 on pp 61 to 62.
 - Photo 1: grey water is being disposed off into the veld
 - Photo 2: toilets in bad state of repair and may cause a serious health risk to people
 - Photo 3: disposal of foreign objects
 - Photo 4: satisfaction with low levels of workmanship – note the taps on the opposite side of the basin
 - Photo 5: poorly maintained pit toilets
 - Photo 6: wind damage to enviro loo vent pipes
 - Photo 7: spillages due to blockages
 - Photo 8: dysfunctional or mismanaged pump station cause spillages

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- The majority of clinics reported that they are willing to do operation and maintenance, but lack capacity.
- Approximately 90 % of people preferred the enviro-loo and eco sanitation above the VIP sanitation system. The social preference is however not reflected in the above statistics where only 3 % of the clinics have eco toilets compared to 23 % with VIP's.
- The average ratio of number of people per toilet is 24. The maximum ratio of 117 was recorded at Potgietersrus LA with 3 toilets per 350 daily visitors.
- Cleaning material used at these facilities were mostly toilet paper and news paper.





3.3.3 Water quality

Water quality results were compared against the South African National Standard for drinking water (SANS 241:2005) and the DWAF Guidelines (1996 and 1998) and are detailed in Annexure A). The results can be summarised as follows:

- Of the two hundred and seventy four samples (community and own source boreholes) analysed for microbial constituents, 13 % tested positive for *E coli* and 19 % tested positive for somatic coliforms. Nitrate concentrations that exceeded the Target Water Quality Range (TWQR) were observed in 26 % of the samples.
- Sixty seven percent of samples from the on and off site boreholes (n = 130) (own supply, excluding community supply) exceeded the Target Water Quality Range (DWAF, 1996) for *E coli*, Somatic Coliforms and Nitrate concentrations. Forty four percent of samples classified as Class 3 (poor) and Class 4 (dangerous) quality due to elevated *E Coli* and Nitrate concentrations (Figure 8, Figure 12).

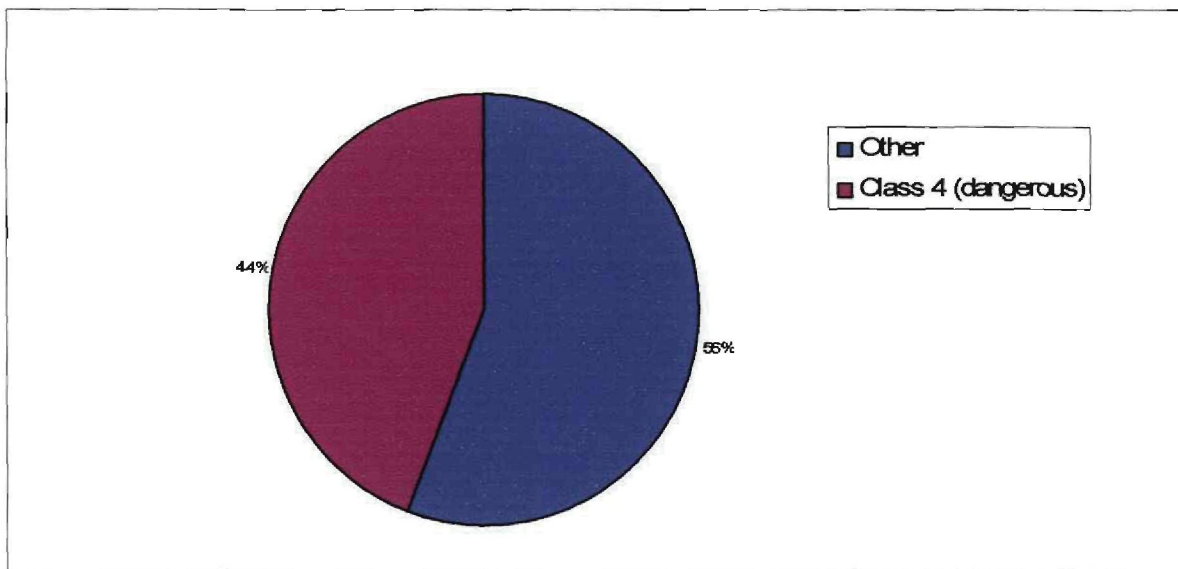


Figure 8: Own water supply boreholes – percentage of samples classify Class 4

On site sanitation: are we exaggerating the impacts?

- The maximum nitrate concentration of 154 mg/L was observed at Seleka 434. This clinic sees approximately 120 patients per day, has their own borehole and is serviced by 10 pit latrines. Water levels recorded (H21-0347) was 9.7 mbd. The geology can be described as an assemblage of compact sedimentary extrusive and intrusive rocks of the Limpopo Mobile Belt and Sand River Gneiss (Figure 11).
- Shongwane 460 clinic is visited daily by approximately 150 patients. The clinic is serviced with a combination of VIPs, septic tank with soakaway and pit latrines. A nitrate concentration of 123 mg/L was observed, rendering this water Class 4 (dangerous) and unsuitable for human consumption. The underlying geology can be described as hornblende and biotite granites of the Lebowa Granite Suite (Figure 11). Regional water levels in close proximity of the site vary between 10 and 15 mbd (Figure 5).
- Nitrate concentrations of 99 mg/L were observed in the onsite borehole (H03-3008) at Tshamahanzi 493 clinic. This clinic receives approximately 170 daily visitors and is serviced by a combination and VIPs and 4 pit latrines. A water level of 25.2 mbd was recorded at borehole, H03-3008. The pit latrines are located less than 50 m from the water supply borehole. The underlying geology can be described as compact sedimentary strata of the quartzite and shale formations of the Pretoria Group (Figure 11).
- The Weltevreden 533 clinic is serviced with a combination of VIPs and pit latrines and is visited by approximately 80 patients per day. Potable water is supplied via an on-site borehole (H03-3255). The sanitation systems are located less than 75 m from the borehole. Nitrate concentrations of 96 mg/L were observed in samples taken during the survey. The lithology can be described as potassic, biotite and leucocratic granites of the Mpageni, Meinhardskraal Group. The water level contour map indicates water levels of between 10 and 15 mbd in close proximity of the site (Figure 5).
- The maximum *E coli* count of 460 counts/100 ml was observed in samples from the water supply borehole at the Thobehle clinic. The clinic is serviced by pit latrines, which is located less than 50 m from the water supply borehole. Elevated nitrate concentrations were also observed in this borehole. The lithology can be described as bronzitite, harzburgite, norite, pyroxenite, anorthosite, gabbro and diorite of the

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Suite (Figure 11). Regional water levels recorded in close proximity of the site varies between 20 and 30 mbdl (Figure 5).

- *E coli* concentrations from community supply boreholes that exceeded 100 counts/100 ml were observed in water samples from Ga-Phaala Clinic, Nchabaleng Clinic, Mogangyaka Clinic and Rietfontein (Boshof) Clinic.
- Seventy one percent of samples taken from the own supply boreholes that tested positive for *E coli* is serviced with septic tanks and soakaways and 17 % of *E coli* positive samples is serviced with pit latrines (Figure 9). Of the samples that displayed elevated nitrate concentrations (>10 mg/L), 61 % were from clinics that are serviced by septic tanks with soakaways (Figure 10) or a combination VIP's, pit latrines and soakaways.
- Thirty-three percent of samples that had elevated nitrate concentrations (>10 mg/L) also tested positive for either *E coli* or somatic coliforms.

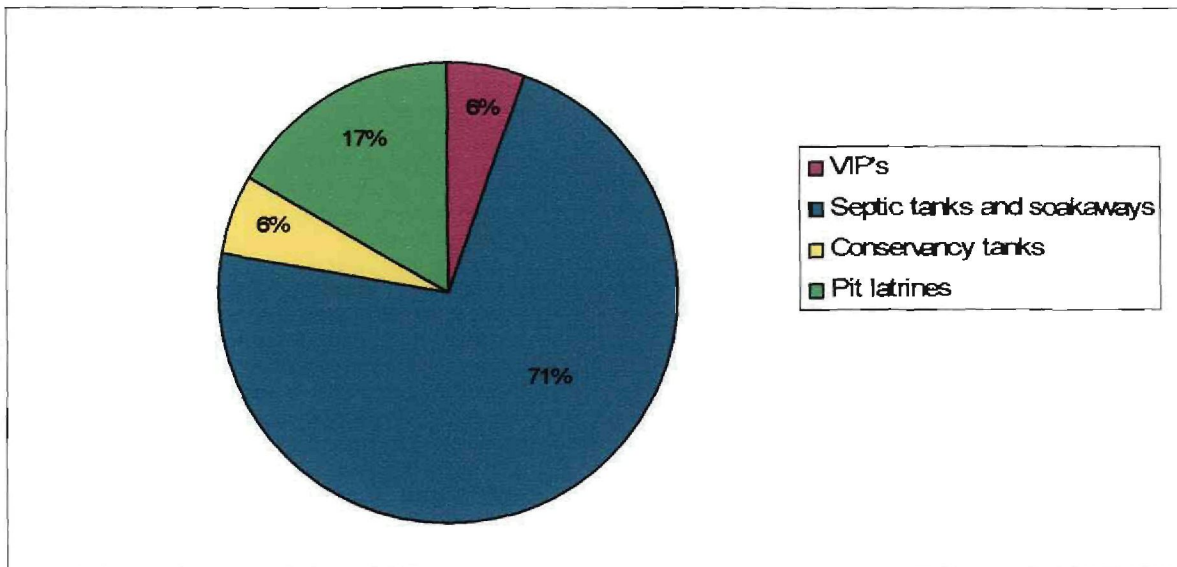


Figure 9: Sanitation distribution for own supply showing elevated E Coli counts

On site sanitation: are we exaggerating the impacts?

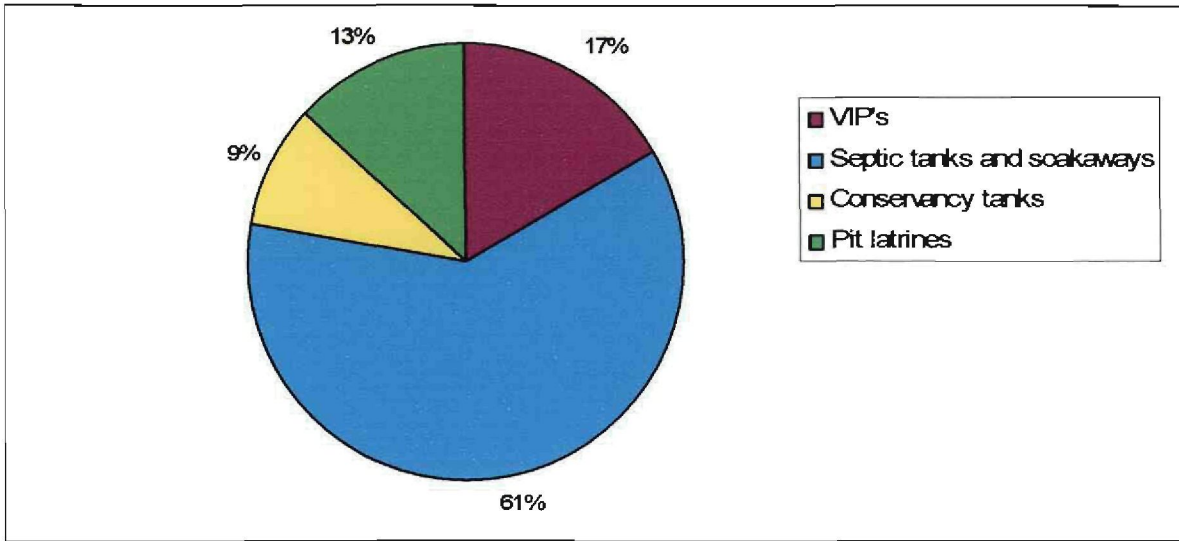
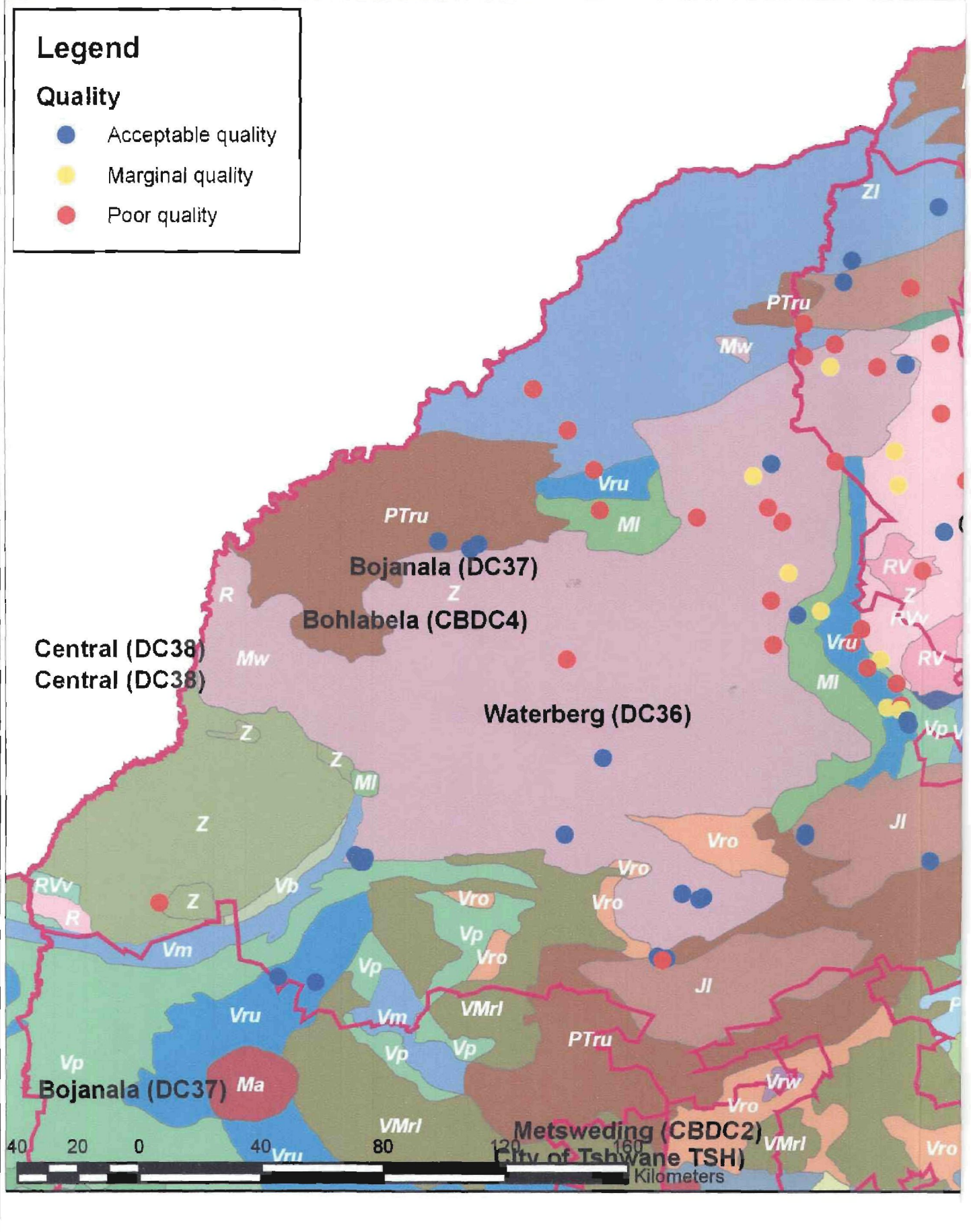
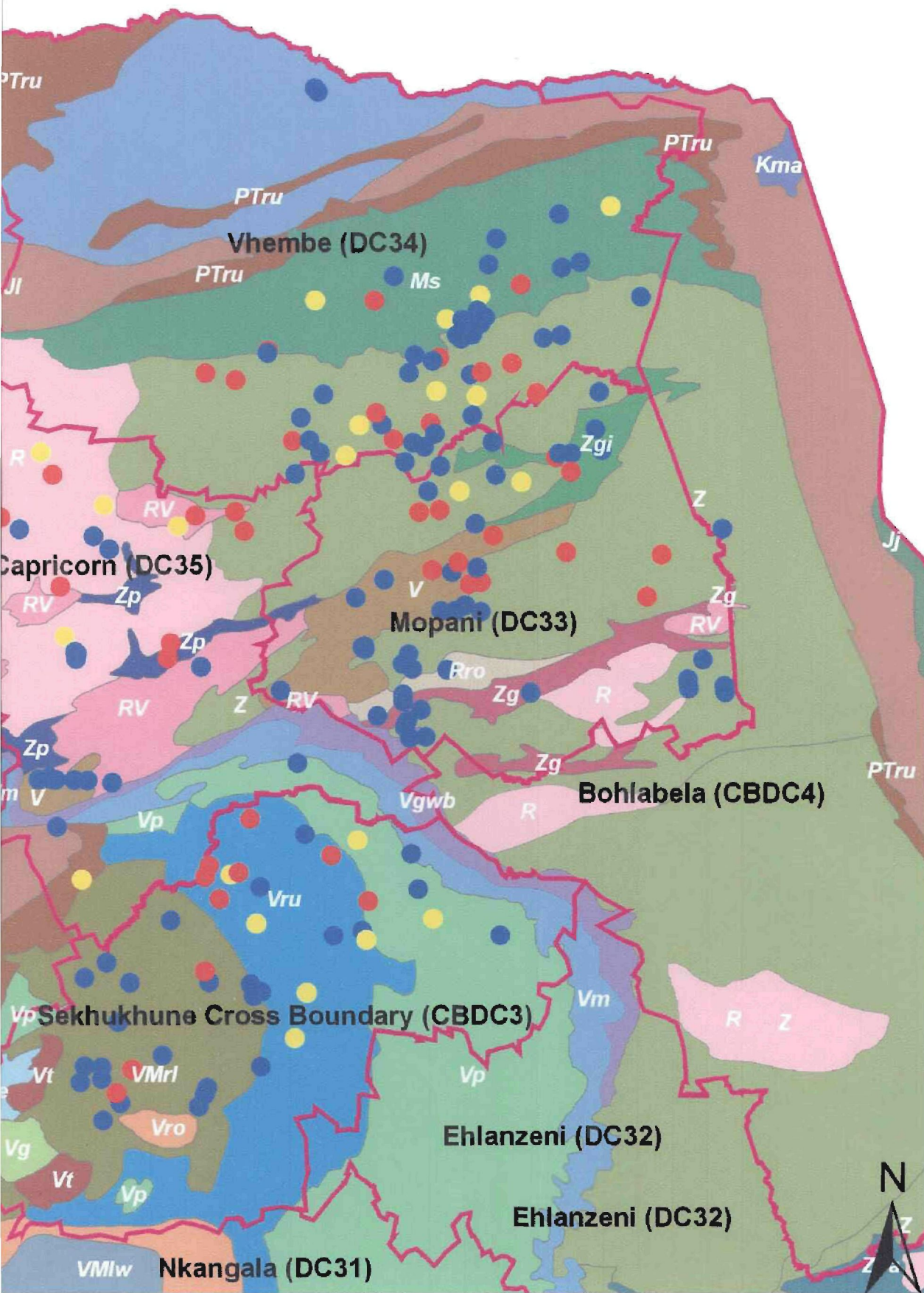


Figure 10: Sanitation distribution for own supply showing elevated Nitrate concentrations

Figure 11 : Regio



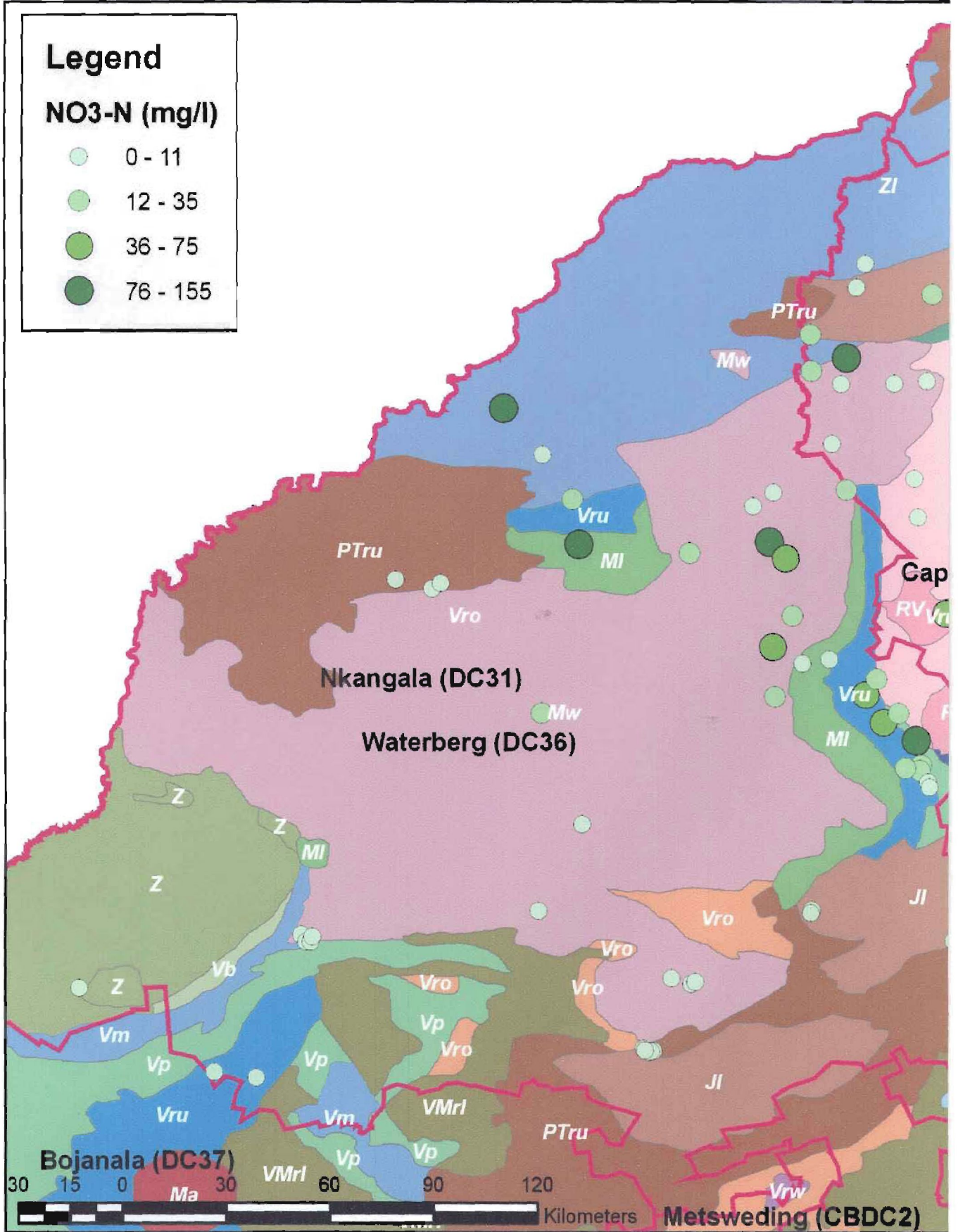
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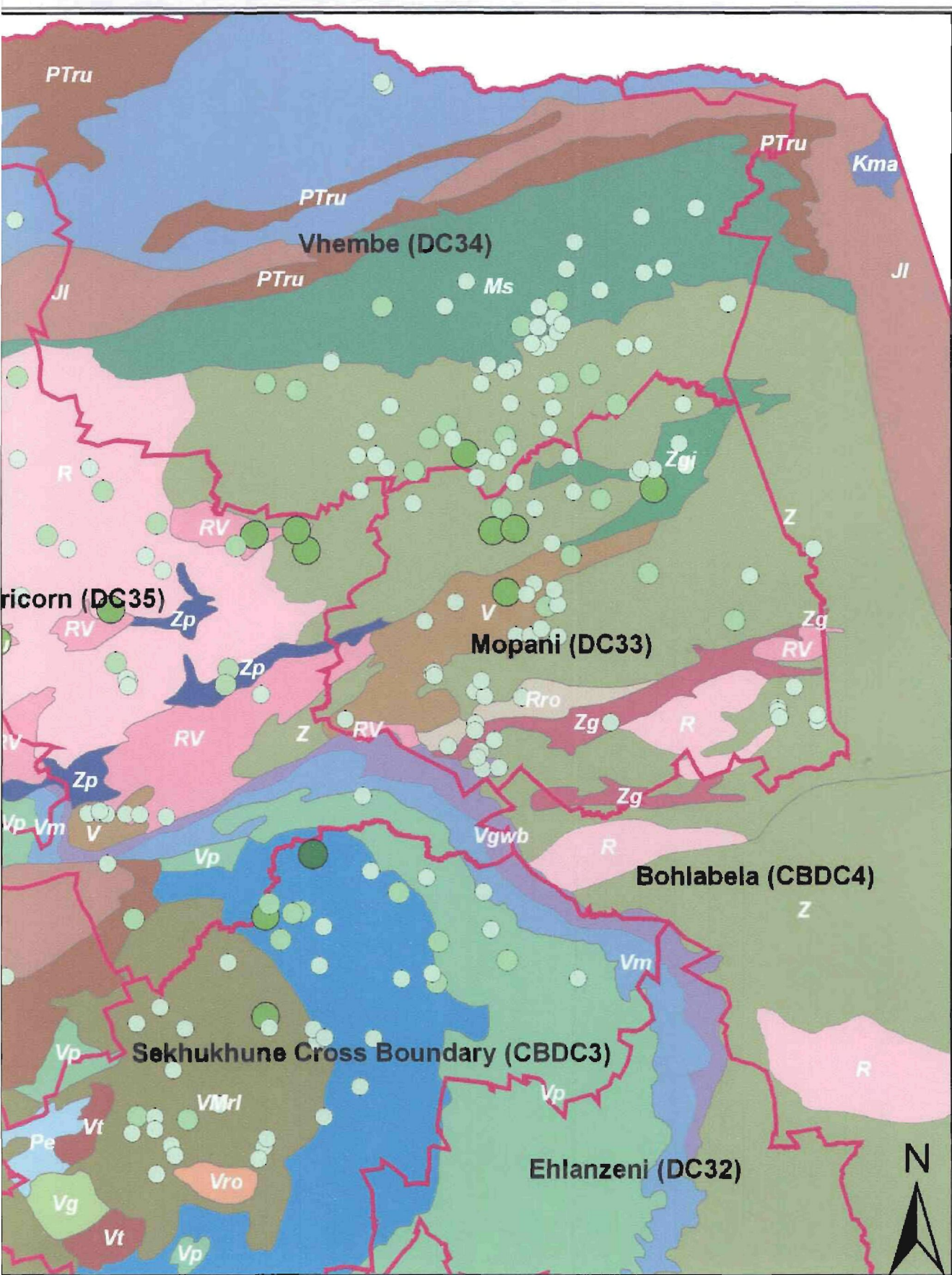
LABEL	LITHOLOGY
PTru	Sandstone, siltstone, mudstone, shale; intruded by dolerite and includes patches of Letaba basalt north of the Soutpansberg
Zl	Migmatite, gneiss; meta-quartzite, meta-pelite, marble, calc-silicate rocks, amphibolite, meta-anorthosite, serpentinite, meta-pyroxenite
Jl	Basalt; north-south trending dolerite dykes along Lebombo range
Kma	Sandstone, conglomerate, marl
Ms	Quartzite, conglomerate, grit, sandstone, siltstone, mudstone, shale, basalt, trachy-andesite, tuff; diabase dykes / sills
Z	Granite, granodiorite, tonalite, gneiss, migmatite
Mw	Conglomerate, grit, sandstone, siltstone, mudstone, shale, trachyte, quartz porphyry; diabase dykes and sills
Zgl	Ultramafic and mafic lavas, schist
RV	Granite, biotite-muscovite granite; diabase / dolerite dykes
Vru	Bronzite, harzburgite, norite, pyroxenite, anorthosite, gabbro, diorite
J	Rhyolite, granophyre, syenite, tuff, breccia, minor sedimentary rocks
MI	Hornblende and biotite granites
V	Potassic biotite and leucocratic granites with northeasterly trending diabase / dolerite dykes
Zp	Ultramafic and mafic lavas, quartzite, conglomerate, chlorite schist
Zg	Ultramafic, mafic and acid lava, tuff, schist, conglomerate, quartzite
Rro	Diorite, gabbro
Vgwb	Lava, tuff, quartzite, shale, conglomerate
Vp	Quartzite, shale, conglomerate, iron formation, breccia, diamictite, limestone, dolomite, and where not shown separately as Vh, andesite;
Zp	Ultramafic and mafic lavas, quartzite, conglomerate, chlorite schist
Vm	Dolomite, chert, subordinate quartzite, conglomerate, shale; diabase and syenite dykes and sills
Vro	Rhyolite, pyroclastics
Vb	Lava, volcanoclastic rocks, quartzite, greywacke, shale
RVv	Andesite, quartz porphyry, dacite, rhyolite, trachyte, ignimbrite, tuff, agglomerate, volcanoclastics, conglomerate, sandstone, arkose, quartzite
R	Biotite-muscovite granite, gneiss, leucogranite, migmatite, potassic granite, quartz monzonite, tonalite, quartz porphyry
Vt	Quartzite, shale, dolomite
Pe	Shale; intruded by dolerite dykes and sheets
Vg	Lava, tuff, schist, gneiss, slate, shale, quartzite
Ma	Foyaite, syenite, lava, tuff
Vrw	Sandstone, conglomerate, rhyolite
Vh	Andesite
VMrl	Granophyre, hornblende and biotite granites
Zba	Sandstone, shale, conglomerate, greywacke, lava, pyroclastic rocks
VMlw	Pyroclastics, lava, quartzite, conglomerate, sandstone, siltstone, grit, shale, diabase sills
CPd	Tillite with subordinate sandstone, mudstone, shale; intruded by dolerite dykes and sheets
Pes	Shale, sandstone; intruded by dolerite dykes and sheets

	UNIT 5
	UNDIFFERENTIATED KAROO SEQUENCE
	LIMPOPO MOBILE BELT, SAND RIVER GNEISS; BEIT BRIDGE COMPLEX; MESSINA SUITE; BULAI GNEISS
	LETABA FORMATION
	MALVERNIA FORMATION
	SOUTPANSBERG GROUP AND BLOUBERG FORMATION
	NELSPRUIT, DALMEIN, HEBRON, HALFWAY HOUSE, GOUDPLAATS AND UNNAMED INTRUSIVES
	WATERBERG GROUP AND GLENTIG FORMATION
	GIYANI GROUP
	MASHASHANE AND MASHISHIMALE SUITES; BADEROUKE, HUGOMOND, LEKKERSMAAK, MATLALA, MATOK, MOLETSI
	RUSTENBURG LAYERED SUITE
	JOZINI FORMATION INCLUDING TSHOKWANE GRANOPHYRE and BUMBENI COMPLEX
	LEBOWA GRANITE SUITE
	MPAGENI, MEINHARDSKRAAL AND UNNAMED INTRUSIVES
	PIETERSBURG GROUP
	GRAVELLOTTE GROUP
	ROOIWATER COMPLEX
	GODWAN FORMATION, WOLKBERG GROUP AND BLACK REEF FORMATION (except where the latter is included with
	PRETORIA GROUP, DUITSCHLAND, PENGE AND LANGRANT FORMATIONS
	PIETERSBURG GROUP
	MALMANI SUBGROUP, ASSEN AND BLACK REEF FORMATIONS (except where the latter is included with Godwan f
	ROOIBERG GROUP
	BUFFELFONTEIN GROUP
shale, chert	VENTERSDORP SUPERGROUP ' KLIPRIVIERSBERG, ZOETLIEF, AMALIA, HARTSWATER AND SODIUM GROUPS; HEREFORD,
	HOUTRIVIER, SALISBURY KOP, MPULUZI, GABORONE, HARMONY AND CUNNING MOOR INTRUSIVES
	PRETORIA AND CHUNIESPOORT GROUPS
	ECCA GROUP
	GROBLERSDAL GROUP ' DENNILTON AND BLOEMPOORT FORMATIONS'
	PILANESBERG AND PIENAARS RIVER ALKALINE COMPLEXES
	RUST DER WINTER FORMATION
	HEKPOORT FORMATION
	RASHOOP GRANOPHYRE AND LEBOWA GRANITE SUITE-
	BARBERTON SEQUENCE
	LOSKOP AND WILGE RIVER FORMATIONS
	DWYKA FORMATION
	ECCA GROUP

Figure 12 : Regional N



Nitrate Concentration



3.4 Discussion

Groundwater is an important source of water supply in South Africa and will become of even greater importance in the future. Groundwater plays an important role in water supply to rural communities. About 15 million South Africans rely on groundwater to some degree. Since 1994, the spotlight in South Africa has been on the poorest of the poor and meeting their basic human needs. By 2001, 7 million people, or 58 % of the original 12 million, had been served with a basic water supply, 4 million of these with groundwater sources. Indications are that 90 % of about 14 000 rural villages could be served from groundwater (DWAF, 2004)

The majority of clinics within the Limpopo Province are reliant on groundwater as the only source of potable water (GRIP). The majority of aquifers in the study area can be classified as sole source aquifers, supplying 50 % or more of domestic water in the absence of any reasonable alternative. Forty-nine percent of clinics have their own water supply (borehole), and are mostly serviced with septic tanks and VIP's or a combination of soakaways, VIP's, and pit latrines.

The National Health Act (Act 63 of 2003) promotes the protection, improvement and maintenance of the health of the population. One of the objectives of the Act is to protect, respect, promote and to fulfil the rights of the people of South Africa to an environment that is not harmful to their health and well-being. Water at 44 % of the clinics with their own water supply source classified as Class 3 (poor) and Class 4 (dangerous) quality based on DWAF criteria and constitutes a significant health risk to highly susceptible individual such as the very young, the elderly, undernourished individuals, pregnant women and immuno-compromised people notably cancer and AIDS patients (Gerba *et al.*, 1996). This water is utilised and consumed without prior treatment in 80 % of the cases.

On-site sanitation, irrespective of the system that was used, was found to be a source of contamination, notably *E coli* and nitrate. A positive correlation was observed between increased *E coli* and nitrate concentrations and the use of septic tanks with soakaways. Seventy one percent of *E coli* positive samples and 61 % of clinics with elevated nitrate concentrations were from clinics serviced with septic tanks and soakaways or a combination of VIPs, pit latrines and soakaways.

On site sanitation: are we exaggerating the impacts?

Except for Shongwane 460, clinics with nitrate concentrations in excess of 85 mg/L were serviced by pit latrines, VIPs or a combination of the two systems. No relationship was observed between elevated nitrate concentrations and water levels or geology type. Water levels of boreholes varied between 9.5 mbd (Seleka 434) and 25.2 mbd (Tshamahanzi 493). A possible explanation for the high nitrate concentrations could be that the underlying geology (gneiss, granite and quartzite) is characterised by low permeability and therefore lower recharge and less dilution. Waterborne systems may cause higher hydraulic loads and consequently higher migration distances, but lower contaminant concentrations, due to dilution.

The higher population densities and hydraulic load at the surveyed clinics make it impossible to apply the given guideline on “minimum distances” between potential pollution sources and groundwater abstraction points. This was evidenced by the number of boreholes further than 75 m that tested positive for *E coli* bacteria and had elevated nitrate concentrations. This is in agreement with Taylor *et al.*, (2004) which stated that the delineation of Well Head Protection areas (WHPA) has a number of shortcomings due to limited information on survival of pathogenic micro-organisms and standard indicator bacteria in the subsurface. Survival times are based on pathogenic bacteria such as *E coli* and are unrepresentative of viruses, which have a greater survival rate and lower infective doses (Taylor *et al.*, 2004). Uncertainty in pathogen survival in the subsurface has a significant impact on the size of WHPAs and setback distances. For example, application of viral decay constant of 0.29 and 0.1 day⁻¹ for groundwater temperatures of 15 °C and 10 °C respectively, results in estimated setback distances in alluvial sand and gravel aquifers of between 80 and 325 m (Robertson and Edberg, 1997). Rapid transport of microbial tracers in groundwater (faster than average linear velocity of groundwater flow) was also observed in a wide range of hydrogeological environments. The wide detection of sewage derived pathogens at depth in groundwater suggests aquifer penetration rates by microorganisms that are in the order of days to weeks rather than years that would be expected for bulk of recharging waters (Taylor *et al.*, 2004).

Although the Department of Water Affairs and Forestry seek to promote the development and implementation of cleaner sanitation and waste disposal practices in rapidly developing areas, it does not always occur in practice as evidenced by the survey. The groundwater policy and

On site sanitation: are we exaggerating the impacts?

strategy document states that the use of pit latrines, septic tanks and soakaways will be discouraged in urban, peri-urban and high population density rural settlement situations (DWAF, 2000). It has also been stated that inappropriate land use around wellheads will be discouraged and regulated or prohibited where necessary (DWAF, 2000). The policy and strategy document further states that the Department places a general ban on waste disposal and other polluting activities within 200 meters of the recharge zone for major aquifers and sole source aquifers (DWAF, 2000). From the surveyed data it is however evident that in practice the above is neither implemented nor enforced.

Operation and maintenance at most of these facilities can be described as *crises maintenance i.e.* maintenance that is undertaken only in response to breakdowns and/public complaints, leading to poor service level, high O&M costs, faster wear and tear of equipment, and users dissatisfaction. The objective will be to move towards *preventative maintenance*. A high percentage of respondents were willing to contribute to Operation and Maintenance, but indicated that they lack capacity.

The literature is virtually unanimous in stating that the final choice of sanitation technology should lie with the people who will use it and who will be responsible for operating and maintaining it. It was interesting to note that in the majority of respondents indicated that they would prefer ecological sanitation to the VIP system. The social preference is however not reflected in the above statistics where only 3 % of the clinics have eco toilets compared to 23 % with VIP's.

3.5 Conclusions

It can be concluded that the impact from on site sanitation on the groundwater system is significant given that 44 % of water samples of clinics with their own water supply classified as either poor or dangerous quality according to DWAF criteria and poses a significant health risk to susceptible individuals. It is therefore of great concern that the protection of groundwater is not a priority to warrant the implementation of BPEO at facilities, especially with high loads such as clinics and schools. Sufficient attention is not always given to factors such as environmental impact, social issues, water supply, reliability or institutional capacity (Austin and Van Vuuren, 2001). The result has often been a legacy of poorly planned and inadequately maintained systems

On site sanitation: are we exaggerating the impacts?

provided by well-intentioned but short-sighted authorities and developers (Austin *et al.*, 2005). It can also be concluded that separation distances and DRASTIC principles which relies on travel time, groundwater levels, geology, soil type etc is not adequate to protect groundwater sources in the event of high load facilities such as clinics and schools and the Groundwater Protocol needs to be reviewed in this regard.

Are we following the tragedy of the commons described by Garrett Hardin in 1968? He used the example of a pasture that is shared by herdsmen to explain the concept of the *Tragedy of the Commons*. Each herdsman will graze as many cows as possible, as each added cow enrich him further. This system works so long as the load imposed by the cumulative burden of all herdsmen does not exceed the carrying capacity of the pasture. At that point Hardin (1968) wrote, "The inherent logic of the commons remorselessly generates tragedy." The logic of the commons is that each individual is logically compelled to add further to the exploitation of the pasture, because altruistic sacrifice is not rewarded. If herdsmen were to withdraw cows from the common pasture, it would still be overwhelmed by other individuals less altruistic moving more cows onto the pasture. The only logical course for each herdsmen is to add still more cows to the pasture, and ultimately the common resource is ruined for all. The lesson of the tragedy of the commons is that a shared or common resource such as groundwater or surface water must be regulated by law or it may be destroyed.



CHAPTER 4

4 DECISION SUPPORT FRAMEWORK METHODOLOGY

4.1 Introduction

Selecting the most appropriate sanitation option requires a thorough analysis of all factors including cost, cultural acceptability, simplicity of design and construction, operation and maintenance, and local availability of materials and skills. Sanitation selection must also take into account the fact that good quality water is a scarce resource in South Africa. The cost of sanitation services involves therefore not only costs of installation and maintenance, but also environmental costs, especially where water sources become polluted as a result of seepage from these systems. The value of sanitation services must be reflected in such a way that it does not undermine long term sustainability and economic growth.

The most common definitions of sustainability are rather vague and imprecise. It is therefore beneficial to use sets of criteria to make the concept of sustainability more operational and practically useful (Pope *et al.*, 2004). The proposed set of criteria can be divided into five main categories: (1) health and hygiene criteria, (2) social-cultural criteria, (3) environmental criteria, (4) economic criteria, and (5) functional and technical criteria.

A decision support system can be defined as any methodology that is helpful to a decision-maker to resolve issues of trade-offs through the synthesis of information (Brunner and Starkl, 2004). The approach needs to be reproducible, consistent, defensible and capable of dealing with constraints of time, cost, and balancing requirements between production and conservation. The framework for decision making will provide a structured approach to problem solving. In this way, there is a progressive direction, with each step building on the results of the previous component. A multiple objective approach is preferred when there are many and possibly conflicting objectives to be addressed simultaneously (George, 2001).

Decision support framework

Decision support systems need input from stakeholders. Ideally stakeholder participation should occur throughout the process, during problem identification, defining decision criteria and feasible alternatives, the selection of weights and scenario analysis (Lawrence *et al.*, 2000). This process must be interactive and the Decision Support Framework (DSF) must be sufficiently flexible to respond to the needs of specific users or groups.

Typically a decision support system (DSS) contains or relies on information from databases, Geographical Information Systems, simulation models, economic analysis as well as decision models (Malczewski, 2004). The analytical procedure may use linear programming techniques, decision theory or expert-rule based systems (Poch *et al.*, 2004). The results of the analysis represent a position for further discussion having considered the trade-offs between social, economic, natural resources, legislation and technological issues. Importantly, the DSS is not intended to be prescriptive. Although the analysis may provide a rank order listing of preferred options, there may be other external factors that need to be considered before deciding on an alternative. However, the outcome of the DSS may be used to identify those options that require further investigation and consideration of resources, while eliminating less desirable options.

This chapter deals with the development of a multiple objective decision support framework (MODSSF) for sanitation selection. The proposed methodology was also tested against a case study (Chapter 5).

4.2 Development of the sanitation decision support framework

The many constraints on improving health through better sanitation centre on the political, economic, social and cultural context of health and disease. Worldwide surveys conducted by the World Health Organization identified the following as the most serious constraints (WHO, 1992)

- Funding limitations
- Insufficiency of trained personnel
- Operation and maintenance
- Logistics
- Inadequate cost recovery frameworks

Decision support framework

- Insufficient health education efforts
- Inappropriate institutional framework
- Intermittent water service, and
- Non involvement of communities.

The demand-responsive approach was the key theme of the World Bank's Community Water Supply and Sanitation Conference held in Washington DC in May 1998. This approach has been promoted internationally by the Bank as the alternative to the traditional supply-orientated or basic services approach. The approach is summarised as one in which technology and services options are "based on willingness to pay – based on the principle that more expensive systems cost more i.e. that the level of service will ultimately depend on what rural consumers are able to pay (Sara *et al.*, 1998). For successful demand-responsive projects, the community must play a role in designing programmes, selecting the type of facility as well as the level of service and conditions required. The Department of Water Affairs and Forestry (DWAFF) has developed a framework of how institutional development could be established and capacitated. Institutional and Social Development (ISD) in a project refers to a set of principles towards ensuring that a development approach is taken when planning, designing and implementing projects. Development is defined as a process of social, economical and human empowerment through which ordinary people gain greater control over the factors which control their lives. It is a process where people are at the centre of their own emancipation with the support of others. ISD requires that:

- Communities participate in decision making and are actively involved in all the phases of the project cycle as well as the ongoing operations and maintenance of services
- Local capacity is built towards managing services and partnerships are developed between communities, local government and service institutions.

The term community participation can be defined as the active involvement of the local population in defining their problems and making decisions concerning the project, the implementation and evaluation thereof. It is further defined as an organized involvement of a community in development effort with all major groups being represented (IRC, 1988).

Decision support framework

The methodology proposed supports the principles of group decision-making and allows stakeholders to express their concerns and preferences prior to decision-making. This process is schematically shown in Figure 13 and includes the following components:

- Objective statement/ situation assessment
- Identification of the stakeholders and technical team that need to be involved
- Defining feasible resource management options
- Defining the decision criteria to evaluate technical options
- Establish an issues matrix to quantify the technical and environmental constraints of each option
- Allow stakeholders to assemble the decision criteria into an order of importance
- Undertake MODSS analysis based on stakeholder scenarios
- Prioritise the options for further analysis.

It is proposed that the process involves two working groups, namely a stakeholder advisory group and a technical reference panel (which may include an engineer, geohydrologist, geotechnical specialist and social consultant). The stakeholder advisory group typically involves representatives of communities and governmental organisations (Department of Water Affairs and Forestry, Department of Health and the Department of Environmental Affairs and Tourism). Within the process stakeholders are allowed to communicate their perspectives, express concerns and to define the decision criteria which should preferably include environmental, economic, social, technological and policy considerations. Within the participatory process stakeholder representatives also rank the decision criteria and assign weights.

The primary role of the technical panel is to quantify the effect of the options on the decision criteria and to assign scores based on these criteria. Quantification may rely on measured data, expert judgement or a combination thereof. In this way the matrix is populated based on the best available science in an objective way.

Decision support framework

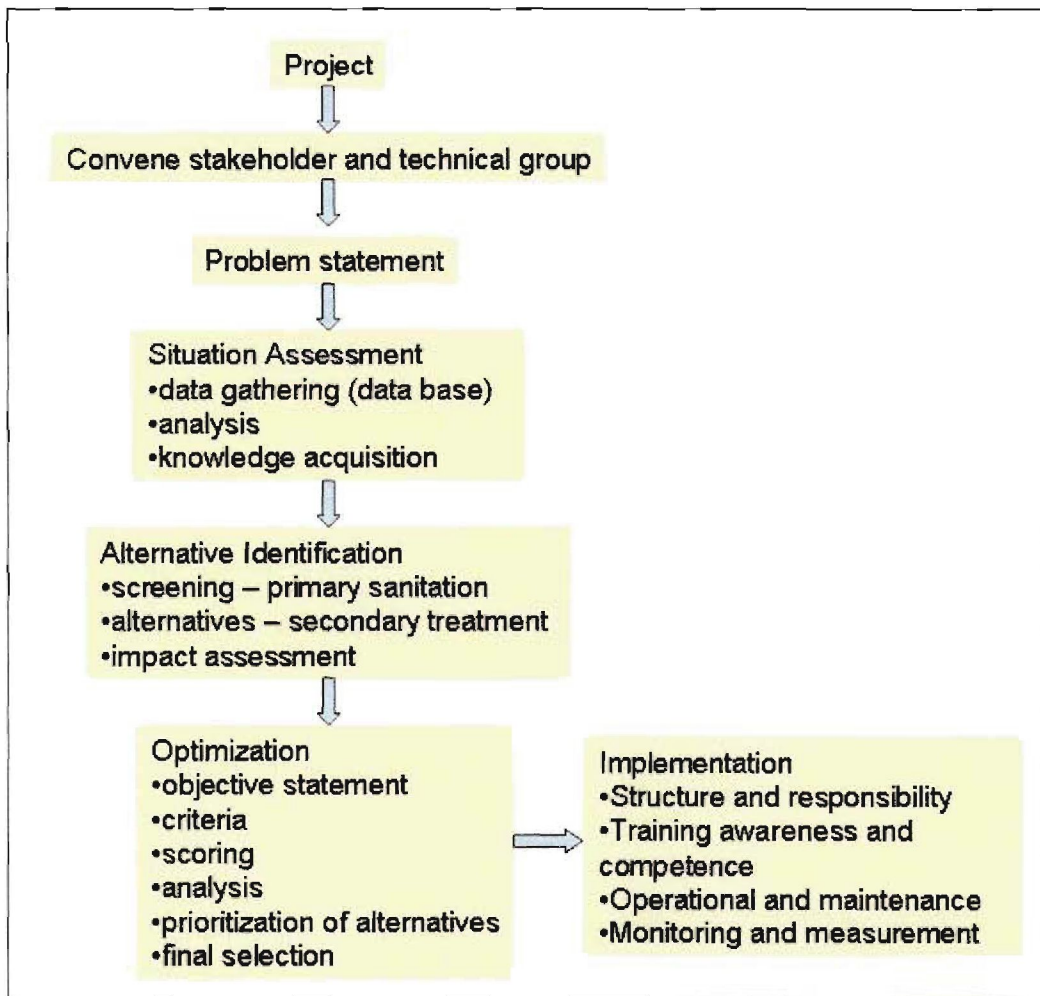


Figure 13: Decision support framework

4.2.1 Objective Statement and situation analysis

The first step should include the environmental problem definition and a review of available information and knowledge related to this problem (Poch *et al.*, 2004). Resource managers and other decision-makers are frequently required to make decisions about priorities. A common question is "Given limited resources (water, finances), what technology option proves most feasible to improve health, social well being and the environment?" Answering this question requires a clear understanding of the problem before actions are taken to protect valued resources, human health, or quality of life. Objective statements can include the following:

- Reduced human health impacts
- Reduced environmental impacts
- Cost savings
- Reduced operational and maintenance requirements
- Optimum water re-use
- Improved social acceptability.

When defining the objective, it is also useful to consider time scales. Economic considerations usually operate on a shorter time scale than environmental impacts. Considering a standard longer term time scale for the entire assessment can help to make the considerations more equal across different value systems.

4.2.2 Data collection and knowledge acquisition

Once the objectives are formulated, data collection and knowledge acquisition commence. This stage involves electing, analysing and interpreting data and knowledge that allow proposing a solution to the problem (Poch *et al.*, 2004). This step includes developing or refining a conceptual model of the site. Specific steps may include: site reconnaissance, data collection and data analysis or situation assessment. The main objective of this step is to form a conceptual model of the area and to describe the status quo (Figure 14). All alternatives should be evaluated against the status quo situation.

Decision support framework

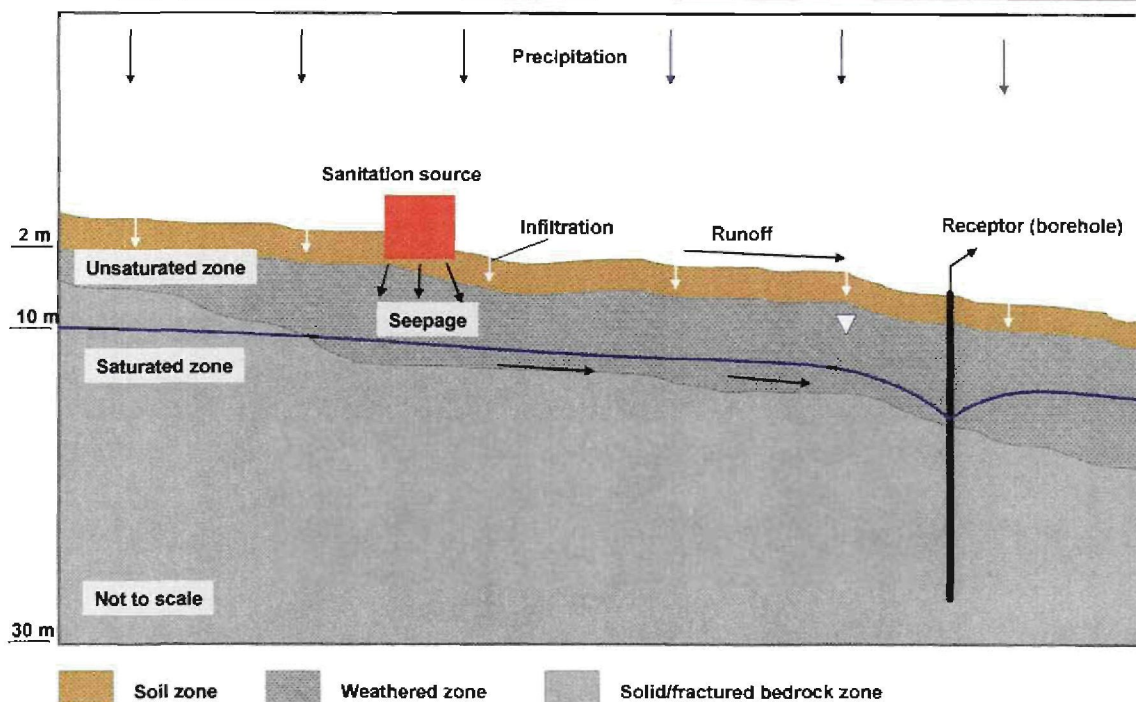


Figure 14: Conceptual model

4.2.2.1 Site reconnaissance

This step is more relevant to site specific assessments. The objective of the site reconnaissance is to visually and physically observe the property and any structure(s) located on the site to determine the likelihood of environmental and health risks. A sketch showing the site layout should be completed (site specific conditions). Important parameters to be noted on the map include locations of various infrastructure and site utilities, such as sanitation systems in relation to the water supply, improvements and details on adjacent plots/sites.

4.2.2.2 Data collection and interpretation

A proper site evaluation is fundamental to the planning, design and evaluation of any sanitation system. As data become available, the conceptual model of the site can be updated. The survey may include both secondary and primary data. Secondary data are obtained from existing reports, maps and statistics. Primary data are obtained by direct and indirect observation, measurements, household surveys, interviews and informal conversations. The following information sources

Decision support framework

can be used:

- Interviews with experts in water management, waste water management and treatment and experts in the ecological state of the receiving environment;
- Reviews from scientific and technical literature
- Data bases (GRIP, NGDB and WEIS) and questionnaires
- Geographical Information Systems
- Field Surveys (hydro census surveys etc).

A database to illustrate the proposed Decision Support Framework has been developed in Visual Basic.NET into which the required data can be archived (demo version of the database included in Appendix B). Specific fields include data on the physiographical setting, regional geological and geohydrological setting, pedology, existing on-site sanitation systems and water supply, other waste sources and social awareness (Figure 15 to Figure 20).

Physical factors that are important for sanitation selection are discussed below. Of greatest importance is the local geology – the underlying rocks and the nature of soils, in particular, the ease of digging and how stable the soil remains after excavation. It is also important to determine whether the soil is permeable so that water drains away, the depth of the top soil, how the soil varies with depth, the depth from surface to hard rocks in which it is difficult to dig, and whether there are any fissures or boulders. Natural gradients and the natural surface water drainage system should be noted, especially if there is local variation. Areas that are prone to regular or occasional flooding should be noted. Any information that can be obtained from groundwater is also useful, for example, the depth to groundwater table, whether there are any seasonal variation or long-term change, the direction in which the groundwater flows, and its quality.

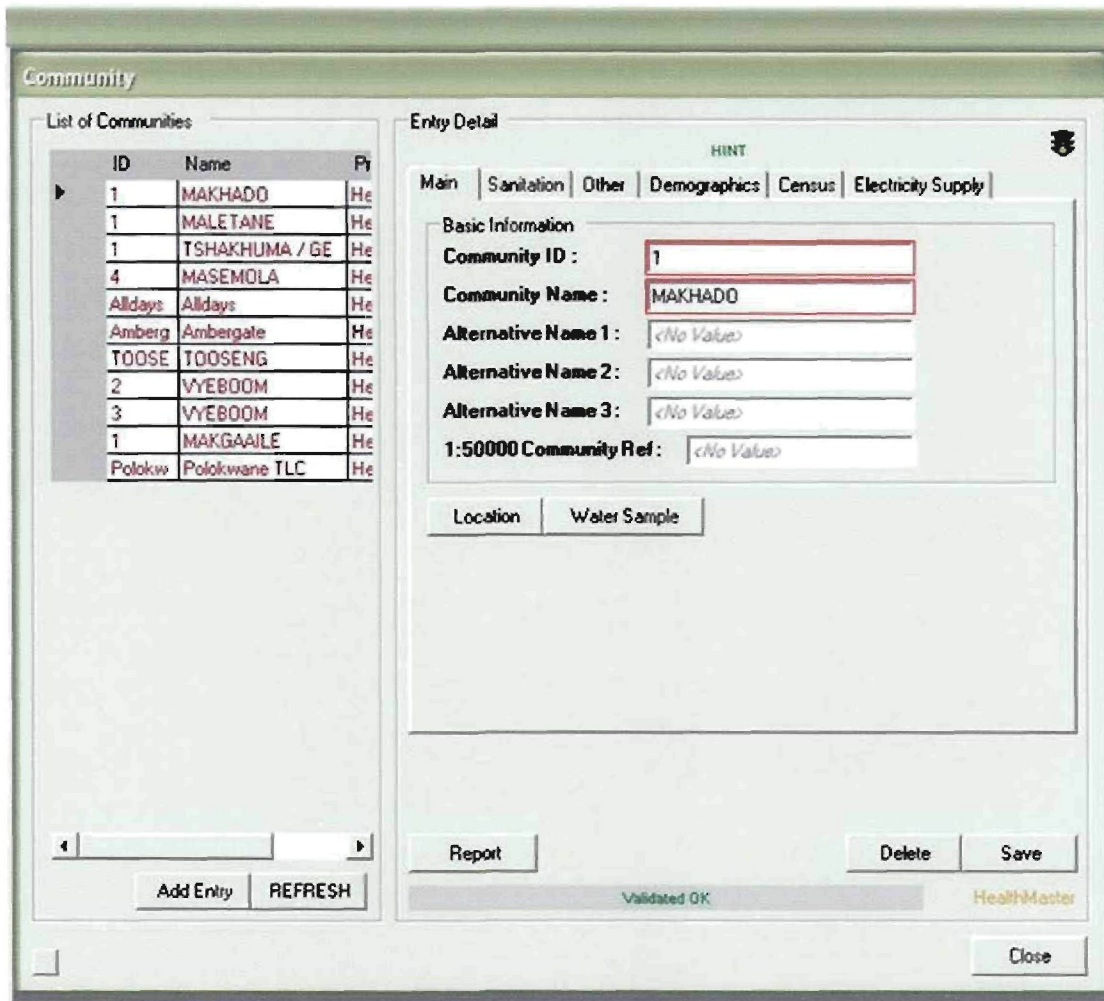


Figure 15: Sanitation database – basic information field

It is essential to obtain as much information as possible about existing sanitation. The methodology is intended to rectify any unsatisfactory situation and the extent of deficiency in sanitation provision is the baseline from which it starts.

The screenshot shows a software window titled "Sanitation" with a "HINT" icon in the top right. The main content area is titled "Sanitation Information" and contains several input fields. At the top, there are fields for "Logged By" (containing "Admin # Admin"), "Date" (containing "2006-04-04"), and "Current water status" (containing "<No Value>"). Below these are tabs for "Physiological Setting", "Geological & Geohydrological Settings", "Soil Description", "Soil Forms", and "Existing Sanitation Systems / W...". The "Physiological Setting" tab is active and contains two columns of fields. The left column includes "Landscape Unit", "Slope Direction", "Site Elevation" (with a unit dropdown set to "mamsl"), "Mean Annual Precipitation" (with a unit dropdown set to "mm"), and "Mean Annual Evaporation" (with a unit dropdown set to "mm"). The right column includes "Land Form", "Slope Class", "Localised Topography", "Weindert's Climatic N-Value", and "Quaternary Surface Catchment". Below these are two sections for "Localised Surface Drainage Features", labeled "Feature # 1" and "Feature # 2". Each feature section has five fields: "Upstream Catchment", "Localised Features", "Distance to Feature" (with a unit dropdown set to "m"), "Importance of Feature", and "End use". At the bottom of the window, there are buttons for "Social Awareness Questionnaire", "Photographs", "Delete", "Save", "Validated OK", "HealthMaster", and "Close".

Figure 16: Sanitation database – physiological setting

Careful note should be made of all water sources in the community. If possible, water sources should be visited and inspected. Special care should be taken to check information relating to dependence on groundwater as a source of drinking water. The depth of the water table and the location of boreholes and springs are particularly important because of the risk of pollution from pit latrines and soakaways. An analysis of the groundwater, including bacterial counts and nitrate concentration should be obtained. Comparison with analysis after the sanitation project has been implemented can then be used to monitor any future groundwater pollution.

The screenshot shows a software window titled "Sanitation" with a sub-header "(Acid Crystalline Rocks! [TP=choice])". The "Sanitation Information" section includes fields for "Logged By: Admin # Admin", "Date: 2006-04-04", and "Current water status: H # Has water - Comm". Below this are tabs for "Physiographical Setting", "Geological & Geohydrological Settings", "Soil Description", "Soil Forms", and "Existing Sanitation Systems / W".

The "REGIONAL GEOLOGICAL SETTING" section lists various rock types with dropdown menus:

- Rock Type
- Basic crystalline rocks: ga # gabbro
- Acid crystalline rocks: # # Unknown
- Arenaceous rocks: <No Value>
- Argillaceous rocks: <No Value>
- Pedogenic materials T: <No Value>
- High-silica rocks: <No Value>
- Carbonate rocks: <No Value>
- Metalliferous rocks: <No Value>
- Diamictites: <No Value>

The "REGIONAL GEOHYDROLOGICAL SETTING" section includes:

- Aquifer Type: F # Fracture
- Distance to Nearest Community Supply Borehole: 20-50 m
- Alternative water sources for community available? (Radio buttons: Yes, No, NV; selected: No)
- Are there any water sources at or near to the site? (Radio buttons: Yes, No, NV; selected: Yes)
- Is the area prone to flooding? (Radio buttons: Yes, No, NV; selected: No)
- Perched water tables present at the site? (Radio buttons: Yes, No, NV; selected: NV)

At the bottom, there are buttons for "Social Awareness Questionnaire", "Photographs", "Delete", "Save", "Validated OK", "HealthMaster", and "Close".

Figure 17: Sanitation database – regional geological and geohydrological setting

The need for improved sanitation may be gauged from information about the prevalence of excrete related diseases (for example cholera). Sometimes records at local health clinics yield this information, particularly in relation to diarrhoeal and parasitic diseases. However, the value of records depends upon the accuracy of diagnosis, the care with which records are kept, and the location of the health clinic relative to the area served. Data obtained in a survey carried out before the implementation of the project can be compared with health data from another survey after implementation to monitor the effectiveness of improvements.

Figure 18: Database – land type

Information obtained from the number of people and the number of houses to be served by the project should be verified and supplemented as necessary. Trends in any migration patterns should be noted. Aspects of houses that affect sanitation are density, quality and level of occupancy. While low densities are common in rural areas, it is not uncommon for dwellings in villages, and even in isolated family compounds, to be clustered at high density.

Customs that influence the selection of the most appropriate type of sanitation system include amongst other:

- The preferred method of anal cleansing (water or solid material such as paper, leaves, stones, grass or corncobs);

Decision support framework

- Whether it is customary to defecate squatting or sitting; the degree of privacy favoured;
- The preferred location of latrines in relation to dwellings; traditional use of human excrete or compost derived from human excrete as a fertilizer;
- Objections to handling excrete even when they have completely decomposed;
- Taboos on use of the same place for men and women, adults and children

The screenshot shows a software window titled "Sanitation" with a sub-header "Sanitation Information". It includes fields for "Logged By" (Admin # Admin), "Date" (2006-04-04), and "Current water status" (H # Has water - Comm). Below these are tabs for "Physiographical Setting", "Geological & Geohydrological Settings", "Soil Description", "Soil Forms", and "Existing Sanitation Systems / W". The "Soil Forms" section is active, displaying a grid of soil types categorized into four groups: 1: predominantly, 2: significant pockets, 3: localised pockets, and 4: highly localised pockets. Each soil type has a selection button with a left arrow and a right arrow. At the bottom, there are buttons for "Social Awareness Questionnaire", "Photographs", "Delete", "Save", "Validated OK", "HealthMaster", and "Close".

Soil Forms			
1: predominantly	2: significant pockets	3: localised pockets	4: highly localised pockets
Arcadia (Ar)	Glencoe (Gc)	Longlands (Lo)	Sterkspruit (Ss)
Avalon (Av)	Glenrosa (Gs)	Magwa (Ma)	Swartland (Sw)
Bainsvlei (Bv)	Griffen (Gf)	Mayo (My)	Tambankutu (Tk)
Bonheim (Bo)	Houwhoek (Hh)	Milkwood (Mw)	Valsrivier (Va)
Cartref (Ct)	Hutton (Hu)	Mispah (Ms)	Vilafontes (Vf)
Champagne (Ch)	Inanda (Ia)	Nomanci (No)	Wasbank (Wa)
Clovelly (Cv)	Inhoek (Ik)	Oakleaf (Oa)	Westleigh (We)
Constantia (Cl)	Katspruit (Ka)	Pinedene (Pn)	Willowbrook (Wo)
Dundee (Du)	Kranskop (Kp)	Rensburg (Rg)	Scattered outcrop
Estcourt (Es)	Kroonstad (Kd)	Shepstone (Sp)	Extensive outcrop
Fernwood (Fw)	Lamotte (Ll)	Shortlands (Sd)	

Figure 19: Sanitation database soil forms

Ease of access by vehicles should also be checked, bearing in mind that many rural roads that are reasonably good in dry weather, may not be accessible for several weeks during the rainy season.

Decision support framework

Vehicle access to properties may affect the choice of type of latrine, for example, where full pits need to be emptied by vacuum tanker.

An assessment should also be made of the likely contribution that beneficiaries will make to the cost of latrine construction and maintenance. It should however be noted that statements made by individuals or community leaders regarding willingness to pay are often unreliable. Responders usually answer questions in a way that they think will give them greatest benefit. In some places it has been found that payments for improved sanitation by the poorest people should not exceed 1 % of their income, but up to 3 % is acceptable for other economic groups (WHO, 1992).

The screenshot displays a software interface for a Sanitation database. The window title is "Sanitation" and it includes a sub-header "Sanitation Information" with a status indicator "(Willingness to perform O M! [TP=choice])".

At the top, there are input fields for "Logged By:" (Admin # Admin), "Date:" (2006-04-04), and "Current water status:" (H # Has water - Comm). Below these are tabs for "Geological & Geohydrological Settings", "Soil Description", "Soil Forms", and "Existing Sanitation Systems / Waste Sources".

The main content area is divided into two columns:

- EXISTING SANITATION SYSTEMS:**
 - Number of people using facility daily:** 120
 - Water Supply:**
 - Source: B0 # Borehole
 - Reliability: U # Unreliable
 - Treatment Method: N # None
 - Primary Sanitation Infrastructure:**
 - Anal Cleansing Method: O # Other objects
 - Willingness to perform O M: Willing, but lack ca
 - Toilet Facility:** (Empty field)
 - What is in your opinion the most important aspects with regard to operation and maintenance requirements?**: <No Value>
- OTHER WASTE SOURCES:**
 - Disposal of solid waste at site:**
 - Present at site: Yes No NV
 - On-site incineration: Yes No NV
 - Waste at site: (Empty field)
 - Disposal of solid waste around site:**
 - Present around site: Yes No NV
 - Waste around site: (Empty field)
 - Disposal of grey water at site:**
 - Grey Water at site: (Empty field)
 - Placenta Pit located at site:**
 - Placenta Pit at site: (Empty field)

At the bottom, there are buttons for "Social Awareness Questionnaire", "Photographs", "Delete", "Save", "Validated OK", "HealthMaster", and "Close".

Figure 20: Sanitation database – existing sanitation options

Decision support framework

4.2.3 Alternative Identification

Knowledge obtained during the previous phase can be useful in the selection of the most appropriate technologies in consultation with the community representatives, governmental organizations and technical team. Alternative treatment processes to the primary systems (cistern flush, poor flush and aquaprivie) can include waste stabilisation ponds, wastewater storage and treatment reservoirs, constructed wetlands, upflow anaerobic sludge blanket reactors, biofilters, membrane bioreactors, aerated lagoons and oxidation ditches (Mara, 2003). Mara (2003) has stated however that the most sustainable options for domestic waste water treatment in developing countries are likely to be:

- Anaerobic technologies, such as anaerobic ponds (especially high rate anaerobic ponds) and upflow anaerobic sludge blanket reactors, and
- Photosynthetic technologies such as facultative and maturation ponds and constructed wetlands.

Generally these two “natural” processes are used in series, treating the wastewater first anaerobically and then photosynthetically. It was stated by Mara (2003) that natural treatment systems are almost always the most appropriate option. More advanced technical systems are only appropriate when the land for natural systems is not available or when the cost of land outweighs the benefits.

The challenge of a decision making process is to identify the best alternative when none of the alternatives are dominating. In such circumstances, there is a necessity to have a scientific, reliable and consistent framework to identify the best alternative given the decision criteria. The general expectation is that any additional cost should provide additional risk reduction and better compliance with legislation. A two stage approach is proposed, i.e. screening stage, followed by a selection stage as detailed in Figure 21.

4.2.3.1 Primary Sanitation Selection

The information and knowledge acquired during the previous step (data gathering) can be presented in a decision tree as a prior step of the selection of an appropriate system and or alternatives. During this stage, technologies which are not feasible from a technical perspective are ruled out. Examples include (Loetscher and Keller, 2002):

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- Off site water borne sewage is only financially viable for communities > 2000 with water availability of more than 10L/person/day (regular supply).
- If the water supply is piped to each house, resulting in large volumes of grey water, aqua-privies, latrines, biogas digesters, septic tanks for excreta re-use and vaults are infeasible if the combined disposal of toilet and grey-water is required. If the soil type is clay (impermeable), latrines cannot accept even small volumes of grey water.
- Cistern flush toilets are only suitable if there is piped water available in the houses (abundant supply required for flushing). Water carriers suffice for pour-flush toilets. If piped water to households is installed, the volume of grey water is probably too large for disposal into latrine, aquaprivies or vaults. Therefore if the combined disposal of grey and black water is desired, these alternatives are infeasible.
- If bedrock is common < 2m below the ground surface, alternatives based on-site soil absorption are infeasible.
- Composting latrines are unfeasible if there is no demand for the re-use of faecal waste or if there are any cultural beliefs against the handling of excreta.

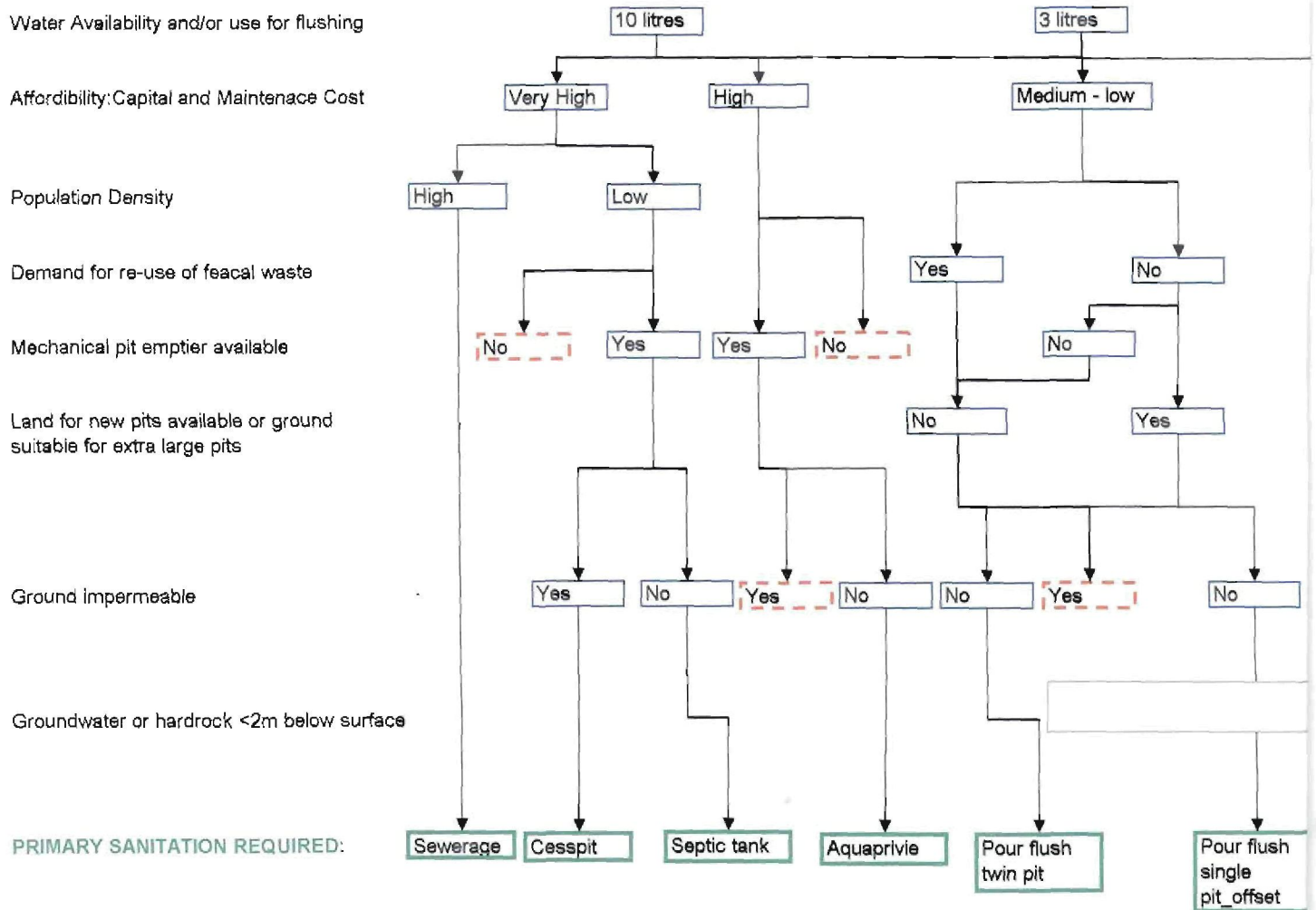
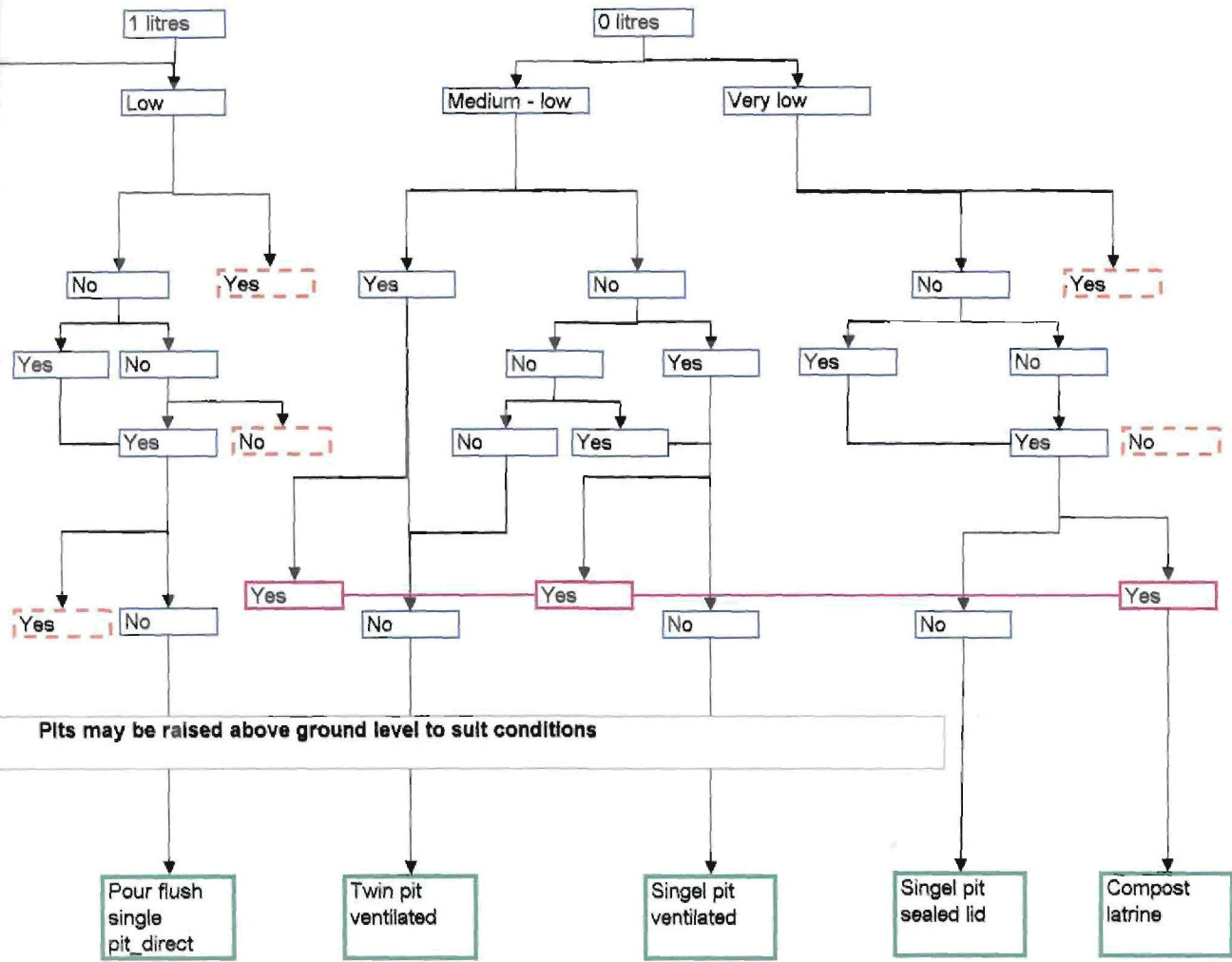


Figure 21 : Primary Sanitation selection process



Pits may be raised above ground level to suit conditions

- Pour flush single pit_direct
- Twin pit ventilated
- Singel pit ventilated
- Singel pit sealed lid
- Compost latrine

4.2.3.2 Secondary Sanitation Selection

Wastewater treatment must be done for a specified purpose – for example, to produce an effluent suitable for agricultural re-use, or to produce an effluent that can be safely discharged into inland or coastal waters because the effluent quality requirements will vary accordingly and consequently the treatment costs (Mara, 2003). The effluent requirements and costs will vary accordingly. Final effluent disposal is usually based on the following three principles/processes:

- Seepage through the vadose zone (pit latrines, VIP's, compost latrines and conventional septic tanks). The main impact of this disposal method is mainly in the groundwater system.
- Irrigation (effluent from package plants, maturation ponds, oxidation ponds, constructed wetlands or combination). Impact from this disposal method is mainly on the soils (salinity) and consequently groundwater quality. Surface water may also be impacted on.
- Discharge into inland or coastal waters (effluent from package plants, maturation ponds, oxidation ponds, constructed wetlands or combinations thereof). The impact is mainly on the surface water quality and quantity.

The National Water Act (Act 36 of 1998) requires large industrial users of water in South Africa to return water to the point (or catchment) from which it is abstracted, in a condition suitable for re-use by down-stream users. Regulations in terms of the Health Act (Act 63 of 1977) lay down rules regarding whether the land application of sewage effluent for specific uses is allowed or not. Therefore, where it is not feasible to treat an effluent to standards required for return to the point of abstraction of the original fresh water, other options should be promoted, such as the re-use of effluent. If the effluent is pathogenic the health regulations may be employed to help determine what reuse options are acceptable for the effluent in question. By utilising moisture in effluent, fresh water which would normally be required for agriculture may be saved for other uses (Murphy, 2000).

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4.2.3.2.1 Develop a list of alternatives

Different levels and kinds of alternatives should be considered. Examples include:

- Substitute technology
- Technology change
- Improved treatment technologies and
- Improved disposal technologies

The worksheet detailed in Box 4-1 can be used to organise the functions and alternatives for the identification of alternatives. These can be filled out by the project team (technical and stakeholder group). One alternative which is usually a good idea to include is the “no go” option or “status quo” situation. This provides a useful comparison for the rest of the alternatives.

Box 4-1: Alternative Identification

Situation assessment - Screening	Alternative	Potential Alternative
High income, low density community (new development). Water availability > 10 L/person/ per day. Regular supply. Community utilised groundwater as drinking supply. Current practice: guest lodge with septic tank systems and soak-aways Primary Sanitation: Cistern flush	1. Technology change	1.1 Existing waste water treatment plant 1.2 Alternative source of domestic water
	2. Improved treatment technologies	2.1 Facultative waste water stabilization ponds (15 – 40 day retention time)
		2.2 Individual package plants (general standard)
		2.3 Communal package plant + ferri chloride
		2.4. Communal package plant + phoslock
2.4 Wetland treatment system (2 to 5 day retention time)		
3. Improved disinfection technologies	2.5. Overland flow treatment and disposal system	
	3.1 Chlorination or ozone of effluent,	
	3.2 Chlorination or ozone treatment of drinking water.	
4. Improved disposal alternatives – effluent	3.3 Combined chlorination and ozonation of effluent and drinking water	
	4.1 Discharge to surface water 4.2 Irrigation.	
5. Improved disposal alternatives - sludge	5.1 Land application (agriculture),	
	5.2 Disposal or contractor	

Decision support framework

4.2.3.2.2 Environmental Impact Assessment

4.2.3.2.2.1 Aquifer vulnerability

The following methodology was proposed in the groundwater protocol (DWAF, 2003b). The assessment of risk of contamination is based on the vulnerability of the aquifer (within a regional context), contamination load (site specific) and the strategic value of groundwater as a resource. Two approaches for groundwater vulnerability are proposed. The first is based on a first order approach and is useful if limited data are available – the confidence level is consequently also lower (groundwater protocol). The second is more comprehensive and based on DRASTIC principles (Aller *et al.*, 1985).

Table 8: Aquifer Vulnerability (DWAF, 2003b)

Vulnerability Class	Measurements	Definition
Extreme (usually highly fractured rock and/or high groundwater table)	High risk and short distance (<2 m) to water table	Vulnerable to most pollutants with relatively rapid impact from most contamination disposed of at or close to the surface
High (usually gravel or fractured rock, and or high water table)	High risk and medium distance (2 – 5 m) to water table	Vulnerable to many pollutants except those highly absorbed, filtered and/or readily transformed
Medium (usually fine sand, deep loam soils with semi-solid rock and average water table (>10))	Low risk and medium to long distance to water table	Vulnerable to inorganic pollutants, but with negligible risk of organic or microbial contaminants.
Low (usually clay) or loam soils with semi-solid rock and deep water table (>20 m)	Minimal and low risk, and long to very long distance to water table	Only vulnerable to the most persistent pollutants in the very long term
Negligible (usually dense clay and/or solid impervious rock with deep water table)	Minimal risk with confining layers	Confining beds present with no significant infiltration from surface areas above aquifer

The DRASTIC model is the most widely used for groundwater vulnerability assessment studies at regional scale. The DRASTIC concept revolves around the following equation:

$$DRASTICIndex = DrDw + RrRw + ArAw + SrS + TrTw + IrIw + CrCw, \text{ where}$$

r = rating for each of the seven parameters and

w = weight for each of the seven parameters

D = Depth to groundwater,

R = Recharge rate,

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A = Aquifer media,

S = Soil Media,

T = Topography,

I = Impact on the Vadose Zone, and

C = Conductivity of the aquifer.

Proposed rating values for use in the DRASTIC concept are detailed in Table 9.

Table 9: Rating values for use in the DRASTIC concept (Modified from Lynch *et al.*, 1994)

Dept to Groundwater(D) DW = 5	Range	Rating
	<2 m	10
	2 – 5 m	8
	5 – 10 m	6
	10 – 20 m	3
	>20 m	1
Net Recharge (R) RW = 2		
	0 – 5 mm	1
	5 – 10 mm	3
	10 – 50 mm	6
	50 – 100 mm	8
	> 100 mm	9
Aquifer Media (A) AW = 3		
	Dolomite	10
	Intergranular	8
	Fractured	6
	Fractured and weathered	3
Soil Media SW = 3		
	Sand	10
	Shrinking and/or aggregated clay	8
	Loamy sand	6
	Sandy loam	4
	Sandy clay loam and loam	3
	Silty clay loam, sandy clay and silty loam	2
	Clay loam and silty clay	1
Topography (T) TW = 1		
	0 – 2 %	10
	2 – 6 %	8
	6 – 12 %	6
	12 – 18 %	4
	> 18 %	2
Impact of the Vadose Zone		

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	Gneiss, Namaqua metamorphic rocks	3
	Ventersdorp, Pretoria, Griqualand West, Malmesbury, Vanrhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutpansberg, Karoo (northern), Bushveld, Olifantshoek	4
	Karoo (southern)	5
	Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6
	Dolomite	9
	Beach Sands and Kalahari	10

Since the minimum possible DRASTIC index using these parameters is 36 and the maximum is 188, this range was divided into five equal classes. These classes were: (a) 36 to 66 (negligible), (b) 67 to 97 (low), (c) 98 to 128 (medium), (d) 129 to 159 (high) and (e) 160 to 188 (Extreme). The classes were also selected to correspond with the classes proposed in the groundwater protocol (Table 14).

The overall risk of contamination is a combination of aquifer vulnerability and expected contamination load (DWAF, 2003b). This relates to the ability of soil to accept sufficient volumes and rates of applied effluent and is determined from a consideration of soil permeability, site drainage, depth to an impermeable layer and the presence of stones within the soil profile. Permeability is the characteristic of soil which governs the rate at which water moves through it. It influences aeration, water flow, water retention, biological activities and the filtration of parasites and pathogens. It is affected by texture, structure, degree of water saturation, degree of compaction, total pore space occupied by large pores, continuity of large pores and spatial changes in any of the variables (Wright, 1999).

Generally, there is little risk of groundwater pollution where there is at least 2 m of relatively fine soil between a pit or drainage trench and the water table, providing that the rate of application is not greater than 50 mm/day (equivalent to 50 litres per m²/day) (WHO, 1992). It should however be noted that in most instances there is less than 2 m of soil in most of the rural villages. Fissures in consolidated rock may allow rapid flow of effluent to underlying groundwater with little removal of micro-organisms. The cumulative impact of a number of systems may also be significant.

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4.2.3.2.2 Assessment of hydraulic and contaminant load

In the evaluation of hydraulic load, two approaches are considered. The first approach is to consider a sanitation system like a pit latrine as a point source and to determine the load and migration potential to a receptor (borehole or spring) (Figure 14 and Figure 22). The second approach is to dilute the effect of all the sources on the development area. The hydraulic load determines the strength of the source, which is the most important single aspect of contaminant transport.

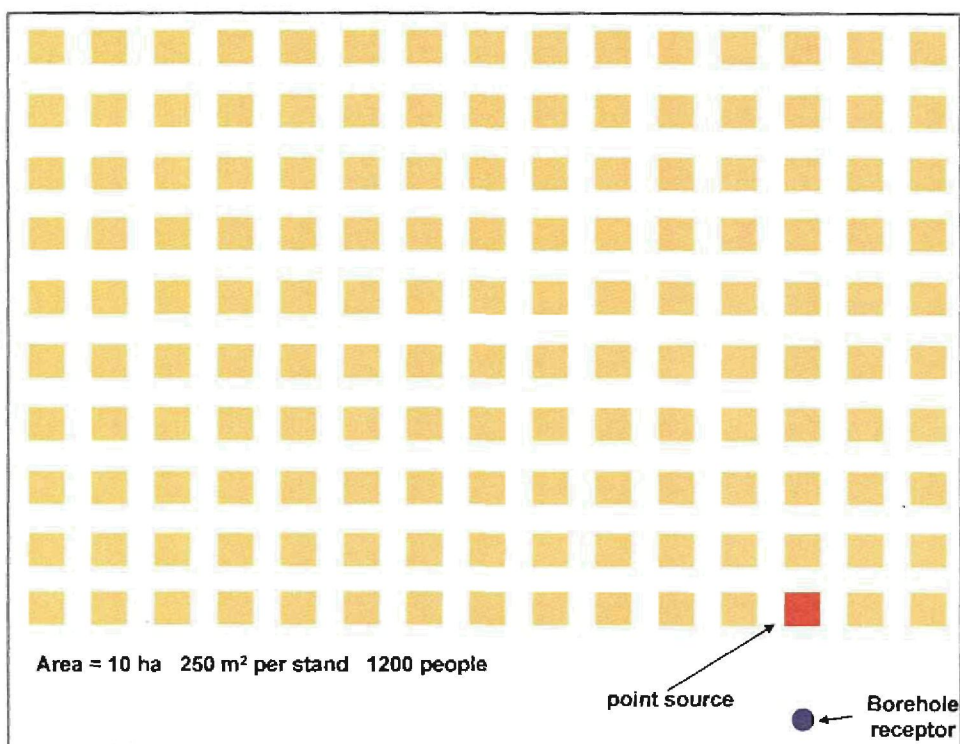


Figure 22: Schematic representation of the aerial and point source approaches

- **Point source approach**

When a sanitation system is considered as a point source, the volume of fluid that is generated is determined from conservative assumptions. For example, if the average number of people that occupy a stand is 4 and each person generates on average 2 L of fluid per day, then 8 L/day or 0.008 m³/d is generated at the point source. If it is further assumed that the pit latrine covers an

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area of 1 m², then the source flux is 0.008 m/d.

Comparing this flux with groundwater recharge from rainfall is important. In a typical fractured aquifer in the Limpopo Province where the MAP is 500 mm/year and the recharge is 3 % of the MAP, the recharge expressed as a daily flux is in the order of 4.0E-05 m/d. This means that the point source flux from sanitation is almost 200 times higher than the groundwater recharge. This volume will be sufficient to saturate the vadose zone below the pit latrine during the operational phase (Figure 22).

The Darcy flux for the point source is given by (Freeze and Cherry, 1979; Bear, 1979);

$$q = K \frac{dh}{dl}$$

Where,

q	=	Darcy flux	[L T ⁻¹]
K	=	Hydraulic conductivity of the subsurface	[L T ⁻¹]
dh/dl	=	Head gradient (assumed to be 1 for vertical seepage)	[1]

In cases where the soil permeability is higher than the hydraulic load, *the hydraulic conductivity should be replaced by the source flux*. If the soil permeability is significantly lower than the hydraulic load, the pit latrine system may overflow with time and not operate properly. The fact that a normal pit latrine or soak away system needs to seep in order to work is an inherent flaw in the system. The most important and often neglected parameter controlling the contaminant migration rate is the subsurface porosity. The advective contaminant migration is given by (Freeze and Cherry, 1979; Botha, 1993);

$$v = \frac{q}{\theta}$$

Where;

v	=	Contaminant transport rate	[L T ⁻¹]
θ	=	Effective porosity	[1]

A small change in porosity can have a significant influence on the contaminant migration rate, especially in fractured aquifers. The reactive contaminant transport rate or attenuation is

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determined by (Freeze and Cherry, 1979);

$$v = \frac{q}{\theta R}$$

R = Retardation factor [1]

The retardation factor is determined from (Spitz and Moreno, 1996);

$$R = 1 + \frac{\rho_b}{\theta} K_d$$

ρ_b = Bulk density of subsurface [M.V⁻¹]

K_d = Chemical partition coefficient [V.M⁻¹]

From a point source perspective, the following are considered as low, medium and high:

- 10 to 20 mm/day is low
- 20 to 50 mm/day high and
- More than 50 mm per day is high

- **Aerial Source Approach**

Whilst a low point source of 8 mm/day (0.008 m/d) may seem to have a low risk, it may not be the case for the cumulative impact associated with a number of stands. For example, a case is considered where 300 stands is planned to be developed on a 10 ha site (Figure 22) to house 1200 people (average 4 people per stand). The average stand size is 300 m².

The average source flux is 0.02 mm/day, which is 60 % of the recharge flux. This is much lower compared to the point source in the previous section. The cumulative flux is 2.4 m³/d.

The aerial or average source approach thus provides a lower unit flux but a higher cumulative impact. Based on the data obtained from the clinics in the Limpopo Province, where the data indicated that a high hydraulic and contaminant load causes groundwater pollution through all soil and geological media, the following criteria was developed where a number of point sources are assessed over a given area:

- <1 m³/d = low

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- $<2 \text{ m}^3/\text{d}$ = medium
- $>2 \text{ m}^3/\text{d}$ = high

Integration of point and aerial sources

For the purpose of environmental management decision making, the point and aerial source approaches should be integrated (Table 10).

Table 10: Hydraulic load rating for point and cumulative sanitation sources.

Point load (mm/d)	Rating	Cumulative load (m^3/d)
<20	L	<1
20-50	M	1-2
>50	H	>2

To test the rating criteria, an evaluation was made based on rural communities where low point sources and possible high aerial sources are important, as well as schools and clinics within the communities where point sources are more important. The rating was done by using a precautionary approach where the highest of either the point or the cumulative load is used for the rating (DWAf, 2000). The point load in Scenario 1 is for example low at 8 mm/d, whereas the cumulative load is high at 6 m^3/d . The overall rating is therefore classified as high (Table 11).

Table 11: Hydraulic load rating for point and cumulative sanitation sources*.

No	Scenario	Area (ha)	No of people	No of people per stand	No of sanitation units per stand	Density (persons/ha)	Avg plot size (m^2)	Point load (mm/d)	Cum load (m^3/d)	Rating
1	Rural community - high density	10	3000	4	1	300.00	133.3	8	6	High
2	Rural community - medium density	10	1000	4	1	100.00	400.0	8	2	Med
3	Rural community - low density	10	400	4	1	40.00	1000.0	8	0.8	Low
4	Clinic	1	150	150	4	150.00	10000.0	75	0.3	High
5	School	1	300	300	8	300.00	10000.0	75	0.6	High

* Source of 2 L/person/day assumed

The evaluation shows that the communities should be evaluated in terms of cumulative aerial loads while point sources are more important at focus areas like schools and clinics (Table 11).

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4.2.3.2.2.3 Groundwater Risk Assessment

Table 12 provides an overall assessment of the risk based on the aquifer vulnerability and the contamination load from the sanitation system.

Table 12: Overall risk of groundwater pollution (DWAf, 2003b)

		Contaminant load risk (hydraulic load)		
		High	Medium	Low
Aquifer Vulnerability	Extreme	Very High	High	High
	High	High	High	Medium
	Medium	High	Medium	Low
	Low	Medium	Low	Low
	Negligible	Low	Low	Low

4.2.3.2.2.4 Strategic value of groundwater

The semi-arid nature of the country, the urgent need for large portions of the population to be supplied with safe drinking water, the lack of economically acceptable alternative water sources and large distances between the point of water source and the point of water demand highlight the high value of groundwater in parts of the country (Parsons, 1995).

The strategic value of groundwater revolves mainly around the following aspects: groundwater usage and groundwater potential. Parsons (1995) proposes such a classification system which is mainly based on five classes i.e. Sole Source Aquifer System, Major Aquifer System, Minor Aquifer System, Non Aquifer system and Special Aquifer systems. The definitions of each are detailed in Table 13.

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Table 13: Definitions of Aquifer System Management Classes (Parsons, 1995)

Aquifer Classification	Definition
Sole Source Aquifer System	An aquifer which is used to supply 50% of domestic water for a given area, and for which there are no reasonably available alternative source should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formations, usually with a known of probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks which do not have a high primary permeability , or other formation of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.
Non Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through rocks, although imperceptible, does take place, and need to be considered when assessing the risk with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

A decision regarding the level of protection for an aquifer can therefore be based on the Aquifer Importance and Overall Risk of contamination. By using a weighting and rating approach, sound decision making can be facilitated (Parsons, 1995). The two ratings are multiplied to yield a groundwater decision-support index. The index is then linked to a management action guide table which would specify the most appropriate management action required (Parsons, 1995). For example, the proposed site is located on a sole source aquifer (weight is 6); the overall groundwater risk to pollution is medium (weight 2), the groundwater quality management index (GQM) is therefore 12; which is strictly non degradation according to Table 14.

Table 14: Ratings for the aquifer management classification system (modified from Parsons, 1995)

Aquifer Classification		Overall Groundwater Risk		Groundwater Protection Level	
Class	Weight	Class	Weight	GQM Index	Level of Protection
Sole Source Aquifer	6	High	3	<1	Limited protection
Major Aquifer	4	Medium	2	1 - 3	Low level protection
Minor Aquifer	2	Low	1	3 - 6	Medium level protection
Non-Aquifer	0			6 - 10	High level protection
Special Aquifer System				> 10	Strictly non-degradation

4.2.3.2.2.5 Surface water impact assessment

Water quality management, in South Africa, has evolved from a pollution control approach, which essentially concentrated on source directed management measures, to the current approach where water quality management consists of an integrated source, remediation and resource directed management approach which recognises the receiving water users', as well as the aquatic ecosystems' water quality requirements.

In order to counter the continuing deterioration of water quality and to meet the challenges of the future, the Department of Water Affairs and Forestry has adopted a Receiving Water Quality Objectives approach, consisting of a Receiving Water Quality Objectives approach for non-hazardous substances and a Pollution Minimization and Prevention approach for hazardous substances (DWAF, 2002).

The Receiving Water Quality Objectives approach for non-hazardous substances accepts that the receiving water environment has a certain, usually quantifiable, capacity to assimilate waste without serious detriment to the quality requirements of its recognised users. However, if applied without the necessary precaution, the Receiving Water Quality Objectives approach for non-hazardous substances will inevitably lead to the deterioration of water resources to the point where they will be less fit for use by the recognised water user sectors. To counter the limitations of this approach, a precautionary approach was accepted to avert danger and minimize

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uncertainty and potential risk of undesirable impacts on the environment (DWAF, 2002).

For those wastes that are hazardous and a threat to the environment due to their toxicity, persistence and extent of bio-accumulation, a precautionary approach aimed at minimizing or preventing their entry into the water environment, was adopted (DWAF, 2002).

Without efficient and effective source directed controls, the water quality objectives set through resource directed water quality management will, in most cases, not be met. Prior to authorising a license application for a water use that may potentially impact on water quality, the applicant must conduct an impact assessment. Such an impact assessment has to demonstrate that the source directed controls proposed, are sufficient to ensure that the water resource remain fit for use by the recognised water user sectors, in accordance with the Receiving Water Quality Objectives approach (DWAF, 2002). Impact assessments must also consider the cumulative effects of actions that in itself may not be significant, but may be significant when added to the impact of other similar actions.

Sewage effluent is one of the most common types of pollution found in urban rivers. Both the quality and quantity of the effluent result in various impacts on the receiving environment. The most obvious of ecological impacts result from increases in nutrient loads in the receiving environment (with concomitants growth of algae and both floating and emergent plants) and changes in flow patterns. From a social perspective, the discharge of effluent into the environment can have negative impacts on human health, primarily from bacteriological and other forms of pathogens. These factors limit potential utilisation (fitness for use) of the downstream rivers.

A challenge facing small communities (especially estate development close to surface water features), not connected to the sewer system, is the provision of effective wastewater treatment services. Treatment facilities may range from individual septic systems loosely regulated by local or provincial/ territorial government which discharge to a surface water body, to advanced tertiary treatment systems.

The General and Special standards (for listed water resources) have been imposed by the Department of Water Affairs for discharged effluent volumes which falls within the ambit of the General Authorisation (DWAF, 1984). These standards do not take into account the baseline quality and flow of the river. It is administratively more convenient to enforce effluent standards

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than a stream or river standard. The impact assessment model for surface water bodies takes cognisance of upstream water quality and flow and the impact of the proposed discharge on the surface water stream.

The evaluation of the impact on the stream is done based on a simple chemical mixing model. The flow rate baseline water quality of an upstream point (1) is mixed with the Purified Sewage Effluent (PSE) (2) to determine the final quality immediate downstream at point 3 (Figure 23).

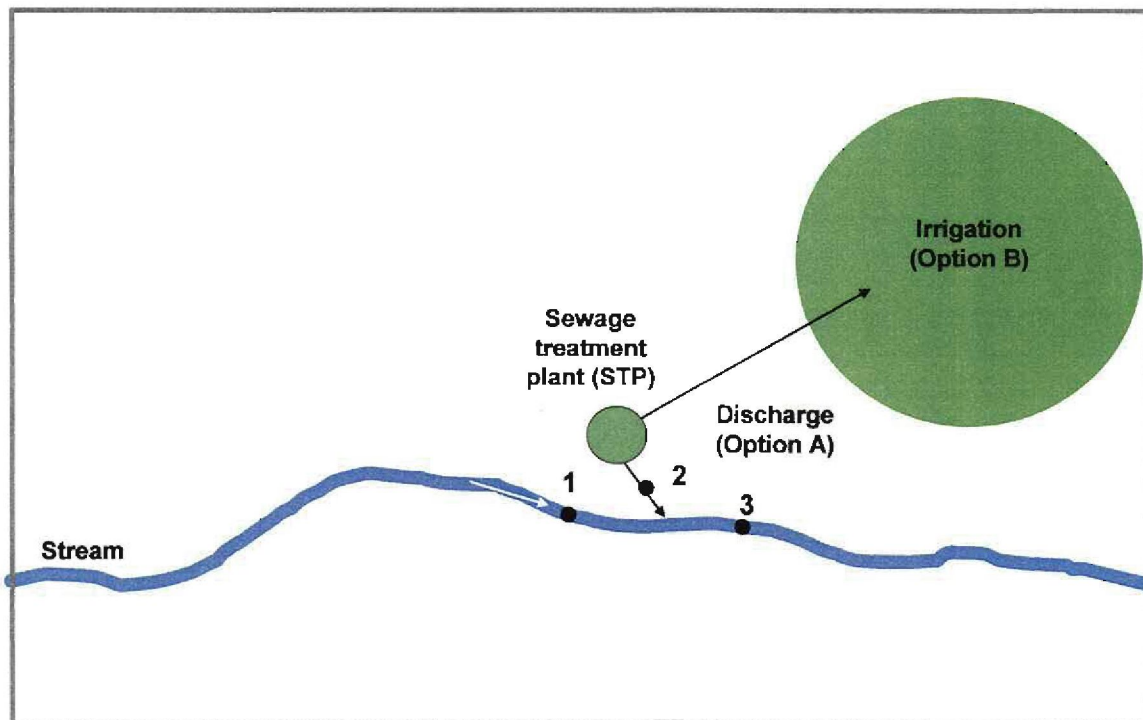


Figure 23: Options for management of purified sewage effluent (PSE).

If the flow in the stream at point 1 is Q_1 at quality C_1 and the flow from the discharge point is Q_2 at quality C_2 , the final quality C_3 can be obtained from:

$$C_3 = \frac{(Q_1 C_1 + Q_2 C_2)}{(Q_1 + Q_2)}$$

The resultant quality C_3 can be compared to the catchment or stream water quality objectives

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(WQO) and also against the DWAF criteria for the specific downstream use.

4.2.3.2.2.6 Irrigation Assessment

The area that would be required for irrigation depends on a number of factors like the water use of specific crops, soils types etc. In a basic assessment, conservative (average) parameters are used e.g. 1100 mm/year (1.1 m³/m²/year) water use. The irrigated area net water use (Q_{net}) is the difference between the mean annual precipitation (MAP) and the mean annual evapotranspiration. The area required for irrigation (A_{irr}) is determined from:

$$A_{irr} = \frac{Q_{dis}}{Q_{net}}$$

Where Q_{dis} is the volume that will be discharged per year.

If for example a volume of 200 m³/d (73 000 m³/year) would be discharged, in an area with MAP of 700 mm/year and mean annual evapotranspiration of 1100 mm/year, the area required to balance this volume is:

$$A_{irr} = \frac{73000}{0.4} = 18.25 \text{ ha}$$

For crop rotation purposes, an area of 36.5 ha will be required for irrigation of purified sewage effluent (PSE).

Important aspects to investigate if irrigation is the preferred management option, are the soil types and crop types that can be irrigated with treated effluent.

The following is a summary of the most important guidelines relating to the irrigation of effluents which display certain characteristics:

- Effluents with high pathogen content require certain treatment stages and controls on crop irrigation practices to be specified, with the aim of protecting human health.
- Effluents with significant quantities of potentially toxic trace elements need to be restricted in terms of annual application rates. This is necessary to protect human health, animal and plant health via different food-chain pathways.

Decision support framework

- Effluents with high nutrient loadings need to be restricted in terms of the amount that can be applied to land in terms of what crops need, and soil liming may be required to counteract the effects of soil acidification by organic and nitrogenous effluents.
- Effluents with significant concentrations of macro elements (TDS, Cl, B, Na) need to be applied to those crops and soils which are relatively insensitive to such concentrations, and sophisticated irrigation and soil management may need to be carried out to minimise the impact of those macro elements on crops and soils.

The value of land lost due to irrigation should also be taken into account when evaluating this option.

4.2.4 Optimization

The multiple objective decision-support system (MODSS) has been developed by the USDA-agricultural Research service in Tucson, Arizona and is available from <http://facilitator.sourceforge.net>. The software is open source, generic and can be tailored to a specific problem or issue. The tool known as Facilitator is a generic decision support system designed to be built by the stakeholders and technical specialists through the process of involvement (Lawrence and Shaw, 1999).

The underlying assumption of the MODSS is that the problem to be resolved can be formulated in terms of a matrix, in which the evaluation criteria represents one axis and the choice of feasible options represents the other axis. The multiple objective decision support system is a computer based method to assist the decision-maker when multiple and possible conflicting objectives need to be addressed (Lawrence *et al.*, 2000). For a given number of alternatives to be evaluated using a set of decision criteria (e.g. cost, environmental risk, health risk, operational and maintenance requirements, social acceptability etc.), the decision-maker is presented with a ranking of the alternatives based on an importance order of the decision-criteria. The importance order may be selected by the stakeholders or interest groups. Major components of the decision model within the MODSS are the score functions and their shapes, the calculation of best and worst composite scores and the method of ranking alternatives. These components are described below.

Decision support framework

4.2.4.1 Score functions

If measured or simulated data are available, score functions are used to scale the decision criteria or attribute from their original units into a dimensionless quantity or score within the range of 0 to 1. This enables all decision criteria to be compared on a common basis. The score functions are based on the 12 score function shapes proposed by Wymore (1988) and reclassified to four basic score shapes and combined with decision rules developed by Yakovitz *et al.* (1993). The four score function shapes are: more is better (MIB); more is worse (MIW); a desirable range (DR); and an undesirable range (UDR). Further refinement of each score function shape can be achieved by specifying whether the shape is constrained by an upper and/or lower threshold. For example thresholds may be used where water quality results are known. For decision criteria that are rated in qualitative terms (for example environmental risk), a user acceptable index is needed to convert the units of quality to a score value.

4.2.4.2 Importance order of criteria

Once each decision criterion is scored, aggregating the scores provides a means of ranking the current and alternative management and or sanitation systems. This can be done by determining an importance order, allocating weights to each score and then summing the scores to determine the total composite score. However assigning weights is a difficult and subjective process for the decision maker and may have a large impact on the outcome. The method of Yakowitz *et al.* (1993), partially overcomes this problem by calculating the best and worst possible scores for all possible weights vectors for an importance order. This importance or priority order is specified by the user or stakeholder group. Without the need to assign explicit weights to the decision criteria, the importance order can be re-arranged to undertake “what if” scenarios using the MODSS. Best and worst composite scores for each alternative are determined by solving two linear programs. The best and worst composite scores reflect the most optimistic and pessimistic solutions consistent with the importance order for the criteria used for evaluation, and represent the full range of possible composite scores for the given importance order.

Decision support framework

4.2.4.3 Ranking alternatives

Computation of the best and worst scores can be used to rank the alternative management systems. By definition, Alternative *j* dominates all other alternatives if the worst score for Alternative *j* is greater than the best score for all other alternatives. If clear dominance is not established between the alternatives, then a method to rank the alternatives is needed. One method to select the preferred alternative is to rank, in descending order, the average of the best and worst composite scores for the management systems (Yakowitz *et al.*, 1993).

The determination of the best and worst composite scores establishes the maximum and minimum overall score possible for any combination of weights consistent with the importance order. In addition the difference between the best and worst composite scores is a measure of the sensitivity of the outcome to the weightings of the decision criteria.

Figure 24 provides an example of an outcome from the MODSS analysis. Here the average of the best and worst score for alternatives (Alt#1, Alt #2 and Alt #3) is better than the current practice, and so all alternatives are preferred to dominate the existing practice. Alternatives #2 and #3 have an equal value, and so both would be preferred to Alternative #1. However, the length of the bars is an indication of the sensitivity of the outcome to the importance order. Consequently Alternative #2 is preferred to Alternative #3 as the worst composite score for Alternative #2 is better than the current practice, while there are some vector weightings in which Alternative #3 even compared to Alternative #1 (Lawrence and Shaw, 1999).

4.2.4.4 Final selection

The optimisation process is iterative. The first run usually provides more information on how the matrix can be refined to develop a useful decision tool in which the people involved have confidence in. Some criteria, alternatives, scores and rankings may need to be revisited several times before a final selection is being made on the best alternative for a given situation.

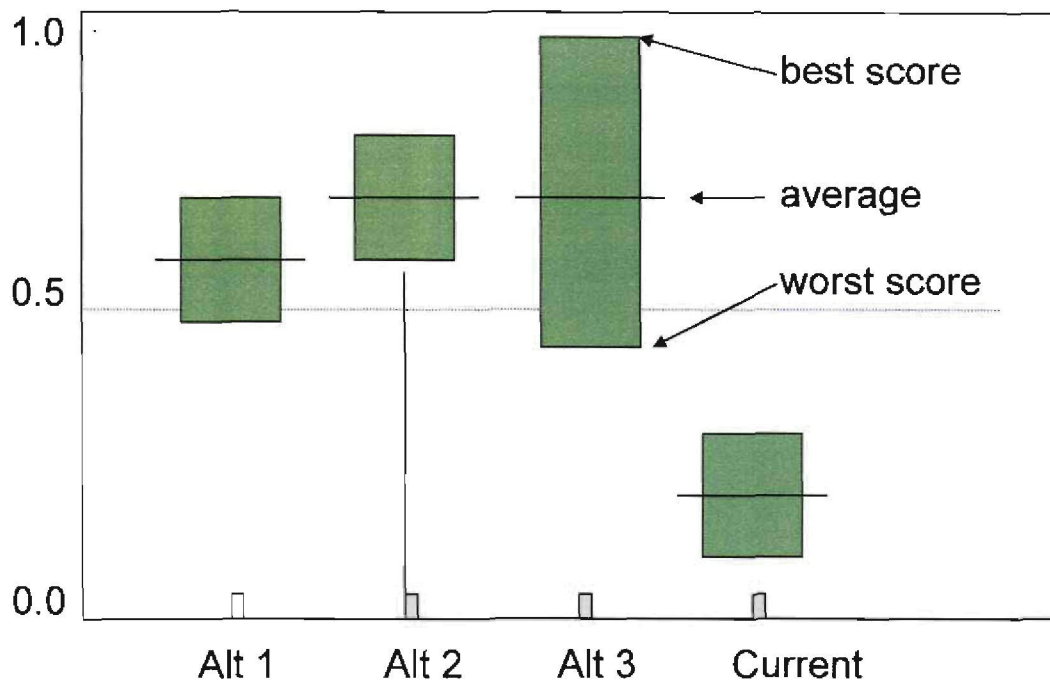


Figure 24: Outcomes of the MODDS analysis showing best, average and worst composite scores for three alternatives (Lawrence and Shaw, 1999)

4.2.5 Implementation

After the initial surveys detailed in the previous section, a demonstration or experimentation phase is required. The demonstration phase is a practical test of the feasibility of the recommended options. This is followed by a consolidation period, primarily to organize the institutional aspects of the project, leading on to the mobilization or expansion phase, when most of the sanitation facilities are constructed (WHO, 1992).

Completion of latrine construction marks the beginning of the real sanitation program in that it is the point at which people can start to realize the benefits of their investment. Continual health education and technical assistance are required to ensure that new systems function properly. Responsibility for operation and maintenance must never be left undecided until the need becomes apparent. Maintenance becomes a particular problem where an institution has been constructing sanitation systems for people without their full involvement in planning and design. If householders are unsure of the ownership of the system, they are less likely to accept

Decision support framework

responsibility for looking after it.

It is advisable to conclude the project with monitoring or evaluation in order to determine how effective it has been. The time scale can vary according to the size of population to be served and financial resources available. The WHO has developed a minimum evaluation procedure for water supply and sanitation projects (<http://www.emro.who.int/mei/mep/Index.htm>). In this, evaluation is defined as a “systematic way of learning from experience and of using the lessons learned both to improve the planning of future projects and also to take corrective action to improve the functioning, utilization and impact of existing projects”. Using the minimum evaluation procedure (MEP), the first consideration is how effectively the facilities are working or functioning. This is followed by an investigation as to how well the sanitation system is being used and maintained by the people; and finally the impact on health and welfare of the community is considered.

A monitoring plan should be developed and documented to evaluate the effectiveness of the chosen alternative and may consider the following:

- Parameters to be monitored
- Inspection requirements
- Sampling location and frequency
- Sampling methods and equipment
- Requirements for checking and interpreting results
- Defining responsibilities
- Documentation and records management and
- Reporting and communication requirements.

A communication program including both consultation and education should be designed to provide active, two-way exchange of information to ensure that the needs and expectations of the community is understood and are being satisfied. A communication program is a long term commitment and should be established prior to a crisis occurring.

CHAPTER 5

5 CASE STUDY: DULLSTROOM POLO ESTATE

The area proposed for an upper class development is situated approximately 7 km south-east of Dullstroom on portions of the farms Valleyspruit 132 JT (Portion A, 6 and 7) and Roodeklip 134 JT (Portion 5, 6, and 7). The area falls within the area of jurisdiction of the Emakhazeni Local Municipality and is accessible via the Kruisfontein Road which links up with the Belfast – Lydenburg Road(R540) approximately 11 km south of Dullstroom (Figure 25). Currently, there is a lodge with restaurant on the north-eastern portion of the farm. The existing farmhouse and wagonshed are developed into guesthouses. Associated with each individual residence is a French-drain type soakaway sewage system into which sewage and waste water is disposed. Approximately 94.5 ha of the farms Valleyspruit 132 JT and Roodeklip 134 JT are proposed for development, which amounts to approximately 20 % of the total property area.

5.1 Convene stakeholder and technical group

Box 5-1 provides a list of the stakeholders that was consulted and involved during the process.

Box 5-1: Convene Stakeholder and Technical Group:

The technical specialists on the project team included:

- Geotechnical specialist: Fred Calitz, Africa Geo-Environmental Services (MSc)
- Geohydrologist: K Vivier, Africa GeoEnvironmental Services (MSc Geohydrology)
- Agronomist: Dr K Ayisi, Africa Geo-Environmental Services (PhD)
- Engineer: Mr E du Plessis, Dombo du Plessis
- Facilitator: Me C Vivier, Africa Geo-Environmental Services

Stakeholders:

- Mr Brent, Kwena Water Users Association
- Department of Water Affairs and Forestry
- Department of Environmental Affairs and Tourism
- Direct neighbours

5.2 Objective statement

The objective statement formulated by the project team and stakeholder group is detailed in Box 5-2:

Box 5-2: Objective Statement

Given limited resources (water, finances), what sanitation technology option proves most feasible to improve health, social well being and the environment at the proposed Dullstroom Polo Estate

Specific objectives include:

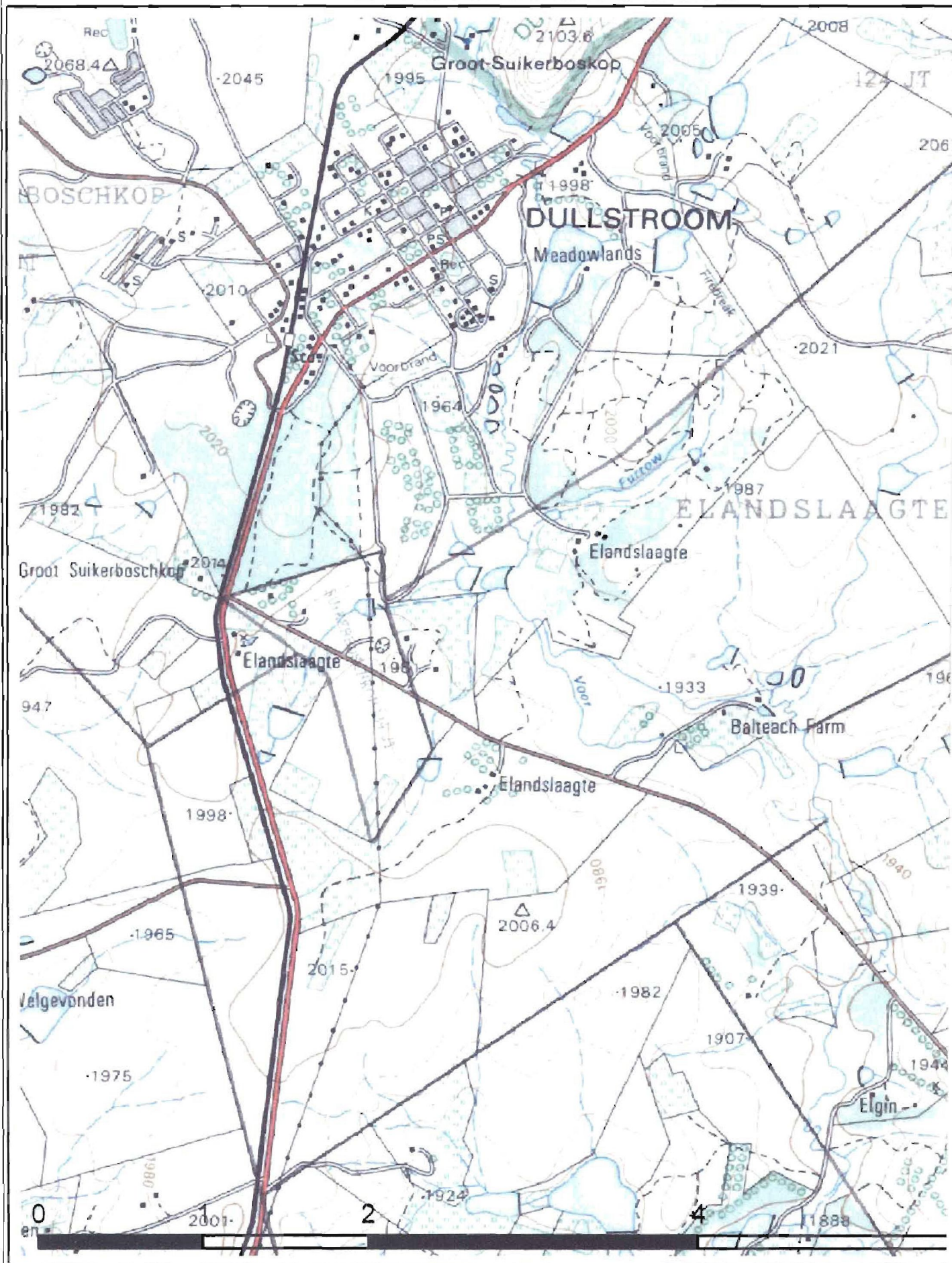
- Reduced human health and aquatic impacts
- Comply to legislative requirements
- Minimise downstream effects
- Minimise impact on groundwater
- Minimise cost
- Reduced operational and maintenance requirements
- Optimum water re-use
- Improved social acceptability
- Minimum land utilisation

5.3 Data collection and knowledge acquisition

Dullstroom lies in the summer rainfall area of South Africa and falls within rainfall zone X2A (DWAF, 1999), which exhibits a mean annual precipitation of 763 mm and a mean annual runoff of 145 mm. The Steenkampsberg Plateau forms the watershed of two major drainage systems i.e. the Olifants River and Crocodile/Nkomati River (Figure 25). The Crocodile River rises in the Steenkampsberg Mountains at an altitude of more than 2 000 m above sea level. The sources of the streams in this eco region are often within wetlands.

The topography of the farm is a combination of moderate steep and gentle slopes and valley floors, with majority of the landscape typified by the slope terrain. The site is drained towards the east by the Valleyspruit and falls within quaternary catchment X21A of the Crocodile/Nkomati River Catchment. Surface water samples were taken in the Valleyspruit up- and down gradient of the proposed development. The water quality is classified as Class 3 (upstream) and Class 4 (downstream) based on microbiological criteria. Elevated total and faecal coliform bacteria were observed in both samples.

Figure 25 : Dullstroom Polo Es



Case Study

The wetlands in the area are located at, and along the stream sources, and most serve to augment flow from the tributaries to these systems. The wetland in the study area is located on the north western boundary of the farm and is classified as a Class 4 wetland according to Marneweck *et al.* (1999). The total surface area of the wetland is 36 ha.

The area is mainly underlain by fine-grained hornfels exhibiting sedimentary structures near the top and base, containing silt and sandstone layers in places, known as the Vermont Formation of the Pretoria Group, Transvaal Supergroup. Extensive dolerite (old term: diabase) sill intrusions occur in the west and northwest, as well as in the extreme southeast.

Several less-prominent dolerite sill intrusions occur within the Vermont Formation strata, while a northwestwardly trending fault cuts through the central portion of the study area. A well defined, northeastwardly trending linear structure observed by means of satellite and aerial photographs, deemed to represent a dolerite dyke intrusion, cuts into the northern portion of this land parcel perpendicular across the contact of the diabase and the hornfels.

The area is covered by a layer of sandy elastic silt. This material becomes ferruginised from a depth of between 0.2 and 0.3 m, deemed to be indicative of the seasonal presence of a perched water table (i.e.: prolonged saturated conditions). The hillwash is underlain by a thin, but prominent, ferruginised pebble marker horizon deemed to represent the base of the transported cover, from a depth of approximately 0.4 m. This layer is composed of sandy silt containing frequent small, loose and soft ferricrete nodules, as well as occasional sub-rounded quartzite gravel. The pebble marker horizon is underlain by residual (i.e.: totally weathered) Vermont Formation hornfels, present as predominantly red-colored sandy clay. This material extends to a depth of at least 0.6 to 0.9 m.

The ferricrete becomes more prominent higher up along the slope, where harder and larger honeycomb ferricrete concretions were encountered within the transported cover. The clayey soils are deemed to be only very slightly permeable, while the overlying transported soils may be slightly permeable.

The site is characterised by Vegter (1995) as being a Minor aquifer and can be defined as:

“... fractured or potentially fractured rocks, which do not have a high primary permeability or

Case Study

other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers. They are moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer (5-20 L/s) of poor quality water.”

It should however be noted that in the case of the estate the aquifer can be classified as a Sole Source aquifer, because the surface water is not adequate to supply in the demand. All water will be supplied from groundwater.

The aquifer is defined as low to moderate yielding formation except where fractured. The borehole statistics indicate that 40 %-60 % of the drilled boreholes are successful, striking more than 1 L/s. Of these boreholes, only 20 %-30 % yielded more than 2 L/s. The water bearing fractures are principally restricted to a shallow zone below the ground water level. The maximum aquifer depth is determined at 24 m from the 1:250 000 scale harvest potential map of South Africa.

Springs in the area are abundant and are usually associated with the contact zones between the different lithologies i.e diabase and hornfels. Seven boreholes were identified on and within close proximity of Valleyspruit, three of which are in use for household water supply purposes. An additional six sites for water abstraction from fountains were also identified within the designated area.

The depth to regional groundwater system varies between 4 m and 35 m. Localised deviations occur along geological structures. The existence of perennial springs associated with dolerite sills means that the water table is perched and intersects the ground surface where the sill outcrops. The local groundwater gradient is from the southwest towards the north east. The piezometric gradient follows the topography and drains towards the Valleyspruit.

5.4 Alternative Identification

Box 5-3 provides a description of all alternatives identified during the brainstorming session with the technical team and stakeholder representatives. All options were compared with the status quo situation. Impracticable alternatives that were ruled out include:

- Connecting to the existing waste water treatment plant in Dullstroom. This option is

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impracticable because area is not serviced and the existing works is located approximately 5 km from the development. The existing works is already operating above capacity.

- Alternative source of domestic water. This alternative was ruled out, because the local catchment is already classified as stressed. Groundwater is the only domestic water source, rendering the aquifer sole source.

Box 5-3: Alternative Identification

Situation assessment - Screening	Alternative	Potential Alternative
<p>High income, low density community (new development). Water availability > 10 L/person/ per day. Regular supply.</p> <p>Community utilised groundwater as drinking supply. Current practice: guest lodge with septic tank systems and soak-aways</p> <p>Primary Sanitation: Cistem flush</p>	1. Technology change	<p>1.1 Existing waste water treatment plant</p> <p>1.2 Alternative source of domestic water</p>
	2. Improved treatment technologies	<p>2.1 Facultative waste water stabilization ponds (15 – 40 day retention time)</p> <p>2.2 Individual package plants (general standard)</p> <p>2.3 Communal package plant + ferri chloride</p> <p>2.4. Communal package plant + phoslock</p> <p>2.4 Wetland treatment system (2 to 5 day retention time)</p>
	3. Improved disinfection technologies	<p>3.1 Chlorination</p> <p>3.2 Ozone</p> <p>3.3 UV disinfection</p> <p>3.2 Chlorination or ozone treatment of drinking water.</p> <p>3.3 Combined chlorination and ozone treatment of effluent and drinking water</p>
	4. Improved disposal alternatives – effluent	<p>4.1 Discharge to surface water</p> <p>4.2 Irrigation</p>
	5. Improved disposal alternatives - sludge	<p>5.1 Land application for agriculture purposes</p> <p>5.2 Disposal by contractor</p>
	6. Status Quo	<p>6.1 Septic tank systems with soakaways</p>

5.5 Environmental Impact Assessment

5.5.1 Groundwater

The aquifer vulnerability was determined using DRASTIC parameters (Box 5-4). The aquifer classified as Medium Vulnerability with a DRASTIC Index of 103.

Box5- 4: Aquifer Vulnerability

Parameter	Weight	Rating	Total
Depth to groundwater	5	8	40
Recharge:	2	8	16
Aquifer Media:	3	3	9
Soil Media	3	4	12
Topography	1	6	6
Impact on the Vadose Zone	5	4	20
Drastic Index (Aquifer Vulnerability)	103		

The overall risk of contamination is a combination of aquifer vulnerability and expected contamination load (DWAF, 2003b). Box 5-5 provides an overall assessment of the risk based on the aquifer vulnerability and the contamination load from the sanitation system. The groundwater pollution risk classified as Medium.

Box 5-5: Groundwater Pollution Risk

		Contaminant load risk (hydraulic load) (cumulative)		
		High	Medium	Low
Aquifer Vulnerability	Extreme	Very High	High	High
	High	High	High	Medium
	Medium	High	Medium	Low
	Low	Medium	Low	Low
	Negligible	Low	Low	Low

A decision regarding the level of protection for an aquifer can therefore be based on the Aquifer Importance and Overall Risk of contamination. The two ratings are multiplied to yield a groundwater decision-support index. The index is then linked to a management action guide table which would specify the most appropriate management action required (Parsons, 1995).

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For example, the proposed site is located on a Sole Source aquifer (weight is 6); the overall groundwater risk to pollution is medium (weight 2), the groundwater quality management index (GQM) is therefore 12; which is strictly non degradation according to Table 15.

Alternatives should therefore be evaluated in terms of maximum protection (non degradation) to groundwater.

Table 15: Ratings for the aquifer management classification system (modified from Parsons, 1995)

Aquifer Classification		Overall Groundwater Risk		Groundwater Protection Level	
Class	Weight	Class	Weight	GQM Index	Level of Protection
Sole Source Aquifer	6	High	3	<1	Limited protection
Major Aquifer	4	Medium	2	1 - 3	Low level protection
Minor Aquifer	2	Low	1	3 - 6	Medium level protection
Non-Aquifer	0			6 - 10	High level protection
Special Aquifer System				> 10	Strictly non-degradation

5.5.2 Surface water

Catchment X21 is excluded from the General Authorisation, meaning that effluent to be discharged into a water resource should comply with the Special Standard for discharge volumes < 2000 m³/day. To ensure compliance with the Special Standard (phosphate concentration <1 mg/L), phosphorus removal in package plants are usually achieved by chemical precipitation, usually with salts of iron (ferric chloride) or aluminium (alum). The advantage of chemical phosphate removal above biological removal (enhanced biological phosphorus removal) is that it requires a significantly smaller equipment footprint than biological removal, is easier to operate and can be more reliable in areas that have wastewater compositions that make biological phosphorus removal difficult.

No mean monthly river flow rates were available for the Valleyspruit. Flow rates were therefore interpolated from the mean annual runoff which is almost 20 % from MAP. Figure 26 details the expected daily flow rates for the Valleyspruit (based on runoff figures).

Case Study

It was calculated that approximately 45 kg/day of ferric chloride will be required to reduce the phosphate concentrations to below 1 mg/L. The chloride concentration will increase from 2 mg/L to 138 mg/L downstream of the point of discharge. Although the impact on the aquatic life (trout) will not be significant (aquaculture can tolerate chloride concentrations up to 600 mg/L), the impact on the baseline river quality is significant.

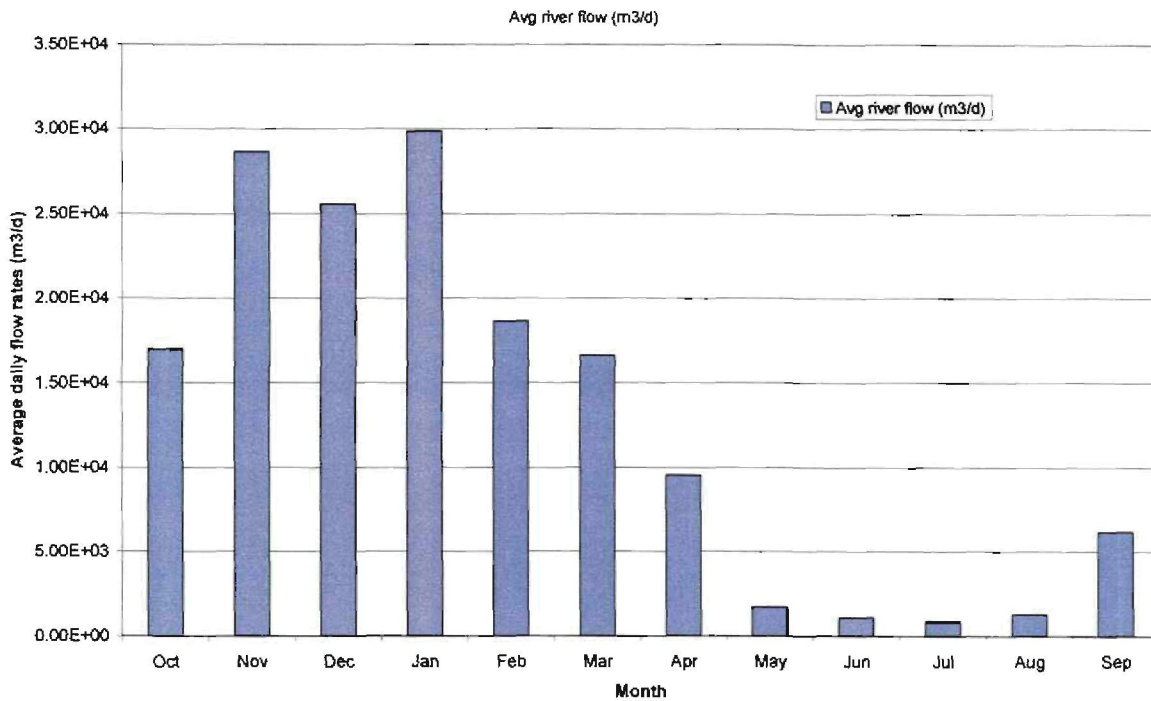


Figure 26: Average daily flow rates (m³/day)

An alternative to ferric chloride and alum for phosphate removal is Phoslock™, a patented product that is capable of removing filterable reactive phosphorus (FRP) efficiently as it descends through a water column. As it settles it forms a capping on the bottom sediment, preventing any further release of FRP into the water column. Although more environmental friendly than ferrichloride or alum, cost may be a factor in evaluating the product (R3.48/m³ versus R1.21/m³ for ferrichloride). Constructed wetlands provide a high degree of aerobic biological improvement and can also be used in stead of secondary treatment. It is however not anticipated that the effluent will comply with the Special Standard required by DWAF for phosphate concentrations. The purpose of disinfection in the treatment of waste water is to reduce the number of living

organisms in the water to be discharged back into the environment. Alternative methods for disinfection include ozone, chlorine or UV light. Chlorination remains the most common form of wastewater disinfection due to its low cost and long term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated organic compounds that may be carcinogenic or harmful to the environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment. Ultraviolet light is becoming the most common means of disinfection in the United Kingdom because of the concerns about the impacts of chlorine in chlorinated residual organics in the waste water and receiving environment. UV radiation is used to damage the genetic structure of bacteria, viruses and pathogens, making them incapable of reproducing.

Ozone (O_3) is generated by passing oxygen O_2 , through a high voltage potential resulting in a third oxygen atom becoming attached and forming O_3 . Ozone is very unstable and reactive and oxidises most organic material it comes in contact with, thereby destroying many disease causing microorganisms. Ozone is considered to be safer than chlorine, because unlike chlorine which has to be stored on site (highly poisonous in the event of an accidental release), ozone is generated on site as needed. A disadvantage of ozone is the high cost of the ozone generation equipment and the requirements for highly skilled operators.

5.5.3 Irrigation

The area that would be required for irrigation depends on a number of factors like the water use of specific crops, soils types etc. In a basic assessment, conservative (average) parameters are used e.g. 1100 mm/year ($1.1 \text{ m}^3/\text{m}^2/\text{year}$) water use. The irrigated area net water use (Q_{net}) is the difference between the mean annual precipitation (MAP) and the mean annual evapotranspiration. The area required for irrigation (A_{irr}) is determined from:

$$A_{irr} = \frac{Q_{dis}}{Q_{net}}$$

Where Q_{dis} is the volume that will be discharged per year.

Therefore,

$$A_{irr} = 4.3 \text{ ha}$$

For crop rotation purposes, double this area and thus approximately 9 ha will be required for irrigation of purified sewage effluent. Permissible utilisation of treated effluent for irrigation (General Standard) includes the following (Department of National Health and Population Development, 1978):

- Fruit trees and vineyards
- Grazing for cattle, including milk producing animals
- Crops not for grazing, but utilised as dry fodder
- Crops cultivated for seed purposes
- Nurseries
- Parks and sport fields.

5.6 Optimisation

The decision criteria and feasible alternatives are detailed in Figure 27. The technical reference group assessed the performance of each alternative against the decision criteria using the Facilitator Software (<http://sourceforge.net/projects/facilitator>). Their judgements were supported by the impact assessment performed in the previous section. Each of the experts provided a score within the range of 0 to 5 to quantify the performance of the alternatives against the criteria. Through discussions with stakeholders and technical specialists, an importance order was developed for the decision criteria (Figure 27). Health impact, groundwater impact and land requirements were ranked with more importance than water re-use and construction costs.

Facilitator: Cost Study.vxl

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MAPPER

	Land Requirem	Groundwater Im	Health impact	nutrient reduction	Aquatic Impact	Operation and m	Construction cost	Water re-use
Facultative Pond • Discharge	4.0	3.5	3.5	3.0	3.0	2.0	3.0	2.0
Facultative Pond • Irrigation	5.0	4.0	4.0	3.5	1.0	3.0	3.0	4.0
Package Plant (General Standard) • Discharge	3.0	2.5	3.0	2.5	3.0	3.5	4.0	2.0
Package Plant (general standard) • Irrigation	3.5	3.0	3.5	3.0	1.0	4.0	4.5	4.0
Package Plant (special standard) • ferri chloride • discharge	2.0	1.5	3.0	4.5	5.0	4.5	5.0	2.0
package Plant (special standard) • phoslock • discharge	2.0	1.0	1.0	5.0	1.0	3.5	5.0	2.0
Septic tank • soakaway	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0
Wetland • discharge	3.0	2.5	3.5	3.5	3.0	2.0	2.0	1.0

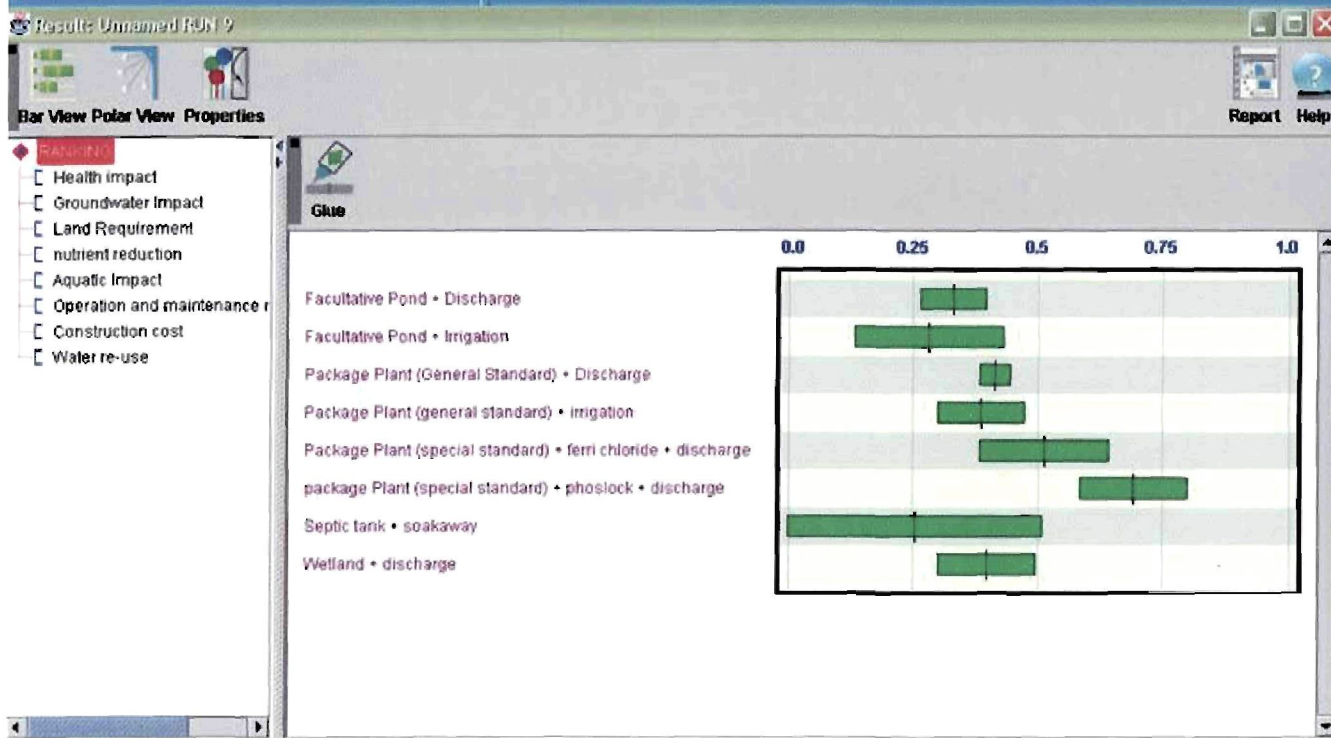


Figure 27: Facilitator analysis

Case Study

The reason for this was the following:

- The outcome of the risk assessment in section 5.5 indicated that the level of groundwater protection should be strictly non degradation.
- The land requirements was given a high rating due to the high value of the land i.e stands are being sold at approximately R800 000 for half a hectare. The developable land is also restricted due to topography.

The outcome of the scenario is shown in Figure 27. The minimum (most pessimistic) composite score is shown by the left hand edge of the horizontal bar (septic tanks with soakaways), while the maximum (most optimistic) composite score is shown by the right hand edge (package plant special standard, phoslock and discharge). Within the horizontal bar for each option represent all weighted composite scores consistent with the chosen importance order for the decision criteria. The centre line indicates the average of the minimum and maximum scores and can be used as the means for prioritising ranking the options.

It was assumed that effluent from all alternative systems proposed, is disinfected by UV light prior to disposal. Sludge management was not addressed in this evaluation, it was assumed that sludge will be collected by an accredited contractor.

The results from the MODDS analysis suggests that all alternatives are preferred (dominate) to the existing practice (septic tanks and soakaways). Of the options considered, the two management options that dominated over the others for all groups and their respective importance orders are Alternative 6 (package plant, phoslock and discharge to the Valleyspruit) and Alternative 5 (package plant ferric chloride and discharge to the Valleyspruit). While there were some vector weightings in which Alternative 5 and 6 compared, Alternative 5 performed worse on the criteria of impacts on the surface water system due to the adverse effects of the addition of ferric chloride. The addition of ferric chloride increased the concentration of chloride in the Valleyspruit from 2 mg/L to 138 mg/L.

Irrigation practices (Alternatives 2 and 4) from both the facultative pond and package plant performed worse than the discharge alternatives and is mainly due to land required for irrigation.

5.7 Implementation: monitoring, operation and maintenance

It is recommended that the spatial distribution of the monitoring points be selected to:

- Monitor the treated sewage effluent to be discharged.
- Monitor groundwater quality up- and down gradient from the maturation pond.
- Monitor surface quality up- and downstream from the irrigation site (if applicable).
- The quantity of treated effluent must be metered regularly and the quality monitored monthly by grab sampling at the point at which the wastewater enters the system and analysed for (pH, TDS, TSS, COD, NH₄-N, TKN, PO₄ and Cl) and microbial parameters (Total coliform and faecal coliform organisms).
- Surface water quality up- and downstream of the discharge point should be monitored quarterly for the macro parameters (pH, TSS, TDS, COD, NH₄-N, TKN, PO₄ and Cl) and microbial constituents (Total coliform and faecal coliform organisms).
- Water level measurements of monitoring boreholes should be taken on a quarterly basis and recorded.
- Impact reports with trend analysis should be compiled annually by a qualified person.
- If and when contamination is detected in the monitoring wells, a rehabilitation plan must be compiled and executed.

An operational, maintenance and emergency plan should be compiled for any system failures that may occur including at least:

- Down stream users should be notified of any system failures and non-compliance with the Special Standard.
- Daily records should be kept of significant events in the works. Significant events include peculiar colour of water, failure of equipment, strange smell, recording the date and time at which this occurred.
- Pipes should be inspected on a regular basis and any leaks reported immediately.
- An emergency plan should be compiled for dealing with leaking pipes.
- An emergency plan should be compiled for dealing with out of order pump station.

CHAPTER 6

6 CONCLUSIONS AND RECOMMENDATIONS

The most significant impacts with regard to poor sanitation are ground- and surface water pollution, which in turn affects human and aquatic health negatively.

The global impact of waterborne disease is reflected by data such as those released by the World Health Organisation (WHO) according to which every year there are 1.7 million deaths related to unsafe water, sanitation and hygiene, mainly through infectious diarrhoea. The vast majority of these deaths are among children under five years of age (Prüss and Havelaar, 2001). An estimated 4 billion of cases account for over 82 million Disability Adjusted Life Years (DALY's), representing 5.7% of the global burden of disease and placing diarrhoeal diseases as the third highest cause of morbidity and sixth highest cause of mortality (Prüss and Havelaar, 2001). In South Africa, diarrhoeal diseases rank as the fifth most important cause of mortality in the entire population, after HIV/AIDS, homicide/violence, tuberculosis and road traffic accidents (Editorial, 2003). Diarrhoeal diseases account for 10.2% (10 786) deaths in the under 5-age group (Bradshaw *et al.*, 2002; Bradshaw *et al.*, 2003).

Groundwater plays an important role in water supply to rural communities. This statement is supported by the survey conducted at clinics within the Limpopo Province where the majority of aquifers in the area can be classified as Sole Source aquifers, supplying 50 % or more of domestic water in the absence of any reasonable alternative. The water quality study also concluded that the impact from on site sanitation on the groundwater system is significant given that 44 % of water samples of clinics with their own water supply classified as either poor or dangerous quality according to DWAF criteria and poses a significant health risk to susceptible individuals. It is therefore of great concern that the protection of groundwater is not a priority to warrant the implementation of BPEO at facilities, especially with high loads such as clinics and schools. Sufficient attention is not always given to factors such as environmental impact, social issues, water supply, reliability or institutional capacity. The result has often been a legacy of poorly planned and inadequately maintained systems.

From the literature survey it can be concluded that sustainability with regard to sanitation relies

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mainly on four interrelated factors: (a) a legal and institutional framework (b) technical factors, (c) environmental factors and (d) community factors. The technical factors which are likely to influence sustainability are: technology selection; complexity of technology; its capacity to respond to a demand and a desired service level; its impact on the environment; the technical skills needed to operate and maintain a system; the availability, accessibility and cost involved (WHO, 2000).

The community factors which are likely to influence sustainability are: availability of technical skills to operate and maintain a service; capacity and willingness to pay, participation of all social groups in the community; the need felt for an improved service; socio-cultural aspects related to water; and behaviour regarding health and sanitation. Ownership and responsibility are key prerequisites for sustainable operation and maintenance. The environmental factors, which are likely to influence sustainability, are: the quality of the water source; its quantity and continuity. All of these should fit within a legal framework. Although the NWA and NEMA give effect to principles such as “best practical environmental option”, “precautionary approach”, and “duty of care” they are not taken in consideration when it comes to sanitation selection and implementation. The installation of sanitation systems in South Africa is mainly influenced and driven by economical factors rather than environmental, social or health considerations. The most cost-effective sanitation systems are being installed in rural areas without considerations for the principles specified in the NEMA, NWA and Groundwater Policy. There is also no consideration of secondary costs resulting from poor or inadequate sanitation technology.

In South Africa the most commonly used sanitation technologies are waterborne sewerage at one end of the scale and pit toilets at the other. There are some intermediate technologies, such as septic tanks, but it is a fact that everybody aspires to the top-of the range article despite implications such as high water usage, high operation and maintenance costs, and the advanced technology and institutional capacity required for removal, treatment and disposal of the excreta.

Ventilated improved pit (VIP) toilets have unfortunately also acquired the stigma of being a poor man’s solution to the sanitation problem.

Operation and maintenance (O & M) are the two words that appeared in the answers of many sector professionals and community workers when they were asked about what could be done to

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improve the performance, efficiency and sustainability of the rural water supply and sanitation services in developing countries. It is well known that O&M has been neglected in the past, or been discussed and introduced only after a project was completed. This neglect or delay in applying proper operation and maintenance has adversely affected the credibility of the investments made, the functioning of the services, the well-being of rural populations, and the development of further projects (Joy *et al.*, 2003). Operation and maintenance in South Africa can still be described as crises maintenance and can be defined as maintenance that is undertaken only in response to breakdowns and/public complaints, leading to poor service level, high O&M costs, faster wear and tear of equipment, and users dissatisfaction. This is also illustrated by the survey conducted at clinics within the Limpopo Province. The objective will be to move towards preventative maintenance which can be defined as maintenance activities undertaken in response to pre-scheduled systematic inspection, repair and replacement, leading to continuity in service level, O&M costs spread over time, user satisfaction and willingness to pay. Linking technology choice with operational and maintenance is a key factor for sustainability.

The literature is virtually unanimous in stating that the final choice of sanitation technology should lie with the people who will use it and who will be responsible for operating and maintaining it. Many sanitation projects adopted interventions and technologies that were selected with poor assessment of the demand for sanitation. Choices are usually made on the basis of the appearance and affordability of the superstructure, rather than the merits of the underlying sanitation technology. The decision support framework developed in this study had therefore a strong stakeholder component, involving stakeholders in the decision making process from the conception of the project through to the resolution of actions. Providing objective information about the performance of options, coupled with an opportunity to participate in the decision-making process, increases the awareness and commitment of the community.

The decision support framework and impact methodology developed in this thesis is appropriate to integrate social, economic and environmental issues with regard to decision making. Although the optimisation software is generic, interactive and designed to accommodate involvement of stakeholders, the approach depends on a human element to deliver the process. Skills in group facilitation are a fundamental requirement. The process also has a strong dependence on expert

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opinion. Field testing of the decision support framework produced good results and sensible recommendations were made with regard to alternative selection.

Recommendations for future research include:

- Sanitation technology improvements especially for low income communities.
- The establishment of a regional monitoring network to monitor the effect of improvements in sanitation technology on groundwater quality.
- The relationship between polluted groundwater and diseases observed within the rural communities.



REFERENCES

7 REFERENCES

ABBASZADEGEN, M., STEWART, P., AND LECHEVELLIER, M. 1999. A strategy for detection of viruses in groundwater by PCR. *Applied and Environmental Microbiology*, 65: 444 – 449.

ACTS see SOUTH AFRICA

ADAMS, B., AND FOSTER, S.S.D. 1992. Land surface zoning for groundwater protection. *Journal of the Institution of Water and Environmental Management*, 6: 312 – 319.

AL-ADAMAT, R.A.N., FOSTER, I.D.L., AND BABAN M.J. 2003. Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azrac basin of Jordan using GIS, Remote sensing and DRASTIC. *Applied Geography*, 23: 304 – 324.

ALLER, L., BENNET, T., LEHR, L.H., AND PETTY, R.J. 1985. DRASTIC – a standardized system for evaluating groundwater pollution potential using hydrogeologic settings: US Environmental Protection Agency, Office of research and development, EPA/600/2-85/018, 163 p.

AUSTIN, L.M., AND VAN VUUREN, S.J. 2001. Sanitation, public health and the environment: looking beyond current technologies. *Journal of the South African Institution of Civil Engineering*, 43(1).

AUSTIN, L.M., DUNCKER, L.C., MATSEBE, G.N., PHASHA, M.C., AND CLOETE, T.E. 2005. Ecological Sanitation – Literature Review. WRC Report No TT 246/05.

BARWICK, R.S., LEVY, D.A., CRAUN, G.F., BEACH, M.J., AND CALDERON, R.L. 2000. Surveillance for waterborne disease outbreaks – United States, 1997 – 1998. *Morbidity and Mortality Weekly Report*, 49: 1 – 21.

References

- BEAR, J. 1979. *Hydraulics of Groundwater*. New York: McGraw-Hill Inc.
- BELLER, M., ELLIS, A., LEE, S.H., DREBOT, M.A., JENKERSON, S.A., FUNK, E., SOBSEY, M.D., and SIMMONS, O.D. 1997. Outbreak of viral gastroenteritis due to a contaminated well: international consequences. *Journal of the American Medical Association*, 278: 563 – 568.
- BILITY, K.M., AND ONYA, H. 2000. Water use, sanitation practices, perceptions and hygiene education in primary school children in the Northern Province and Western Cape, South Africa. WRC Report no 960/1/00.
- BLOCH, A.B., STRAMER, S.L., SMITH, J.D., MARGOLIS, H.S., FIELDS, H.A., MCKINLEY, T.W., GERBA, C.P., MAYNHARD, J.E., AND SIKES, R.K. 1990. Recovery of hepatitis A virus from a water supply responsible for a common source outbreak of hepatitis A. *American Journal of Public Health*, 80: 428 – 430.
- BOTHA, F.S. 1999. *Groundwater resource development in hard crystalline rock aquifers on the Nebo Plateau, South Africa*. Pretoria: University of Pretoria (MSc Thesis).
- BOTHA, J.F. 1993. *The Physics of Subsurface Flow and Contaminant Transport*. Lecture notes: Institute for Groundwater Studies. South Africa: University of the Free State. Bloemfontein (Unpublished).
- BOWEN, G.S., AND MCCARTHY, M.A. 1983. Hepatitis A associated with a hardware store water fountain and a contaminated well in Lancaster County, Pennsylvania, 1980. *American Journal of Epidemiology*, 117: 695 – 705.
- BRADSHAW, D., SCHNEIDER, M., LAUBSCHER, R., AND NOJILANA, B. 2002. Cause of death profile, South Africa 1996. Burden of Disease Research Unit Report May 2002. South African Medical Research Council. Available from www.mrc.ac.za/bod/profile.pdf. Date of access 12 June 2004.
- BRADSHAW, D., BOURNE, D., AND NANNAN, N. 2003. What are the leading causes of

References

death among South African children. MRC Policy Brief No 3, December 2003. Available from www.mrc.ac.za/bod/bod.htm. Date of access 12 June 2004.

BRESLIN, N., NETSHISWINZHE, B., AND HOLDEN, R. 1998. 'Lessons from the Field: PHAST - South Africa'. Mvula Trust report, May 1998. (Unpublished).

BRUNDTLAND, G.H. (Ed.). 1987. Our common future: The World Commission on Environment and Development. Oxford: Oxford University Press.

BRUNNER, N., AND STARKL, M. 2004. Decision aid systems for evaluating sustainability: a critical survey. *Environmental Impact Assessment Review*, 24: 441 – 469.

CDC (Centre for Disease Control). 1996. Memorandum of EPI-AID Trip report: Epidemic Dysentery in South Africa. No 96 – 26. Food and Diarrhoeal Disease Branch. Available from <http://www.cdc.gov>. Date of access 17 July 2004.

CDC (Centre for Disease Control). 2003 –Fact Sheet: Healthy Water. Nitrate and drinking water from private wells. Available from <http://www.cdc.gov/ncidod/dpd/healthywater/factsheets/pdf/nitrate.pdf>. Date of access 17 July 2004.

CLEARY, T.C.B.F. AND CLEARY, R.W. 1991. Delineation of wellhead protection areas: theory and practice. *Water Science and Technology*, 24: 239 – 250.

COMMITTEE REPORT. 1999. Committee Report: Emerging pathogens – bacteria. *Journal of the American Water Works Association*, 91: 101 – 109.

DAHLING, D.R., SAFFERMA, R.S., AND WRIGHT, B.A. 1989. Isolation of enterovirus and reovirus from sewerage and treated effluents in selected Puerto Rican communities. *Applied Environmental Microbiology*, 55: 503 – 506.

DEELSTRA Y., NOOTEBOOM SG., KOHLMAN HR., VAN DEN BERG J., INNANEN S. 2003. Using knowledge for decision making purposes in the context of large projects in the

References

Netherlands. *Environmental Impact Assessment Review*, 23: 517 – 541.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT. 1978. Guide: Permissible utilisation and disposal of treated sewage effluent. Available from <http://www.dwaf.gov.za/dirwqm/docs/PolPermisUtilisation.doc>. Date of access 3 November 2004.

DE SERRES, G., CROMEANS, TL., LEVESQUE, B., BRASSARD, N., BARTHE, C., DIONNE, M., PRUD'HOMME, H., PARADIS, D, SHAPIRO, CN., NAINAN, OV., AND MARGOLIS, HS. 1999. Molecular confirmation of hepatitis A from well water: epidemiology and public health implications. *Journal of Infectious Diseases*, 179: 37 – 43.

DUDLEY, E. 1996. Technological options for dry latrines. Dry sanitation: an eco-sustainable alternative. Workshop, San Salvador, El Salvador.

DU PREEZ, M., AND GERICKE, M. 1999. Occurrence and survival of protozoan parasites in source water used by unserved rural communities. WRC Report no 685/1/99.

DUNSTAN AND ASSOCIATES. 1998. Evaluation of On-site sanitation for a socio-economic perspective. WRC Report No KV 114/98.

DWAF (Department of Water Affairs and Forestry). 1984. General and Special Standards. Requirements for the purification of waste water or effluent. Government Gazette No. 9225, 18 May.

DWAF (Department of Water Affairs and Forestry). 1996. South African Water Quality Guidelines. 2nd ed. Volume 1: Domestic Use. Pretoria.

DWAF (Department of Water Affairs and Forestry). 1998. Quality of Domestic Water Supplies. 2nd ed. Volume 1: Assessment Guide. WRC Report No TT101/98.

DWAF (Department of Water Affairs and Forestry). 2000. Policy and strategy for groundwater quality management in South Africa. 1st ed. Report No W.1.0. Pretoria.

References

DWAF (Department of Water Affairs and Forestry). 2001. White Paper on Basic Household Sanitation. September 2001. Pretoria.

DWAF (Department of Water Affairs and Forestry). 2002. Water Quality Management Series, Sub Series No. MS7. National Water Quality Management Framework Policy, Draft 2. Pretoria.

DWAF (Department of Water Affairs and Forestry). 2003a. Water for all for life [Brochure]. Pretoria.

DWAF (Department of Water Affairs and Forestry). 2003b. A protocol to manage the potential of groundwater contamination from on site sanitation. 2nd Ed. March 2003. Pretoria.

DWAF (Department of Water Affairs and Forestry). 2004. National Water Act News. February 2004. Focus on groundwater. [Brochure]. Pretoria.

EDITORIAL. 2003. Top 20 specific causes of premature mortality burden (YLLs) by sex, South Africa, 2000. *AIDS Bulletin*, 12: 13 – 20.

EDZWALD, J.K., AND KELLEY, M.B. 1998. Control of *Cryptosporidium*: From reservoirs to clarifiers to filters. *Water Science and Technology*, 37(2): 1 - 8.

ERVERS, S., AND LERNER DN. 1998. How uncertain is our estimates of a wellhead protection zone. *Groundwater*, 36: 49 – 57.

EZZATI, M., LOPEZ, A.D., ROGERS, A., VAN DER HORN, S., AND MURRAY, C.J.L. 2002. Comparative risk assessment collaborating group. Selected major risk factors and global and regional burden of disease. *Lancet*, 360: 1347 – 1360.

FEACHEM, R., BRADLEY, D., GARELICK, H., AND MARA, D.D. 1983. Sanitation and disease: health aspects of excreta and wastewater management. Chichester: John Wiley & Sons. Available from <http://www.leeds.ac.uk/civil/ceri/water/tphe/publicat/watsan/sandis.html>. Date

References

of access 10 June 2005.

FOURIE, A.B., AND VAN RYNEVELD, M.B. 1994. Environmental impact of on-site sanitation: A literature review with particular application to South Africa. WRC Report No KV57/94.

FREEZE, R.A., AND CHERRY, J.A. 1979. Groundwater. New Jersey: Prentice-Hall Inc.

FULLER, K. 2002. IA for sustainable development report: IAIA output report WS07. Proceedings of the 22nd annual conference of the International Association for Impact Assessment.

GEORGE, C. 2001. Sustainability appraisal for sustainable development: integrating everything from jobs to climate change. *Impact Assessment Project Appraisal*, 19 (1): 95 – 106.

GERBA, C.P., ROSE, J.B., HAAS, C.N., AND CRABTREE, K.D. 1996. Waterborne rotavirus: a risk assessment. *Water Research*, 12: 1929 – 2940.

GIBSON, R. 2001. Specification of sustainability-based environmental assessment decision criteria and implications for determining “significance” in environmental assessment. Available from <http://www.sustreport.org/downloads/sustainabilityEA.doc>. Date of access 10 June 2005.

GLAZEWSKI, J. 2000. Environmental Law in South Africa. South Africa, Butterworth Publishers (Pty) Ltd.

GOSS, M.J.; BARRY, D.A.J., AND RUDOLPH, D.L. 1998. Contamination in Ontario farmstead domestic wells and its association with agriculture: Results from drinking water wells. *Journal of Contaminant Hydrology*, 32: 267 – 293.

GOSSELIN, D.C., HEADRICH, J., TEMBLAY, R., CHEN, X., AND SUMMERSIDE, S. 1997. Domestic water well quality in rural Nebraska: focus on nitrate nitrogen, pesticide and coliform bacteria. *Groundwater Monitoring and Remediation*, 17: 77 – 87.

GRABOW, W.O.K. 1996. Waterborne disease: update on water quality assessment and control.

References

Water SA, 22: 193 – 202.

GRABOW W.O.K. 2004. Assessment of the risk of infection associated with viruses in South African Drinking Water Supplies. WRC Report no K5/1164.

HÄFLINGER, D., HÜBNER, P., AND LÜTHY, J. 2000. Outbreak of viral gastroenteritis due to sewerage contaminated drinking water. *International Journal of Food Microbiology*, 54: 123 – 126.

HANCOCK, C.M., ROSE, L.B., AND CALLAHAN, M. 1998. Crypto and Giardia in US groundwater. *Journal of the American Water Works Association*, 90: 58 – 61.

HAUPT, C.J. 1995. Explanation Sheet of the 1: 500 000 Hydrogeological Map 2326 Pietersburg. WRC Report, TT 75/95.

HARDIN, G. 1968. The tragedy of the commons. *Science*, 191: 1301 – 11310.

HARGROVES, K. AND SMITH, M. (eds.). 2005. *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*. Earthscan/James&James. Available from www.thenaturaladvantage.info. Date of access: 4 July 2006.

HAVELAAR, A.H. 1994. Application of HACCP to drinking water. *Food Control*, 5: 145 – 152.

HOWARD, J., QUINN, N., EALES, K., AND VOLLER, R. 2000. The development of an on-site sanitation planning and reporting aid (SSPRA) for the selection of appropriate sanitation technologies for developing communities. WRC Report no 586/2/00.

HUTTON, G., AND HALLER, L. 2004. *Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level*. World Health Organization. Geneva.

IRC. 1988. *Community self improvement in water supply and sanitation*. Training series no 5.

References

The Hague: IRC International Water and Sanitation Centre.

JACKSON, B.M. 1998. Are we exaggerating the dangers of groundwater pollution from on-site sanitation systems such as pit latrines? *Borehole Water Journal*, 40: 18 – 21.

JIWAN, H., AND GATES, J. 1998. Microbiological contamination of groundwater in New South Wales, Australia. (In Weaver TR, Lawrence CR, eds. *Groundwater: Sustainable Solutions. Proceedings of the International Association of Hydrogeologists International Groundwater Conference held in Melbourne, Australia on Feb 8 – 13*).

JOY, D., KINSLEY, C., SCHAEFER, K., PILEGGI, V., SKOG, S. AND KOK, S. 2003. Wastewater treatment for small communities. CCME Linking Water Science to Policy Workshop Series. Report No 2. Canadian Council of Ministries of the Environment, Winnipeg, Manitoba.

KRIKELIS, V., SPYROU, N., MARKOULATOS, P., AND SERIE, C. 1985. Seasonal distribution of enteroviruses and adenoviruses in domestic sewerage. *Canadian Journal of Microbiology*, 31: 24 – 25.

LAWRENCE, P., AND SHAW, R. 1999. A framework for evaluating options for improved irrigation management. (In proceedings MODSS'99, 2nd International Conference on Multiple Objective Decision Support Systems for Land, Water and Environmental management, held in Brisbane on 1-6 July, 1999). Available from <http://www.coastal.crc.org.au/modss/papers.html>. Date of access: 2 July 2006.

LAWRENCE, O., SHAW, R., LANE, L., AND EISNER, R. 2000. Participatory multiple objective decision making process: Emerging approaches with new challenges. Paper presented at the American Society for Civil Engineering (ASCE), Watershed Management 2000 Symposium held in Ft Collins Colorado USA on 20 – 24 June 2000. Available from <http://www.coastal.crc.org.au/modss/papers.html>. Date of access: 2 July 2006.

LEVINE, M.M., AND LEVINE, O.S. 1994. Changes in human ecology and behaviour in relation to the emergence of diarrhoeal diseases, including cholera. *Proceedings of the National Academy of Sciences of the United States of America*, 91: 2390 – 2394.

References

LOETSCHER, T., AND KELLER J. 2002. A decision support system for selecting sanitation systems in developing countries. *Socio-economic Planning Sciences*, 36:267 – 290.

LYNCH, S.D., REYNDERS, A.G., AND SCHULZE, R.E. 1994. Preparing input data for a national scale groundwater vulnerability map of South Africa. *Water SA*, 20: 239 – 246.

MACLER, B.A., AND MERKLE, J.C. 2000. Current knowledge on groundwater microbial pathogens and their control. *Hydrogeology Journal*, 8: 29 – 40.

MACLER, B.A. 1995. Developing a national drinking water regulation for disinfection of groundwater. *Groundwater Monitoring Review*, 15: 77 – 84.

MAHONEY, M., AND POTTER, J. 2004. Integrating health impact assessment into the triple bottom line concept. *Environmental Impact Assessment Review*, 24: 151 – 160.

MALCZEWSKI, M. 2004. GIS-based land use sustainability analysis: a critical overview. *Progress in Planning*, 62: 3 – 65.

MARA, D.D. 2003. Domestic waste water treatment in developing countries. London: Eartscan.

MARNEWECK, G.C., GRUNDLING, P.L. & GRUNDLING, A.T. 1999. Environmental plan for the protection, maintenance and wise-use of wetlands on the Steenkampsberg Plateau. Report for use in conjunction with the associated map of the Steenkampsberg Plateau Part 1 and 2. Wetland Consulting Services. Pretoria. (Unpublished).

MORRIS, K. 2004. Silent emergency of poor water and sanitation. *The Lancet*, 363: 954.

MURPHY, K.O.H. 2000. Land-Based Effluent Disposal and Use: Development of Guidelines and Expert-Systems-Based Decision Support. WRC Report No TT 125/00.

NEVONDO, T.S. AND CLOETE, T.E. 1999. Bacterial and chemical quality of water supply in the Dertig Village Settlement. *Water SA*, 25: 215 – 219.

References

NEWBY, D.T., PEPPER, I.L., MAIER, R.M. 2000. Microbial transport. *In: Environmental Microbiology*. London: Academic Press.

NRC (National Research Council). 1999. Setting priorities for drinking water contaminants. Committee on drinking water contaminants. Washington DC: National Academy Press.

PALERM, J.R. 1999a. Public participation in EIA in Hungary: Analysis through three case studies. *Environmental Impact Assessment Review*, 19: 201 – 220.

PALERM, J.R. 1999b. Public participation in environmental impact assessment in Spain: three case studies evaluation national, Catalan and Balearic legislation. *Impact Assessment and Project Appraisal*, 17: 259 – 271.

PALMER DEVELOPMENT GROUP. 1995. Review of rural sanitation in South Africa – Executive summary and main report. WRC Report no KV 71/95.

PARSONS, R. 1995. A South African Aquifer System Management Classification. WRC Report No. KV 77/95

PEARSON, L.A., BHAGWAN, J., KARIUKI, W., AND BANDA, W. 2001. Guidelines on appropriate technologies for water supply and sanitation in developing communities. WRC Report No 520/1/01.

PEGRAM, G.C, ROLLINS, N., AND ESPEY, Q. 1998. Estimating the costs of diarrhoea and epidemic dysentery in KwaZulu-Natal and South Africa. *Water SA*, 24: 11 – 20.

PIEPER, A.P., RYAN, J.N., HARVEY, R.W., AMY, G.L., ILLANGASEKARE, T.H., AND METGE, D.W. 1997. Transport and recovery of bacteriophage PRD 1 in a sand and gravel aquifer: effect of sewage-derived organic matter. *Environmental Science and Technology*, 31: 1163 – 1170.

References

PISCOPO, G. 2001. Groundwater vulnerability map, explanatory notes, Castlereagh Catchment, NSW. Department of land and water conservation, Australia. Found at <http://www.dlwc.nsw.gov.au/care/water/groundwater/reports/pdfs/castlereaghmapnotes.pdf>. Date of access: 2 February 2006.

POCH, M., COMAS, J., RODRÍGUEZ-RODA, I., SÀNCHEZ, M., AND CORTÉS, U. 2004. Designing and building real environmental decision support systems. *Environmental Modelling and Software*, 19: 857 – 873.

POPE, J., ANNANDALE, D., AND MORRIS SAUNDERS, A. 2004. Conceptualizing sustainability assessment. *Environmental Impact Assessment Review*, 24: 595 – 616.

POST, R., KOLHOFF, A., AND VELTHUYSE, B. 1997. Towards integration of assessment with reference to integrated water in third world counties. *Impact Assessment and Project Appraisal*, 16: 50.

POWELL, K.P., TAYLOR, R.G., CRONIN, A.A., BARRETT, M.H., PEDLEY, S., SELLWOOD, J., TROWSDALE, S.A., AND LERNER, D.N. 2003. Microbial contamination of two urban sandstone aquifers in the UK. *Water Research*, 37: 339 – 352.

PRÜSS, A., AND HAVELAAR, A. 2001. The global burden of disease study and applications in water, sanitation and hygiene. (In: Fewtrell, L., and Bartram, J., eds. *Water Quality: Guidelines, Standards and health*. World Health Organisation Water Series.) , London: IWA Publishing.

REHMANN, L.L., WELTY, C., AND HARVEY, R.W. 1999. Stochastic analysis of virus transport in aquifers. *Water Research*, 35: 1987 – 2006.

ROB, C. LOË, D.E., AND KREUTZWISER, R.D. 2005. Closing the groundwater protection implementation gap. *Geoforum*, 36: 241 – 256.

ROBERTSON, J.B., AND EDBERG, S.C. 1997. Natural protection of spring and well drinking water against surface microbial contamination. *Critical Reviews in Microbiology*, 23: 143 – 178.

References

ROTA, L. 2004. SA could move from a water-stressed to a water-scarce category. *Engineering News*, 24(12): 28 – 29.

RUSIN, P., ENTRIQUEZ, C.E., JOHNSON, D., AND GERBA, C.P. 2000. Environmentally transmitted pathogens. *In: Environmental Microbiology*, London: Academic Press.

SAMPSON, I. 2001. Introduction to a legal framework to pollution management in South Africa. WRC Report no TT 149/01.

SANS (South Africa National Standard). 2005. SANS 241. Standards South Africa. Pretoria.

SARA, J., GARN, M. AND KATZ, T. 1998. Some key messages about demand responsive approach on efficient water use in urban areas: innovative ways of finding water for cities. *Proceedings of the International Symposium*. Washington.

SCRASE, I., AND SHEATE, W. 2003. Integration and integrated approaches to assessment: what do they mean for the environment? *Journal of Environmental Policy and Planning*, 4: 275 – 294.

SPITZ, K., AND MORENO, J. 1996. A practical guide to groundwater and solute transport modelling. New York: John Wiley & Sons Inc.

STEWART SCOTT. 1998. An evaluation of the Enviro Loo Composting Latrine in an informal settlement area in Greater Johannesburg. WRC Report no KV 112/98.

SOUTH AFRICA. 1996. Constitution of the Republic of South Africa as adopted by the Constitutional Assembly on 8 May 1996 and as amended on 11 October 1996. (B34B-96) (ISBN: 0-260-20716-7).

SOUTH AFRICA. 1997. Water Services Act, 1997. Government Gazette Vol 390, No 18522. Cape Town. 19 December 1997.

References

SOUTH AFRICA. 1998. Local Government Demarcation Act, 1998. Government Gazette vol 397, No 19020. Cape Town. 3 July 1998.

SOUTH AFRICA. 1998. National Environmental Management Act, 1998. Government Gazette Vol 401, No 19519. Cape Town. 27 November 1998.

SOUTH AFRICA. 1998. National Water Act, 1998. Government Gazette Vol 398, No 19182. Cape Town. 26 August 1998.

SOUTH AFRICA. 2000. Local Government: Municipal Structures Amendment Act, 2000. Government Gazette Vol 444, No 23543. Cape Town. 20 June 2002.

SOUTH AFRICA. 2003. National Health Act, 2003. Government Gazette Vol 469, No 26595. Cape Town. 23 July 2004.

SWARTZ, C.D., AND RALO, T. 2004. Guidelines for planning and design of small water treatment plants for rural communities, with specific emphasis on sustainability and community involvement and participation. WRC Report No 1185/1/04.

SUN, N., ELIMELECH, M., SUN, N., AND RYAN, J.N. 2001. A novel two dimensional model for colloid transport in physically and geomechanically heterogenous porous media. *Journal of Contaminant Hydrology*, 49: 173 – 199.

TAYLOR, R., CRONIN, A., PEDLEY, S, BARKER J AND ATKINSON T. 2004. The implications of groundwater velocity variations on microbial transport and wellhead protection-review of field evidence. *FEMS Microbiology Ecology*, 49: 17 – 26.

THIRUMALAIVASAN, D., KARMEGAM, M. AND VENUGOPAL, K. 2003. AHP-DRASTIC: software for specific aquifer vulnerability assessment using DRASTIC model and GIS. *Environmental Modelling and Software*, 18: 645 – 656.

References

TREDOUX, G. 2004. Nitrate and associated hazard quantification and strategies for protecting rural water supplies. WRC Report No 1058/1/04.

TYRRELL, D.A. AND KAPIKIAN, A.Z. 1982. Virus infections of the gastrointestinal tract. New York: Marcel Dekker Inc.

USEPA. 1991. Handbook – groundwater and wellhead protection. United States Environmental Protection Agency, Rep no EPA/625/R-94/001, Washington.

USEPA. 2000. National Primary Drinking Water Regulations: Ground Water Rule. Available from: [http: www.epa.gov](http://www.epa.gov). Date of access: 17 November 2005.

VAN RYNEVELD, M.B., MARJANOVIC, P.D., FOURIE, A.B., AND SAKULSKI, D. 2001. Assignment of a financial cost to pollution from sanitation systems, with particular reference to Gauteng. WRC Report No 631/1/01.

VEGTER, J.R. 1995. An explanation of a set of national groundwater. WRC Report No. TT 74/95.

VEGTER, J.R. 2001. Groundwater Development in South Africa and an introduction to the hydrogeology of the groundwater regions. WRC document TT 134/00.

VIDEIRA, N., ANTUNES, P., SANTOS, R., AND GAMITO, S. 2003. Participatory modelling in environmental decision-making. *Journal of Environmental Assessment Policy and Management* 5: 421 – 447.

VIVIER, J.C., EHLERS, M.M., AND GRABOW, W.O.K. 2004. Detection of enteroviruses in treated drinking water. *Water Research* 38: 2699 – 2705.

WAGENKNECHT, L.E., ROSEMAN, J.M. AND HERMAN, W.H. 1991. Increased incidence of insulin-dependent diabetes mellitus following an epidemic of coxsackie B5. *American Journal of Epidemiology*, 133: 1024 – 1031.

References

WEAVER, J.M.C. 1992. Groundwater sampling: A comprehensive guide for sampling methods. Groundwater Program Division of Water and Technology. WRC Report no TT54/92.

WRC (Water Research Commission). 2006. Strategic sanitation planning and technology choice. Workshop. University of Pretoria, Pretoria.

WINBLAD, U. (1996a). Rethinking sanitation. Dry sanitation: an eco-sustainable alternative. Workshop, San Salvador, El Salvador.

WINBLAD, U. (1996b). Towards an ecological approach to sanitation. International Toilet Symposium, Toyama, Japan.

WOOD, S., SAWAYER, R., AND SIMPSON-HÉBERT, M. 1998. Phast step-by-step guide: a participatory approach for the control of diarrhoeal disease. Geneva, World Health Organization (unpublished document WHO/EOS/98.3/)

WORLD BANK. 1996. Handbook of economic analysis of investment operations. The World Bank, Washington DC. Available from http://www.wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2000/08/14/000094946_00072905315620/Rendered/PDF/multi_page.pdf. Date of access: 2 July 2005.

WHO (WORLD HEALTH ORGANIZATION). 1992. A Guide to the development of on-site sanitation. Available from: http://www.who.int/docstore/water_sanitation_health/onsitesan/ch03.htm. Date of access: 4 July 2005.

WHO (WORLD HEALTH ORGANIZATION). 1997. Introducing the Hazard Analysis and Critical Control Point System. WHO/FSF/FOS/97.2. Available at: www.who.int/fsf/Codex/IntroducingHACCP.pdf. Date of access: 4 July 2005.

WHO (WORLD HEALTH ORGANISATION). 2000. Operational and maintenance of rural water supply and sanitation systems. A training package for managers and planners. Operation and Maintenance Network of the Water Supply and Sanitation Collaborative Council. IRC International Water and Sanitation Centre, Delft, Netherlands.

References

WHO (WORLD HEALTH ORGANIZATION). 2002. Children bear the heaviest burden of environmental disease. Available at <http://www.who.int/peh/ceh/articles/burden.htm>. Date of access: 4 July 2005.

WRIGHT, A. 1999. Guidelines for the use of septic tank systems in the South African Coastal zone. WRC Report no TT 114/99

WYMORE, A.W. 1988. Structuring system design decisions. (In: C. Weiman, ed, Systems Science and Engineering. Proceedings International Conference on Systems Science and Engineering (ICSSE'88), held in Beijing, China on July 25 – 28. Beijing. p. 704 – 709.)

YAKOVITZ, D.S., LANE, L.J., AND SZIDAROVSKY, F. 1993. Multi attribute decision making: dominance with respect to an importance order of the attributes. *Applied Mathematics and Computation*, 54: 197 – 181.

YATES, M.V., GERBA, C.P., AND KELLEY, M. 1985. Virus persistence in groundwater. *Applied Environmental Microbiology*, 49: 778 – 781.

ZOLLER, U., GOLDENBERG, L.C., AND MELLOUL, A.J. 2003. The “short cut enhanced contamination of the Gaza Strip coastal aquifer. *Water Research*, 32(6): 1779 – 1788.

ANNEXURE A

8 ANNEXURE A: WATER QUALITY SURVEY DATA

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Sehlaie clinic (2)				Septic tank with soakaway	<3	<3	ND	424	0.6	0.2	8.6	Acceptable
Kganya Clinic	23.56741	29.47912	Community source	Water borne system	<3	<3	ND	54	0.1	0.4	8.1	Acceptable
Eisleben Clinic	-23.51861	29.84150	Off site borehole	Water-borne system and septic tank with soakaway	1.1 x 10 ³	<3	ND	230	0.3	65.3	8.2	Poor/Dangerous
Ramokgopa Clinic	23.46666	29.81617	On site borehole	Septic tank with soakaway	9.3 x 10 ¹	<3	ND	982	1	55.6	8.3	Poor/Dangerous
Maboks Clinic	23.47775	29.70948	Community source	Pit latrines	<3	<3	ND	1234	2.3	54.1	8.4	Poor/Dangerous
Makgalo Clinic	23.50663	29.66384	Off site borehole		<3	<3	ND	786	1	15	8.7	Marginal
Louis Trichardt Clinic	23.03739	29.90759	Community source	Water-borne system	2.3 x 10 ¹	7.4 x 10 ⁰	ND	288	0.3	3.2	7.8	Poor/Dangerous
Louis Trichardt LA	23.04243	29.90673			<3	<3	ND	228	0.3	2.1	7.8	Acceptable
Madombidzha	23.11479	29.81923	On site borehole	Pit latrines	2.3 x 10 ¹	9.2 x 10 ⁰	ND	1120	0.3	31.1	7.9	Poor/Dangerous
Tshilwavukusiku HC	23.09627	29.73847	On site borehole	Pit latrines and waterborne system	4.3 x 10 ¹	9.2 x 10 ⁰	ND	972	0.6	16.9	7.7	Poor/Dangerous

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Moila Clinic	23.36661	29.97922	Community source	Water borne system	7.4 x 10 ⁰	<3	ND	352	0.2	3.9	7.8	Acceptable
Mulima Clinic	23.30913	30.04608	Community source	Water-borne system	1.5 x 10 ¹	<3	ND	170	0.1	4.4	7.5	Acceptable
Nthabalala	23.27793	29.97242	Off site borehole	Water-borne system	3.6 x 10 ⁰	3.6 x 10 ⁰	ND	670	0.3	0.1	7.9	Poor/Dangerous
Vleifontein clinic	23.21650	29.99494		Water-borne system	3.6 x 10 ⁰	<3	ND	100	0.1	0.7	7.4	Acceptable
Manyima Clinic	23.27665	30.01898	On site borehole	Water-borne system	<3	<3	ND	390	0.1	6.7	7.9	Acceptable
Olifantshoek Clinic	23.33457	30.27490	off site borehole	Pit latrines and waterborne system	<3	<3	ND	204	0.2	1.1	7.7	Acceptable
Tiyani Health Centre	23.30773	29.29453	On site borehole	Water-borne system	9.2 x 10 ⁰	<3	16	514	0.4	10.6	7.6	Marginal
Helderwater Clinic	23.28186	30.29575	Community source	Water-borne system	<3	<3	4	276	0.2	<0.1	7.8	Acceptable
Masakone Clinic	23.27364	30.24405	On site borehole	Water-borne system	3.6 x 10 ⁰	<3	11	704	0.4	40.2	7.7	Poor/Dangerous
Wayeni clinic	23.23502	30.21380	Community source	Water-borne system	<3	<3	ND	200	0.3	<0.1	8.0	Acceptable
Mashamba Clinic	23.23552	30.15356	Community source	Pit latrines	<3	<3	2	484	0.2	12.0	7.8	Marginal
Mowaweni clinic	23.31752	30.11554	Off site borehole	Water-borne system	<3	<3	ND	494	0.2	19.4	7.1	Marginal
Makahulele Clinic	22.89242	30.91166	Tanker	Water-bone system	3.6 x 10 ⁰	<3	1	26	0.1	0.2	7.4	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Makhuva	23.58201	30.96643	On site borehole	Septic tank with soakaway	4.6 x 10 ²	9.2 x 10 ⁰	ND	80	0.2	0.1	7.5	Poor/Dangerous
Dzumeri HC	23.57659	30.70871	On site borehole	VIP's 10/ Pit latrines:9 septic tank soakaway	1.1 x 10 ³	<3	ND	446	0.7	27	7.3	Poor/Dangerous
Shimange UP	23.38970	30.58760	On site borehole	VIP's=3, septic tank with soakaway	4.6 x 10 ²	9.2 x 10 ⁰	11	534	0.6	14.7	7.4	Marginal
Olifantshoek VP	23.84811	30.28345	Community source	Pit latrines	<3	<3	8					Acceptable
Slypsteen kliniek	24.45200	29.40331	Off site borehole	Pit Latrines	<3	<3	ND	652	0.4	11.6	8.2	Marginal
Groothoek	24.30985	29.33646	Community source	Septic tank with soakaway	<3	<3	ND	588	0.2	3	7.7	Acceptable
Magote Clinic	-24.34836	29.268489	Off site borehole	Septic tank with soakaway	<3	<3	ND	294	0.7	0.2	7.7	Acceptable
Molepo clinic	-24.03608	29.733333	On site borehole	Eco-toilets	<3	<3	ND	330	0.9	0.1	7.9	Acceptable
Zebediela Clinic	-24.32544	29.2929847	Off site borehole	Septic tank with soakaway	9.3 x 10 ¹	3.0 x 10 ⁰	ND	1436	0.3	30.9	7.4	Poor/Dangerous
Groothoek clinic	24.31074	29.33743	Community source	Septic tank with soakaway	<3	<3	ND	494	0.3	2.8	7.7	Acceptable
Msengi(Kgapane)	23.41207	30.33594	On site Borehole	Pit latrines	<3	<3	15	630	0.3	34.9	7.5	Acceptable
Msengi(Nkensani)	23.34581	30.37006	On site borehole	VIP's	<3	<3	7	32	0.2	<0.1	7.7	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Hlaneki Clinic	23.28156	30.50967	On site borehole	VIP's	<3	<3	5	96	0.2	<0.1	7.7	Acceptable
Lebaka Clinic	23.46331	30.36741	On site borehole	VIP's and Septic tank with soakaway	9.2 x 10 ⁰	<3	2	1160	0.4	49.6	7.5	Poor/Dangerous
Giyani HC	23.31281	30.72289	Community source	Pit latrines	1.5 x 10 ¹	<3	36	74	0.2	0.1	7.8	Acceptable
Kremertart	23.32228	30.68181	Community source	VIP's	2.4 x 10 ²	3.6 x 10 ⁰	ND	264	0.2	0.4	7.8	Poor/Dangerous
Basani Clinic	23.36977	30.51910	On site borehole	Pit latrines	<3	<3	ND	174	0.2	<0.1	7.9	Acceptable
Bellevue Clini	23.41212	30.42094	On site borehole	Pit latrines	<3	<3	3	1312	0.3	6.2	7.6	Marginal
Thomo	23.24797	30.78814	Community source	VIP's and Septic tank with soakaway	1.5 x 10 ¹	<3	ND	166	0.2	<0.1	8.0	Acceptable
Maphalle clinic	23.46838	30.31178	On site borehole	VIP's and Septic tank with soakaway	2.1 x 10 ¹	1.5 x 10 ¹	35	1552	0.5	54.5	7.9	Poor/Dangerous
Messina Hospital	22.34178	30.04281	Community source	VIP's	2.4 x 10 ²	<3	ND	358	0.4	0.9	8	Acceptable
Nancefield Clinic	22.33150	30.03408	Community source	VIP's and Waterborne	<3	<3	ND	266	0.4	1.2	7.9	Acceptable
Makhado HC	22.90081	30.03442	On site borehole	VIP's and Waterborne	3.6 x 10 ⁰	<3	ND	1336	0.2	18.5	7.8	Marginal
Siloam hospital	22.90026	30.19386	On site borehole	VIP's and Waterborne	2.4 x 10 ²	4.3 x 10 ¹	ND	64	<0.1	<0.1	8.0	Poor/Dangerous
Van de Merwe kraal (2)			Off site borehole	Septic tank with soakaway	<3	<3	14					
Bydrift Clinic	-24.54583	29.50369	Off site borehole, unreliable	Septic tank with soakaway	3.6 x 10 ⁰	<3	ND	1340	1.8	22.8	7.5	Poor/Dangerous

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Chuene clinic	24.19145	29.48561	Community source	Septic tank with soakaway	<3	<3	ND	354	0.8	<0.1	7.6	Acceptable
Lebowakgomo Parliament Clinic	24.18312	29.28709	Community source	Water-borne system (off site disposal)				366	0.4	0.1	7.8	Acceptable
Lebowakgomo Clinic	24.18140	29.31830	Community source	Water-borne system (off site disposal)				302	0.4	0.1	7.8	Acceptable
Lebowakgoro Clinic	24.18507	29.33445	Community source	Water-borne system (off site disposal)				280	0.4	0.1	7.7	Acceptable
Dikgale Clinic	23.45023	29.46390	On site borehole	Conservancy tank	<3	<3	ND	26	0.1	13.8	7.6	Marginal
Seketeng Clinic	24.18484	29.38334	Off site borehole	Pit-latrines				234	0.2	1.7	7.6	Acceptable
Lebowakgomo Hospital	24.17714	29.31722	Community source	Water-borne system (off site disposal)	<3	<3	5	42	0.4	0.1	7.7	Acceptable
Mashte Clinic	24.18629	29.41877	Community source		<3	<3	11	98	0.4	0.8	7.8	Acceptable
Mankweng Hospital	23.88158	29.72625	Community source	Water-borne system (off site disposal)	<3	<3	4	168	<0.1	0.1	7.9	Acceptable
Mankweng Clinic	23.53148	29.43626	Community source	Water-borne system (off site disposal)	<3	<3	1	50	<0.1	0.1	8	Acceptable
Mothiba Clinic	23.85806	29.63583	Off site borehole	Septic tank with soakaway	9.2 x 10 ⁰	3.6 x 10 ⁰	ND	542	0.4	15	7.6	Poor/Dangerous
Makotopong	23.81811	29.64375	On site borehole		1.5 x 10 ²	<3	2	194	0.2	21.9	7.6	Poor/Dangerous
Matabanyane/ Mashaba	23.66635	29.34658	On site borehole	Conservancy tank	3.6 x 10 ⁰	<3	1	586	0.4	45.8	7.5	Poor/Dangerous
Perskebult	23.80111	29.35833	On site borehole	Conservancy tank	<3	<3	ND	460	0.2	14	7.3	Marginal
Seshego Clinic (Zone 3)	23.84131	29.38614	Community source	Water-borne system (off site disposal)	<3	<3	3	40	0.2	0.3	7.7	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Seshego Zone 2	23.84617	29.39128	Community source	Water-borne system (off site disposal)	<3	<3	7	150	0.2	1.9	7.5	Acceptable
Seshego Zone 1	23.85997	29.38942	Community source	Water-borne system (off site disposal)	<3	<3	ND	22	0.1	0.1	7.6	Acceptable
Seshego Hospital	23.51291	29.23770	Community source	Water-borne system (off site disposal)	<3	<3	ND	62	0.1	<0.1	7.5	Acceptable
SADU Clinic	23.30593	28.76156	Community source	Conservancy tank	<3	<3	3	2006	0.4	9.9	7.2	
Uitkyk Clinic	23.39545	28.97516	On site borehole	Pit-latrines	<3	<3	ND	1050	0.2	9.9	7.3	Marginal
Rozenkranz	23.49476	28.98423	On site borehole	Conservancy tank	<3	<3	ND	1088	0.9	11.3	8	Marginal
Ziest Clinic	23.02206	28.70565	Off site borehole	Septic tank with soakaway	<3	<3	ND	534	0.4	32.9	7.9	Poor/Dangerous
Grootdraai Clininc	23.11753	28.70795	Community source - unreliable		2.3×10^1	<3	ND	1444	0.6	22.3	7.9	Poor/Dangerous
Sekhang Clinic/Lesfontein	23.14949	28.78551	On site borehole		<3	<3	ND	8118	0.3	11.0	7.7	Marginal
My Darling	23.08314	28.79856	On site borehole		1.1×10^3	7.5×10^1	1	1502	0.7	86.5	7.9	Poor/Dangerous
Buffelshak	23.14925	28.92419	Off site borehole	Conservancy tank	1.5×10^2	1.5×10^1	ND	856	0.2	0.4	7.9	Poor/Dangerous
Blouberg Hospital	23.14248	29.00828	Off site borehole	Water-borne system (off site disposal)	3.6×10^0	<3	ND	854	0.3	7.9	7.9	Acceptable
Jane Furse Memorial	24.73146	29.85826	Community source - unreliable	Water-borne system (off-site disposal)	<3	<3	ND	122	0.4	<0.1	8.0	Acceptable
Old Jane Furse Hospital	24.76323	29.86759	Community source - unreliable	Water-borne system (off-site disposal)	<3	<3	2	116	0.5	0.5	7.9	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Dichoelang Clinic	24.75229	29.8874	Community source - unreliable	VIP's	<3	<3	2	84	0.4	0.4	7.9	Acceptable
Ga-Marishane Clinic	24.72669	29.74681	Community source - unreliable	Water-borne system (off-site disposal)	3.6 x 10 ⁰	<3	ND	82	0.3	5.7	7.7	Acceptable
Ga-Phaala Clinic	24.69798	29.73544	Community source - unreliable	Eco-toilets	>1.1 x 10 ⁴	2.4 x 10 ²	ND	1106	0.5	75.0	7.7	Poor/Dangerous
Mohlaletse	24.47169	29.88451	Community source	Pit-latrines	2.4 x 10 ²	<3	ND	808	0.1	3.3	8.1	Acceptable
Ikageng Clinic	24.57080	29.87376	Community source	VIP's	<3	<3	1	1154	0.5	8.8	8.3	Marginal
Khakha Clinic	22.83622	30.24732	On site borehole	Pit latrines	9.3 x 10 ¹	<3	ND	102	<0.1	4.7	7.7	Acceptable
Tshiombo Clinic	22.80568	30.50098	On site borehole	Pit latrines, septic tank with soakaway	2.0 x 10 ¹	<3	ND	146	0.1	1.7	7.7	Acceptable
Mutale HC	22.73648	30.52118	Community source	VIP'S, Water-bone system	<3	<3	ND	66	<0.1	0.3	7.8	Acceptable
Tshikundamalema Clinic	22.67168	30.69104	Off site borehole	VIP'S, septic with soakaway	2.3 x 10 ¹	<3	ND	84	<0.1	0.4	7.6	Acceptable
Elim Hospital	23.15439	30.05571	Community source	None, VIP's	<3	<3	ND	148	0.1	3.2	7.8	Acceptable
Bungeni HC	23.20298	30.19757	On site borehole	VIP's, septic with soakaway	9.3 x 10 ¹	<3	ND	554	0.3	25.0	7.6	Poor/Dangerous
Marseilles Clinic	23.23030	30.34362	On site borehole	Pit latrines, septic with soakaway	<3	<3	ND	526	0.5	20.9	7.9	Poor/Dangerous

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Kurhuleni Clinic	23.14564	30.35966	Community source	VIP's, septic with soakaway	4.3 x 10 ¹	3.6 x 10 ⁰	ND	82	0.7	5.2	8.0	Marginal
Ngobe Clinic	23.36188	30.72203	On site borehole	VIP'S, septic with soakaway	<3	<3	1	1042	0.3	45.0	8.0	Poor/Dangerous
Homu	23.30448	30.80530	Community source	Pit latrines	<3	<3	ND	44	0.2	<0.1	8.1	Acceptable
Nkensani Hospital	23.31240	30.69095	Community source	Waterbone system and VIP's	<3	<3	ND	34	0.2	0.3	7.9	Acceptable
Davhana Clinic	23.20963	30.45648	Off site borehole	VIP's	<3	<3	ND	58	<0.1	0.1	8.0	Acceptable
Tshimbupfe Clinic	23.15767	30.46838	On site borehole	VIP's	2.0 x 10 ³	<3	ND	336	0.4	11.3	7.6	Marginal
Manavela Clinic	23.10077	30.45176	Community source	VIP's	<3	<3	ND	20	<0.1	8.1	7.9	Acceptable
Muswana VP	23.15050	30.62964	Community source	Pit latrines	9.2 X 10 ⁰	3.6 X 10 ⁰	ND	568	0.4	24.6	8.0	Poor/Dangerous
Dakari VP	23.09473	30.48049	Community source		3.6 X 10 ⁰	<3	ND	908	0.4	31.9	7.9	Poor/Dangerous
Mpambo HC	23.05505	30.367160	Off site borehole	VIP's, septic with soakaway	9.2 x 10 ⁰	3.6 x 10 ⁰	ND	538	0.4	6.2	7.7	Poor/Dangerous
Mukomi Clinic	23.07206	30.56144	On site borehole	VIP's, septic with soakaway	<3	<3	5	220	0.2	21.5	7.6	Poor/Dangerous
Mavambe Clinic	23.00359	30.64898	Off site borehole	VIP's	<3	<3	ND	794	0.4	4.0	7.9	Acceptable
Malamulele Hospital	22.99699	30.69669	On site borehole	VIP's and Waterbone	<3	<3	ND	94	0.1	<0.1	8.0	Acceptable
Mninginisi VP	23.14845	30.79879	Community source	Pit latrines	<3	<3	ND	8	0.2	<0.1	8.0	Acceptable
Shihimu VP	23.29444	30.32654	Community source	pit latrines	<3	<3	ND	16	0.2	0.2	8.1	Acceptable
Ntshuvi VP	23.25852	30.35516	Community source	Pit latrines	<3	<3	ND	180	0.2	0.8	8.1	Acceptable
Thobehlale	24.50401	29.77522	Off site borehole	Pit-latrines	4.6 x 10 ²	4.6 x 10 ²	ND	1560	0.9	16.8	7.9	Poor/Dangerous
Nchabaleng Hospital	24.43902	29.8056	Off site borehole	Septic tank with soakaway	9.2 X 10 ⁰	<3	ND	1336	0.7	13.0	8.0	Marginal
Mooiplaas/Mankotsane	24.41455	29.74685	Off site borehole - unreliable	Pit-latrines	<3	<3	8	1000	0.3	19.5	8.0	Poor/Dangerous
Paulus Masha	24.44519	29.73635	Community source - unreliable	Pit-latrines	<3	<3	ND	2394	1.3	70.3	7.7	Poor/Dangerous

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
mangameng Clinic			Community source	Eco-toilets	<3	<3	ND	866	0.1	24.4	7.9	Poor/Dangerous
Sch noord Clinic	24.75470	30.01053	On site borehole	Pit-latrines	<3	<3	ND	390	0.7	10.1	7.8	Marginal
Ngoane Clinic	24.87643	29.97701	Community source - unreliable	Pit-latrines	<3	<3	ND	1270	0.5	4.2	8.0	Marginal
Boschkloof			Off site borehole - unreliable	Septic tank with soakaway	9.2 x 10 ⁰	3.6 x 10 ⁰	2	162	0.1	0.7	8.0	Poor/Dangerous
Muledane Clinic	22.99444	30.45596	On site borehole	VIP's	<3	<3	ND	164	0.1	7.6	7.7	Acceptable
Shayandima Clinic	23.00510	30.42655	On site borehole	VIP's and Waterbone	<3	<3	ND	196	0.1	3.0	7.8	Acceptable
Mamutsha Clinic	23.06416	30.34983	Off site borehole	VIP's, septic with soakaway	<3	<3	ND	8	0.1	0.5	7.6	Acceptable
Tshakhuma Clinic	23.04840	30.30222	Off site borehole	VIP's	<3	<3	ND	72	<0.1	0.1	7.6	Acceptable
Leuubu clinic	23.09564	30.28614	Community source	VIP's, septic with soakaway	<3	<3	ND	24	0.1	3.2	7.0	Acceptable
Makura Clinic	22.64997	30.83027	Community source	VIP's, septic with soakaway	<3	<3	ND	90	0.1	10.3	6.9	Marginal
Donald Frazer Hospital	22.88810	30.47777	Community source	VIP's, septic with soakaway	<3	<3	ND	14	<0.1	12.0	7.3	Marginal
Tshihvase Thondo clinic	22.90202	30.432021	On site borehole	VIP's, septic with soakaway	<3	<3	ND					
Phiphidi clinic	22.95122	30.38724	On site borehole	VIP's, septic with soakaway	<3	<3	ND	26	<0.1	16.3	7.6	Marginal
Pfananani Clinic	22.95281	30.42953	Community source	Septic with soakaway	<3	<3	ND	6	<0.1	0.8	7.5	Acceptable
Tshifundi Clinic	22.81461	30.69869	Community source	VIP's	<3	<3	ND	116	0.1	0.6	7.8	Acceptable
Tshaulu Clinic	22.79991	30.74777	Community source	VIP's	<3	<3	ND	4	0.1	1.0	7.9	Acceptable
Makula Clinic	22.85935	30.58778	On site borehole	VIP's	3.0 x 10 ¹	3.0 x 10 ¹	ND	214	0.3	4.1	7.7	Poor/Dangerous
Mbilwe	22.92896	30.46890	Off site borehole	VIP's, septic with soakaway	<3	<3	ND	70	<0.1	0.6	7.5	Acceptable
Sibasa Clinic	22.94654	30.49153	Community source	VIP's	<3	<3	9	28	<0.1	0.1	7.8	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Thohoyandou	22.96578	30.47845	Community source		<3	<3	ND	158	<0.1	0.6	7.8	Acceptable
Tshilidzini Hospital	22.99470	30.41415	Community source	VIP's	<3	<3	ND	18	0.1	0.9	7.6	Acceptable
Seloane	23.69513	30.92766	On site borehole	VIP's, septic with soakaway	<3	<3	ND	1698	0.6	28.3	7.4	Poor/Dangerous
Mamanyoha Clinic	23.53156	30.51082	Off site borehole	VIP's, septic with soakaway	1.5 x 10 ²	3.8 x 10 ¹	ND	514	0.6	22.4	7.5	Poor/Dangerous
Seopole clinic	23.49968	30.46339	On site borehole	VIP's	<3	<3	ND	468	0.5	9.1	7.5	Acceptable
Haenerstburg LA	23.94509	29.93936	Community source	VIP's	<3	<3	3	92	<0.1	0.7	7.8	Acceptable
Cravelotte VP	23.95258	30.61297	Community source	VIP's and Waterbone	<3	<3	3	914	0.3	8.4	7.4	Acceptable
Lesitele LA Clin	23.89017	30.38647	Community source	VIP's and Waterbone	<3	<3	ND	212	0.2	1.5	7.6	Acceptable
Tzaneen LA	23.82987	30.15832	Community source	VIP's				32	<0.1	0.2	7.9	Acceptable
Eerstegeluk Clinic			Community source	Water-borne system (off-site disposal)	7.4 x 10 ⁰	7.4 x 10 ⁰	ND	308	0.1	8.4	7.5	Poor/Dangerous
Motsepe Clinic	24.28835	29.85742	Community source - unreliable	Eco-toilets	9.3 x 10 ¹	<3	ND	2702	<0.1	99.9	7.4	Poor/Dangerous
Phasha Clinic	24.33083	30.00415	On site borehole	Septic tank with soakaway	<3	<3	ND	132	<0.1	2.2	7.9	Acceptable
Mecklenburg Hospital	24.38624	30.07453	On site borehole	Water-borne system (off-site disposal)	4.3 x 10 ¹	<3	ND	624	<0.1	20.4	7.8	Poor/Dangerous
Motlolo Clinic	24.50960	30.17524	On site borehole	Septic tank with soakaway	2.1 x 10 ²	<3	ND	60	0.2	32.4	7.6	Poor/Dangerous
Praktiseer Clinic	24.58977	30.15924	Community source - unreliable	Pit-latrines	<3	<3	ND	18	0.1	0.5	7.8	Acceptable
Naboomkopies Clinic	24.55717	30.34909	Own water-own source		9.2 x 10 ⁰	<3	ND	1242	0.3	15.1	7.7	Marginal
Nchabaleng Clininc	24.43284	29.82698	Community source	Pit-latrines	4.6 x 10 ²	2.4 x 10 ²	ND	2436	0.1	24.1	7.5	Poor/Dangerous
Helen Franz Hospital	23.28513	29.11165	Off site borehole	Water-borne system (off site disposal)	9.3 x 10 ¹	7.4 x 10 ⁰	ND	1094	0.5	10.7	7.9	Poor/Dangerous

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Indermark Clinic	23.07950	29.11053	On site borehole	Conservancy tank	<3	<3	ND	1120	0.3	30.0	7.8	Poor/Dangerous
WF Knabel Hospital	23.63194	29.12000	On site borehole	Water-borne system (off site disposal)	<3	<3	ND	544	0.3	5.1	7.9	Acceptable
Matlala Clinic	23.74639	29.05611	Community source - unreliable	Conservancy tank	<3	<3	ND	648	2.9	45.0	8.0	Poor/Dangerous
Kibi Clinic	22.83644	28.84697	Off site borehole	Conservancy tank	2.1 x 10 ¹	<3	ND	962	0.5	3.1	7.5	Acceptable
Ratshaathaa Health Centre	22.89881	28.82448	Off site borehole	Water-borne system (off site disposal)	9.2 x 10 ⁰	<3	ND	388	0.2	6.3	7.8	Acceptable
De Vrede Clinic	22.91736	29.02086	On site borehole	Septic tank with soakaway	2.4 x 10 ²	3.6 x 10 ⁰	ND	398	0.5	18.9	7.9	Poor/Dangerous
Dudron Clinic	23.36725	29.32750	Community source	Water-borne system (off site disposal)	1.5 x 10 ³	9.2 x 10 ⁰	ND	570	0.5	22	8.7	Poor/Dangerous
Alldays Clinic	22.67864	29.10375	Community source	Water-borne system (off site disposal)	3.6 x 10 ⁰	<3	1	34	0.7	4.1	7.8	Acceptable
Percy Clinic	23.48083	29.18611	Community source	Pit-latrines	2.1 x 10 ¹	9.2 x 10 ⁰	ND	76	0.2	26.1	7.7	Poor/Dangerous
Tzaneen PHC	23.82597	30.16397	Community source	VIP's and Waterbone	<3	<3	ND	28	<0.1	<0.1	8.2	Acceptable
Julesburg HC	24.06938	30.32855	Off site borehole	VIP's	<3	<3	ND	12	<0.1	0.4	7.7	Acceptable
Mogapeng Clinic	24.07159	30.28648	On site borehole	VIP's	<3	<3	ND	28	0.1	3.7	7.6	Acceptable
Shiluvua Hospital	24.04308	30.27355	Community source	VIP's and Waterbone	<3	<3	ND	108	0.2	1.5	7.7	Acceptable
CN Phatudi	24.02606	30.28080	On site borehole	VIP's and Waterbone	<3	<3	ND	176	0.1	3.6	7.5	Acceptable
Carlotta Clinic	23.99710	30.31651	On site borehole	VIP'	<3	<3	ND	388	0.2	2.0	7.6	Acceptable
Duiwelskloof	23.69699	30.14150	Community source	VIP's	<3	<3	ND	70	0.1	0.3	7.9	Acceptable
Nkambako VP	23.73546	30.47826	Community source	Pit latrine	<3	<3	ND	112	0.1	0.2	7.7	Acceptable
Grace Mugobeni HC	23.71664	30.43652	Off site borehole	VIP's, septic with soakaway	<3	<3	ND	158	0.2	<0.1	7.4	Acceptable
Mamitwa Clinic	23.73270	30.40866	Off site borehole	VIP's, septic with soakaway	<3	<3	ND	792	0.3	2.1	7.5	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Mandlakazi VP	23.73261	30.37109	Community source	Pit latrines	<3	<3	ND	260	0.2	10.3	7.4	Acceptable
Runnymede VP	23.66077	30.44787	Community source	Pit latrines	<3	<3	ND	476	0.3	29.2	7.3	Poor/Dangerous
Shihoko Clinic	23.65583	30.47856	Off site borehole	VIP's, septic with soakaway	1.5 x 10 ²	6.1 x 10 ⁰	ND	946	0.6	5.6	7.5	Poor/Dangerous
Kgapane Hospital	23.64877	30.21840	Community source	VIP's and waterbone	<3	<3	ND	66	0.1	0.3	8.2	Acceptable
Bolobedu	23.62330	30.34633	On site borehole	VIP's, septic with soakaway	<3	<3	ND	702	0.1	50.6	7.2	Poor/Dangerous
Madumme Clinic	23.62895	30.39977	Community source		<3	<3	ND	30	0.1	0.1	7.5	Acceptable
Morapalala clinic	23.60322	30.41761	On site borehole	VIP's, septic with soakaway	4.6 x 10 ³	3.6 x 10 ⁰	2	430	0.4	2.9	7.9	Poor/Dangerous
Ga-Mookgo	23.61726	30.46853	Off site borehole		3.6 x 10 ⁰	<3	ND	504	0.5	5.4	7.6	Acceptable
Phalaborwa Clinic 381	23.95092	31.13704	Community source	VIP's and water-borne system	<3	<3	2	232	0.2	0.1	7.7	Acceptable
Phalaborwa Bus stop	23.51330	31.12872	Community source	VIP's and Waterbone	<3	<3	ND	32	0.2	0.1	7.5	Acceptable
Phalaborwa Hospital	23.93348	31.13538	Community source		<3	<3	ND	86	0.2	<0.1	8.1	Acceptable
Lulukan HC	23.86462	31.07726	Community source	VIP's	<3	<3	ND	84	0.2	<0.1	7.7	Acceptable
Benfara Clinic	23.91605	31.03690	Off site borehole	VIP's, septic with soakaway	<3	<3	ND	898	0.3	10.4	7.4	Acceptable
Maphuta L Malatji	23.92448	31.03667	Community source	VIP's and Waterbone	<3	<3	ND	32	0.2	0.1	7.8	Acceptable
Namakgale (old)	23.94103	31.03990	Community source	VIP's and Waterbone	<3	<3	ND	294	0.2	0.2	7.8	Acceptable
Tzanees Van velden	23.83555	30.16558	Community source	VIP's and waterbone	<3	<3	1	64	<0.1	0.1	7.9	Acceptable
Letaba Hospital	23.87423	30.26715	Community source	VIP's and waterbone	<3	<3	21	62	0.1	1.4	7.9	Acceptable
Nkowankowa HC	23.88662	30.29328	Community source	Vip's	<3	<3	1	114	0.1	1.2	7.8	Acceptable
Xikwambana	23.95564	30.26833	Community source	Pit latrines	<3	<3	1	284	0.1	3.5	7.6	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Lenyenyene Clinic	23.97417	30.26822	On site borehole	VIP's and septic tank soakaway	<3	<3	3	84	<0.1	0.1	8.2	Acceptable
Magobopa Clinic	24.01336	30.19949	On site borehole	VIP's and septic tank soakaway	<3	<3	1	60	<0.1	0.1	7.7	Acceptable
Elandskraal PHC	24.71463	29.41105	Community source	VIP's and waterbone	4.0 x 10 ⁶	<3	5	194	0.3	0.3	8.1	Acceptable
Roedtan 411	24.59637	29.07899	Community source	VIP's and waterbone	<3	<3	1	72	0.2	3.5	7.9	Acceptable
Mookgopong 288	24.52475	28.70833	Community source	VIP's	<3	<3	ND	306	0.4	4.4	7.7	Acceptable
Naboomspruit LA	24.51600	28.70989	Community source	VIP's	<3	<3	ND	210	0.5	4.7	7.8	Acceptable
Mookgopong 301	24.51927	28	Community source	VIP's and waterbone	<3	<3	ND	274	0.4	4.4	7.9	Acceptable
Settlers LA	24.96045	29.53919	On site borehole	VIP's and septic tank with Soakaway	>1.1 x 10 ⁶	<3	ND	816	0.2	20.3	7.6	Poor/Dangerous
Warmbad Salus Oord PHC	24.88206	28.29809	Community source		4.0 x 10 ⁶	<3	ND	146	0.2	<0.1	7.6	Acceptable
Motshana Clinic	24.47843	30.30911	On site borehole	Septic tank with soakaway	<3	<3	ND					Acceptable
Penge Hospital	24.38287	30.29001	On site borehole	Water-borne system (off-site disposal)	<3	<3	ND					Acceptable
Magalies Clinic	24.56172	29.64279	Community source - unreliable	Boiling-for mixing medicine. None	<3	<3	ND					Acceptable
St Ritas Hospital			Community source - unreliable	Water-borne system (off-site disposal)	<3	<3	ND					Acceptable
Eensaam Clinic	24.95337	29.88606	On site borehole	Eco-toilets	<3	<3	1					Acceptable
Hlogothlou Clinic	25.02867	29.73357	Community source - unreliable	Water-borne system (off-site disposal)	<3	<3	ND					Acceptable
Goedgedaght Clinic	25.06032	29.71819	On site borehole	Pit-latrines	<3	<3	1					Acceptable
Klipspuit Clinic	25.00877	29.74088	Community source - unreliable	Water-borne system (off-site disposal)	<3	<3	ND					Acceptable
Ramapudu Cinic	25.05105	29.50739	Community source - unreliable		<3	<3	ND	274	1.8	1.6	7.9	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Motetema Clinic	25.09764	29.46089	Community source	Septic tank with soakaway	7.4×10^0	7.4×10^0	ND	176	0.2	0.2	7.6	Acceptable
Marulaleng Clinic	24.95152	29.41015	On site borehole	Water-borne system (off-site disposal)	<3	<3	ND	244	1.7	26.6	7.9	Acceptable
Mogangyaka Clinic	24.99441	29.39906	Community source	Water-borne system (off-site disposal)	4.6×10^2	1.5×10^2	ND	256	0.3	0.2	7.3	Acceptable
Moeding Clinic	24.95391	29.45719	Community source	Septic tank with soakaway	<3	<3	132	364	0.3	0.4	7.7	Acceptable
Digalaopeng Clinic	24.98555	29.45711	Community source	Septic tank with soakaway	<3	<3	ND	264	0.3	0.3	7.6	Acceptable
Matsepe Clinic	25.02423	29.49784	On site borehole	Pit-latrines	4.3×10^1	4.3×10^1	ND	266	2.2	7.7	7.4	Poor/Dangerous
Setlabosoane Clinic	24.67406	29.46992	Community source	Septic tank with soakaway	<3	<3	1	352	0.3	0.1	7.5	Acceptable
Mampane Clinic	24.72809	29.53316	On site borehole	Eco-toilets	<3	<3	1	876	2.8	<0.1	7.7	Acceptable
Matlala Hospital	24.83300	29.50241	Own dam	None	<3	<3	ND	298	0.4	0.3	7.8	Acceptable
Mmotwoaneng Clinic	24.92237	29.62116	On site borehole	Septic tank with soakaway	<3	<3	2	298	0.4	0.3	7.4	Acceptable
Dilokong Hospital (HC Boshoff New)	24.61344	30.17025	Off site borehole	Water-borne system (off-site disposal)	<3	<3	ND	742	0.4	15.3	7.8	Marginal
Maandagshoek	24.60267	30.08159	Community source	Water-borne system (off-site disposal)	<3	<3	ND	244	0.1	1.1	7.9	Acceptable
Mmutlane Clinic	24.34719	30.14544	On site borehole	Septic tank with soakaway	<3	<3	ND	1402	0.3	8.7	7.9	Marginal
Rietfontein (Boshof) Clinic	24.60224	30.52995	Community source	Septic tank with soakaway	6.1×10^2	<3	ND	316	0.5	0.1	8.1	Acceptable
Warmbad Town PHC	24.88420	28.29172	Community source	VIP"s	<3	<3	ND	144	0.3	0.3	7.9	Acceptable
Warmbad Spar Park 529	24.87661	28.27267	Community source	Water-bone system	<3	<3	ND	34	0.3	<0.1	7.6	Acceptable

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Warmbad Jinnah Park PHC	24.88057	28.27593	Community source	None	<3	<3	ND	68	0.3	0.3	8.2	Acceptable
Warmbad Hospital 525	24.88633	28.28783	On site borehole		>1.1 x 10 ³	2.4 x 10 ²	ND	376	0.3	1.0	8.1	Poor/Dangerous
FH Odendaal Nylkstroem Hospital	24.70868	28.39548	Community source	Reliability	<3	<3	ND	104	0.2	0.2	7.7	Acceptable
Nylstroem LA, Nylstroem LA VP	24.70366	28.40659999	Community source	VIP's and waterbone	<3	<3	ND	286	0.2	0.1	7.7	Acceptable
Phagameng LA	24.69377	28.344320	Community source	VIP's	<3	<3	ND	190	0.2	0.5	7.8	Acceptable
Northam 354	24.95265	27.26440	Community source	VIP's and septic tank with soakaway	<3	<3	ND	362	0.3	<0.1	7.9	Acceptable
Swartklip 473	24.93774	27.15574	Community source	VIP's	<3	<3	ND	330	0.4	<0.1	7.9	Acceptable
Dwaalboom PHC	24.71970	26.80507	On site borehole	VIP's and septic tank with soakaway	7.2 x 10 ²	4.3 x 10 ¹	ND	662	0.2	6.3	8.2	Poor/Dangerous
Regorogile Clinic 1	24.58088	27.38280	Community source	VIP's and waterbone	6.1 x 10 ¹	<3	ND	534	0.4	0.5	7.8	Acceptable
Regorogile Clinic 2	24.59870	27.39535	Community source	VIP's and septic tank with soakaway	<3	<3	ND	368	0.4	1.3	7.7	Acceptable
Rebone Clinic	23.43191	28.60938	On site borehole	VIP's								Acceptable
Thabazimbi Hospital	24.59871	27.40690	Community source	VIP's	3.0 x 10 ⁰	<3	ND	172	0.5	0.5	7.6	Acceptable
Thabazimbi Hospital LA 477	24.58576	27.4112	Community source	VIP's	<3	<3	ND	398	0.4	0.2	7.5	Acceptable
Vaalwater PHC	24.29443	28.11321	Community source	VIP's	2.8 x 10 ¹	<3	ND	104	0.1	2.7	7.3	Acceptable
Bokwalakwala 21	24.14756	28.95105	On site borehole	VIP's and septic tank with soakaway	<3	<3	ND	582	0.8	12.5	8.0	Marginal
Mahwelereng Zone 1	24.14007	29.98385	No water	VIP's	4.3 x 10 ¹	<3	ND	156	0.2	1.2	7.8	Acceptable
Mahwelereng Zone 2	24.13987	28.99190	On site borehole	VIP's and septic tank with soakaway	9.0 x 10 ⁰	<3	ND	690	0.2	34.4	8.1	Poor/Dangerous

Facility Name	Latitude	Longitude	Water status	Primary Sanitation Infrastructure Type	CF/100ml	EC/100ml	CPH/10ml	TDS	F	NO3-N	pH	DWAF Classification
Mokopane Hospital	24.15264	28.98872	Off site borehole	VIP's and waterbone	4.3 x 10 ¹	<3	ND	172	0.2	16.4	8.1	Marginal
Potgittersrus LA	24.18376	29.01007	Community source	VIP's	2.3 x 10 ¹	<3	ND	234	0.2	1.5	7.5	Acceptable
Voortrekker Pogitersrus hospital	24.19624	29.01405	Off site borehole	VIP's	4.3 x 10 ¹	<3	ND	138	0.2	1.4	7.4	Acceptable
Markem VP	23.59004	28.39024	Community source	None	7.2 x 10 ²	<3	ND	882	0.6	25.4	7.8	Poor/Dangerous
Shongwane 460	23.56788	28.10358		VIP's and septic tank with soakaway	<3	<3	ND	1362	2.4	122.9	7.7	Poor/Dangerous
Seleka 434	23.21500	27.90836	Off site borehole	VIP's and septic tank with soakaway	<3	<3	1	1750	0.9	154.9	7.6	Poor/Dangerous
Witpoort Hospital	23.33479	28.00965	Community source	VIP's and waterbone	4.0 x 10 ⁰	4.0 x 10 ⁰	ND	794	0.6	3.5	7.9	Poor/Dangerous
Abbotspoort Clinic	23.45050	28.08689	Off site borehole	VIP's and septic with soakaway	<3	<3	ND	616	0.7	21.5	7.9	Poor/Dangerous
Mankuwe Clinic 215	23.46785	28.555984	Off site borehole	VIP's and septic tank with soakaway	2.4 x 10 ²	<3	6	1054	1.2	10.2	7.6	Marginal
Ellisras Hospital	23.68151	27.72306	Community source	VIP's and waterbone	<3	<3	ND	150	0.1	0.1	9.4	Acceptable
Ellisras Town	23.66762	27.74567	Community source	VIP's	<3	<3	9	34	0.1	0.2	9.5	Acceptable
Marapog LA	23.65849	27.62877	Community source	VIP's	4.0 x 10 ⁰	<3	8	84	0.1	0.5	8.2	Acceptable
Tshamahanzi 493	24.07703	28.97951	On site borehole	VIP's	<3	<3	ND	680	1	98.5	7.7	Poor/Dangerous
Vaalkop 515	24.00505	28.93250	Community source	VIP's	<3	<3	ND	590	0.7	11.6	7.9	Marginal
Phafola 378	23.91629	28.87582	On site borehole	VIP's	4.3 x 10 ¹	<3	ND	1544	1.1	24	7.8	Poor/Dangerous
Mapela Clinic 221	23.95679	28.84733	Off site borehole	VIP's and septic tank with soakaway	9.3 x 10 ¹	9.3 x 10 ¹	ND	950	0.4	42.6	8.1	Poor/Dangerous
Mamaselela	24.00615	28.00615	On site borehole	VIP's	<3	<3	ND	730	0.2	28.4	7.6	Poor/Dangerous
Balepi Clinic	24.02995	28.89335	On site borehole	VIP's	<3	<3	ND	994	0.6	70.2	7.7	Poor/Dangerous
Matlanau 258	23.42477	28.79828	Off site borehole	VIP's and septic tank with soakaway	7.5 x 10 ²	3.0 x 10 ⁰	ND	384	0.8	12.5	7.7	Poor/Dangerous
Weltevreden 533	23.56084	28.59858	On site borehole	VIP's	<3	<3	ND	2758	0.9	95.5	7.8	Poor/Dangerous
Segole Clinic	23.60238	28.64036	On site borehole	VIP's	<3	<3	ND	2646	1.3	73	7.6	Poor/Dangerous

